Energy Research and Development Division

FINAL PROJECT REPORT

Accelerating Deployment of Advanced Energy Communities: The Oakland EcoBlock

Appendices A-N

California Energy Commission

Gavin Newsom, Governor

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APPENDIX A: ECOBLOCK REPORT AUTHOR CONTACT INFORMATION

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APPENDIX B: MAP ANALYSIS

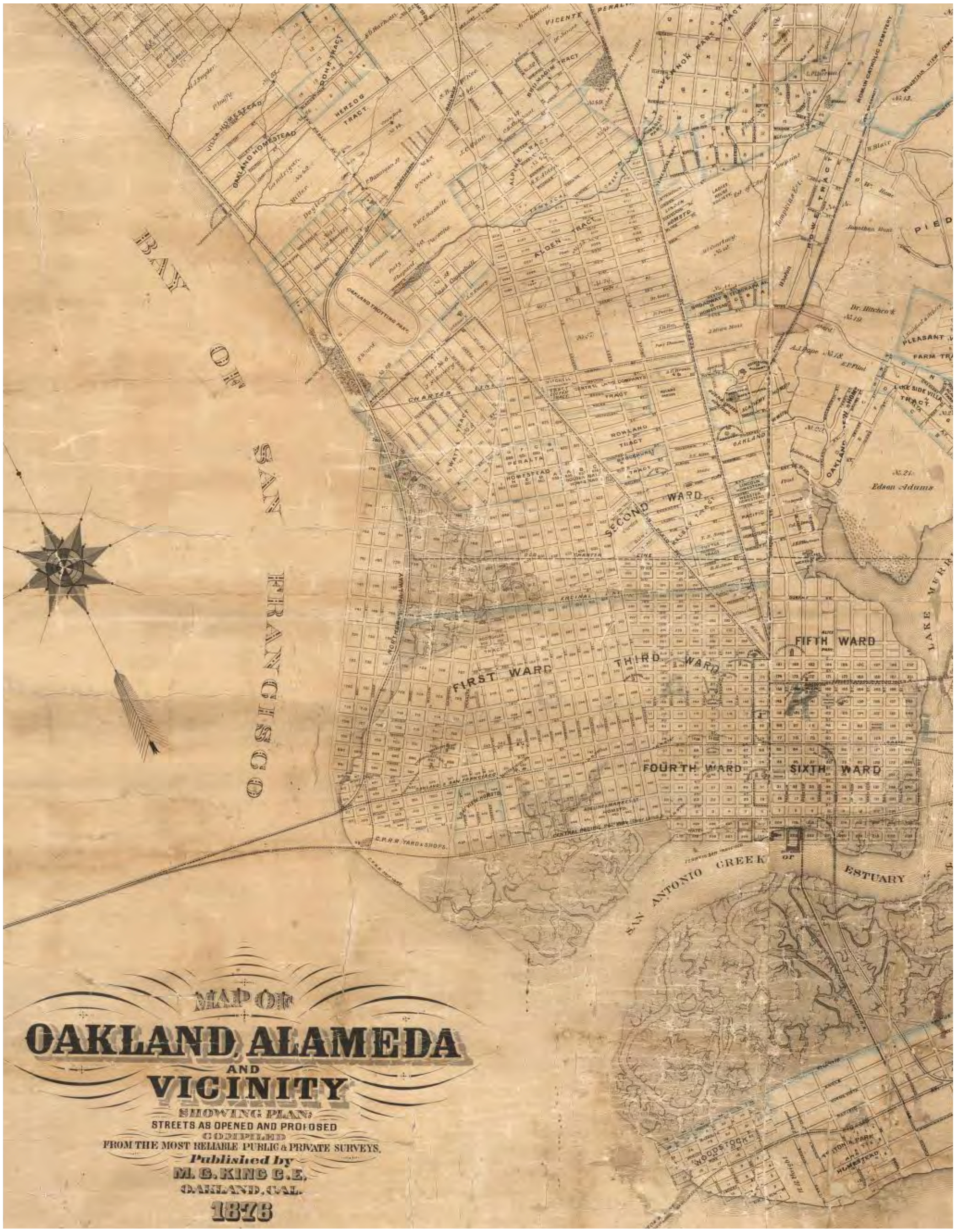
Figure 1: 1852 Chart of the Bay of San Pablo

The Oakland EcoBlock is located on land that was once identified as Contra Costa (the other coast) as part of the Vincente and Domingo Peralta owned Rancho San Antonio. The trace of the old road to Rancho San Pablo and the town of San Pablo is visible in the approximate location of present-day San Pablo Avenue. In 1852, California had been recognized as a state for two years and 17 years later, in 1969 the transcontinental railroad to the Pacific would be completed. Credit: Ringgold, Cadwalader, 1802-1867, San Pablo Bay, Carquines Straits (Rumsey Map Collection, downloaded 08.29.2017).

Figure 2: 1872 Sale Map No. 11: Salt Marsh & Tide Lands

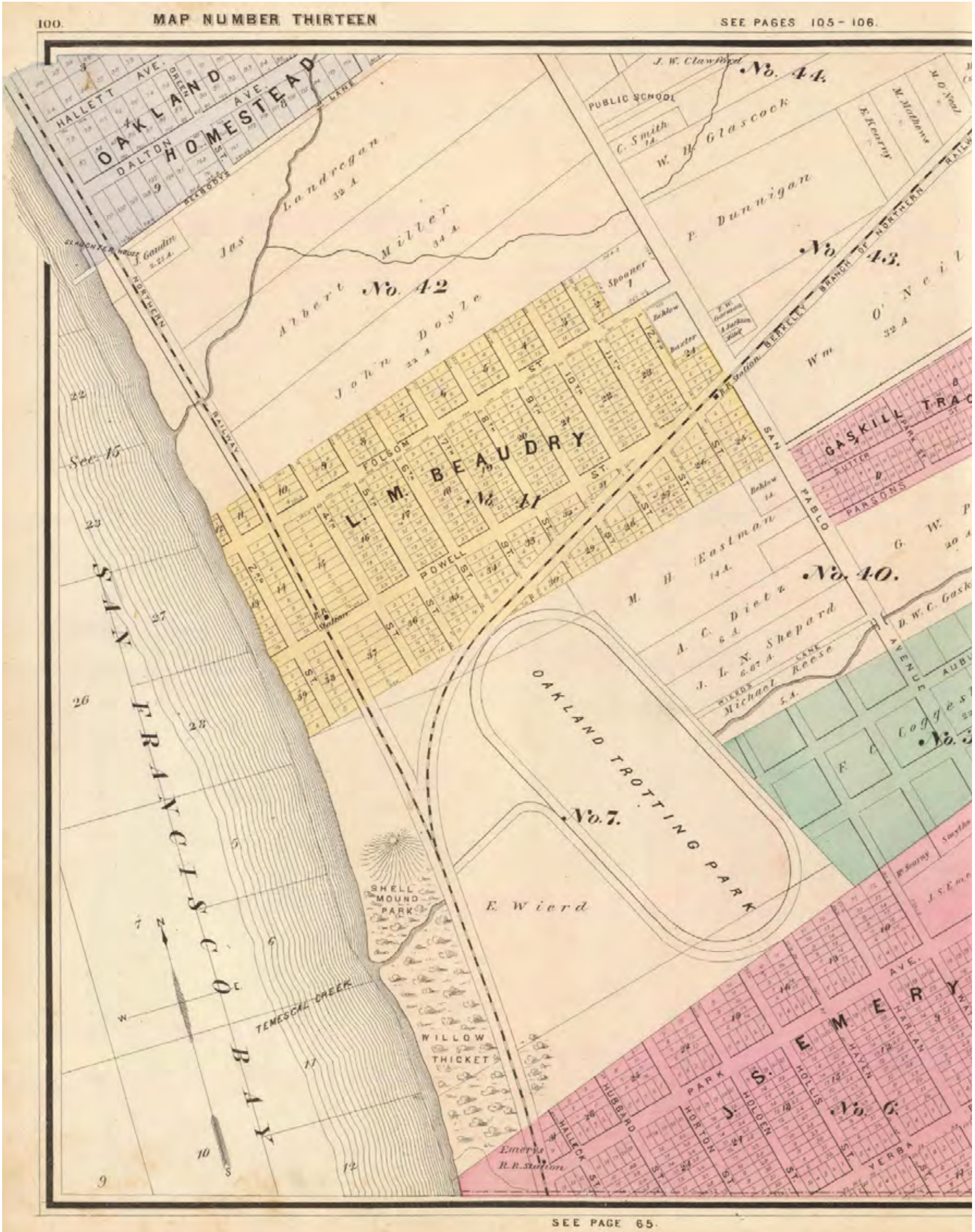
By 1872, the projected line of the Central Pacific railroad was visible running parallel to San Pablo Avenue. Land development accelerated with the location of new infrastructure. The State of California sold the shallow tidelands at public auction, initiating the movement of the bay edge to the west of the railroad alignment. Credit: Allardt, G. F., Sale map no. 11. Salt marsh, tide lands, counties of Alameda and Contra Costa (Rumsey Map Collection, downloaded 08.29.2017).

Figure 3: 1876 Map of Oakland, Alameda and Vicinity



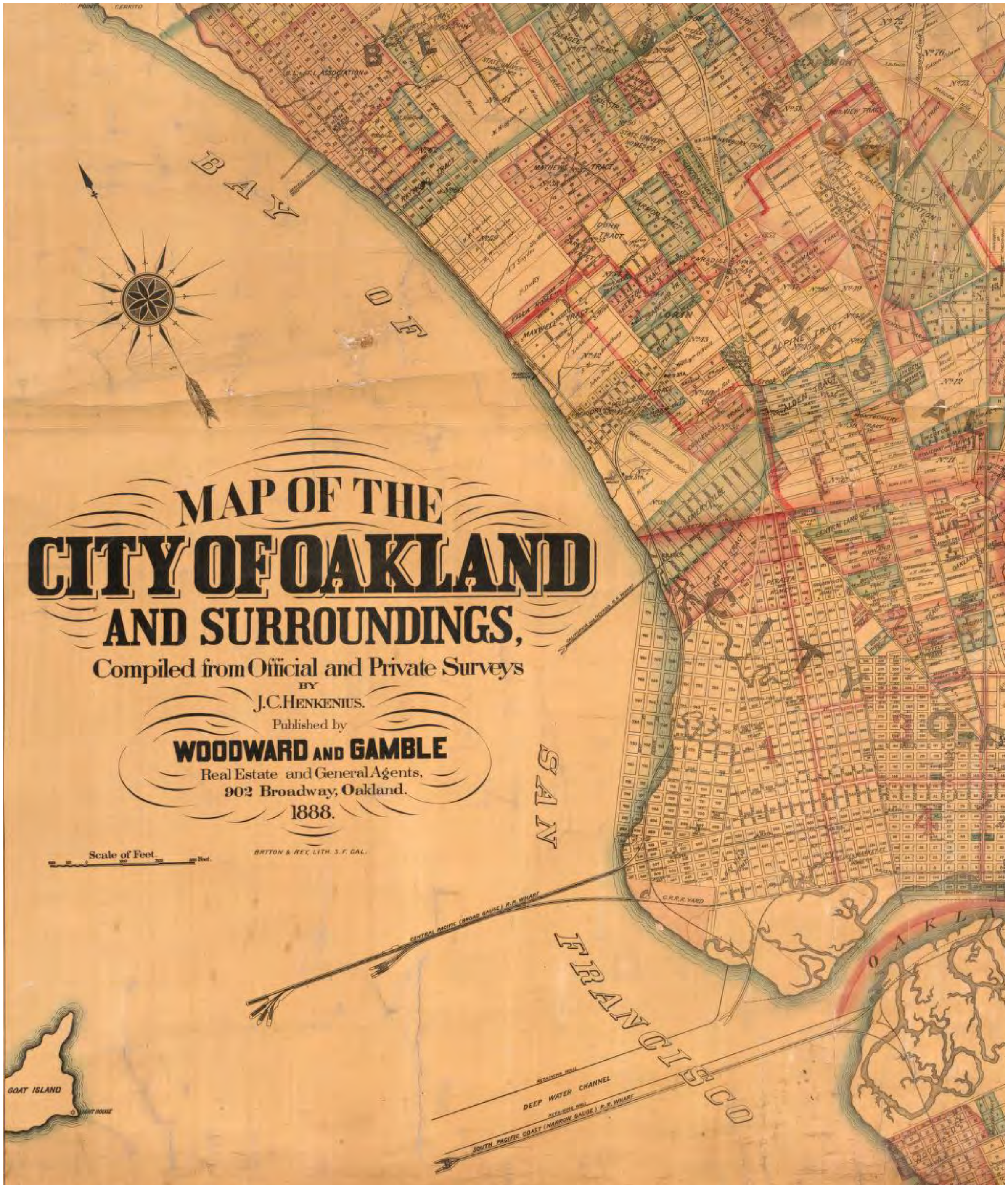
By 1872, the Berkeley Branch of Pacific Northern Railway was visible and two railway stations service the area. One at Montague Street serving the western edge of the plat and a second at the intersection of Kierney St. and San Pablo Ave. serving the eastern edge of the plat. Credit: King, M. G. (Malcolm G.), Map of Oakland, Alameda and Vicinity (Rumsey Map Collection, downloaded 08.29.2017).

Figure 4: 1878 Oakland Map Atlas, Map No. 13



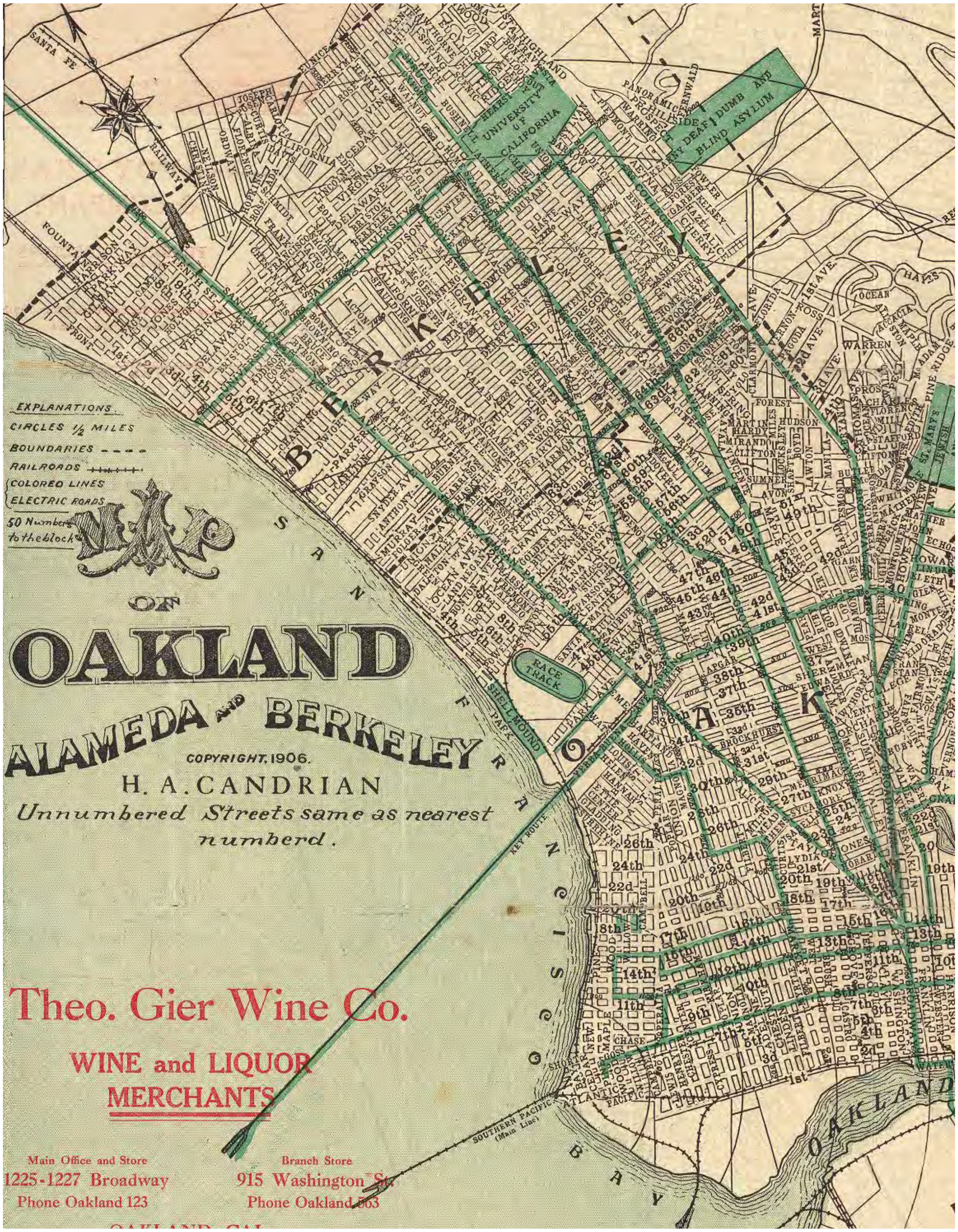
Map of the Oakland EcoBlock area and surroundings. Lots are visible, measuring 50' x 100' for an approximate size of 5,000 square feet per lot. The railroad station at Powell St. and San Pablo Ave. is still visible. *Credit: Thompson & West, Oakland, vicinity 13 (Rumsey Map Collection, downloaded 08.29.2017)*

Figure 5: 1888 Map of the City of Oakland and Surroundings



By 1888, the community of Emeryville was visible (incorporated 1896) and more than one-half of the original tract was in this new community. The location of the Oakland EcoBlock is identified as part of Temescal in the Oakland township, beyond the edge of the City of Oakland. Credit: Henkenius, J.C., Map of the City of Oakland and Surroundings. (Rumsey Map Collection, downloaded 08.29.2017)

Figure 6: 1906 Map of Oakland, Alameda and Berkeley



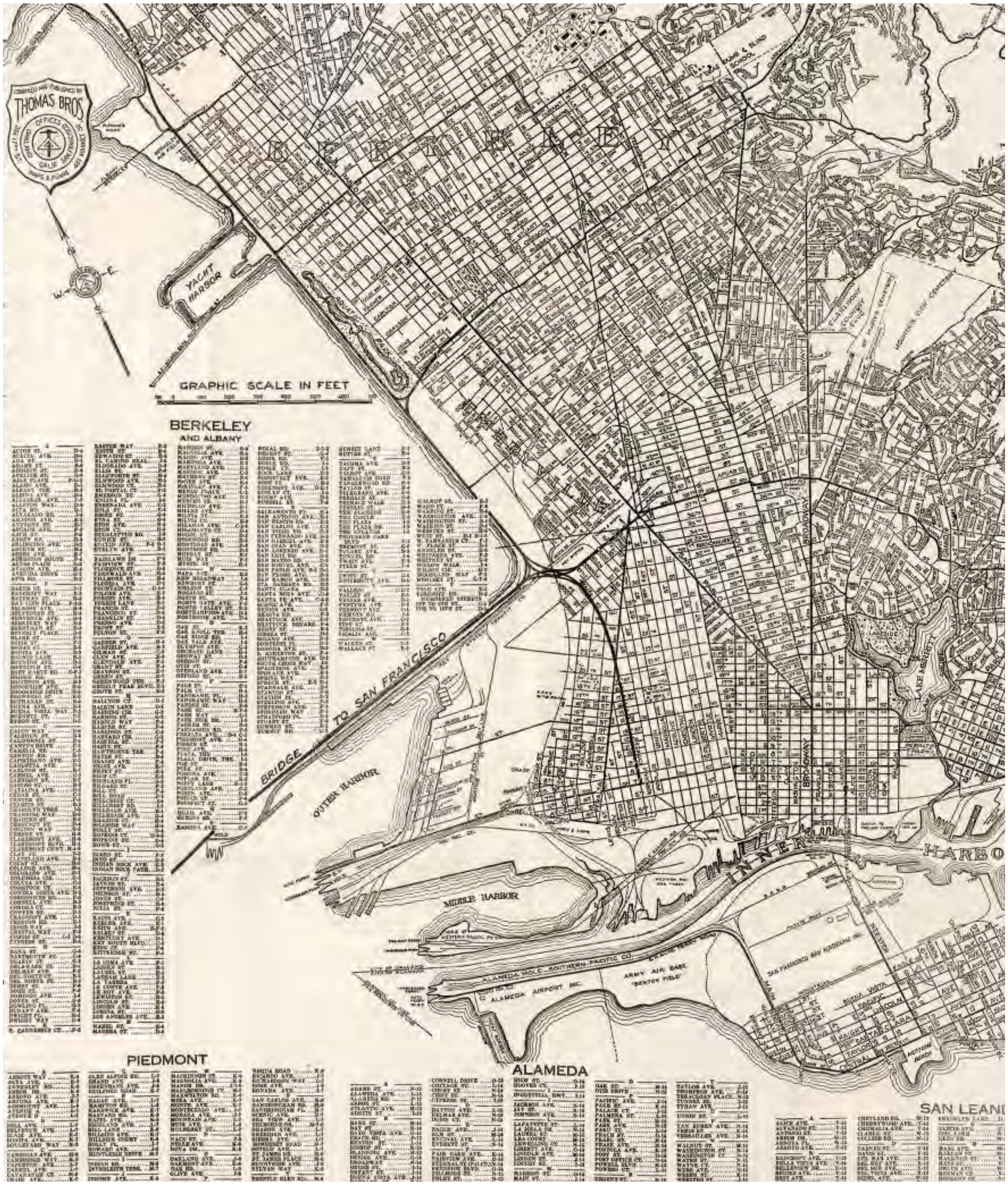
By 1906, electric roads are indicated in green, with San Pablo Avenue electrified into Downtown Oakland.

Credit: Candrian, Herman Anton, Map of Oakland, Alameda and Berkeley. Copyright, 1906. (Rumsey Map Collection, downloaded 08.29.2017)

Figure 7: 1912 Map of Oakland and Vicinity

The Oakland EcoBlock is located north and west of the race track. By 1912, another Southern Pacific rail line cut through the center of the tract. The San Francisco-Oakland Terminal Railways ran down the length of San Pablo Ave. Credit: Realty Union, Map of Oakland And Vicinity (Rumsey Map Collection, downloaded 08.29.2017)

Figure 8: 1935 New Map of Oakland



By 1935, the Bridge to San Francisco had been completed, and railroad-based development of Oakland had been concluded. Credit: Thomas Bros., City and County Of San Francisco. (Rumsey Map Collection, downloaded 08.29.2017)

APPENDIX C: HOME ENERGY SAVER SINGLE FAMILY BATCH RUN INPUT VALUES

Energy Simulation Input Value Table

The initial EcoBlock single family simulation runs were executed using the Home Energy Saver API system (http://developers.buildingsapi.lbl.gov/home) and were submitted in a batch execution method using the following input values. The input values shown below are only the values submitted and input categories not represented in the table are automatically defaulted by the Home Energy Saver backend server. Engineering documentation for all defaulted values are located at https://sites.google.com/a/lbl.gov/hes-public.

BuildingID	Model Case	Unit Count	Occ. Count	Last Year Constr.	House Orient.	Stories Above Ground	Dimension 1	Dimension 2	Ceiling Height	Air Sealing Present	HW Fuel	HW Year	Refrig. Count	First Fridge Type	First Fridge Size	Second Fridge Type	Second Fridge Size	Third Fridge Type	Third Fridge Size
B1	Basecase-as-built	2	4	1898	180	2	38.9765	23.3859	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B1	Basecase-all-elec	2	4	1898	180	2	38.9765	23.3859	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B1	EE-retrofit-package	2	4	2020	180	2	38.9765	23.3859	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B2	Basecase-as-built	4	4	1912	180	2	45.1664	27.0998	8.5	0	gas		3	RefAS	30	RefAS	20	RefAT	20
B2	Basecase-all-elec	4	4	1912	180	2	45.1664	27.0998	8.5	0	ele		3	RefAS	30	RefAS	20	RefAT	20
B2	EE-retrofit-package	4	4	2020	180	2	45.1664	27.0998	8.5	1	ele	2017	3	RefAS	30	RefAS	20	RefAT	20
B3	Basecase-as-built	3	5	1924	180	2	42.6615	25.5969	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B3	Basecase-all-elec	3	5	1924	180	2	42.6615	25.5969	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B3	EE-retrofit-package	3	5	2020	180	2	42.6615	25.5969	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B4	Basecase-as-built	2	4	1934	180	1	50.4149	30.249	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B4	Basecase-all-elec	2	4	1934	180	1	50.4149	30.249	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B4	EE-retrofit-package	2	4	2020	180	1	50.4149	30.249	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B5	Basecase-as-built	2	3	1924	180	2	41.2513	24.7508	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B5	Basecase-all-elec	2	3	1924	180	2	41.2513	24.7508	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B5	EE-retrofit-package	2	3	2020	180	2	41.2513	24.7508	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B6	Basecase-as-built	4	7	1924	90	1	58.2523	34.9514	8.5	0	gas		3	RefAS	30	RefAS	20	RefAT	20
B6	Basecase-all-elec	4	7	1924	90	1	58.2523	34.9514	8.5	0	ele		3	RefAS	30	RefAS	20	RefAT	20
B6	EE-retrofit-package	4	7	2020	90	1	58.2523	34.9514	8.5	1	ele	2017	3	RefAS	30	RefAS	20	RefAT	20

BuildingID	Model Case	Unit Count	Occ. Count	Last Year Constr.	House Orient.	Stories Above Ground	Dimension 1	Dimension 2	Ceiling Height	Air Sealing Present	HW Fuel	HW Year	Refrig. Count	First Fridge Type	First Fridge Size	Second Fridge Type	Second Fridge Size	Third Fridge Type	Third Fridge Size
B7	Basecase-as-built	3	2	1900	90	2	42.7298	25.6379	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B7	Basecase-all-elec	3	2	1900	90	2	42.7298	25.6379	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B7	EE-retrofit-package	3	2	2020	90	2	42.7298	25.6379	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B8	Basecase-as-built	1	0	1900	90	2	22.8035	13.6821	8.5	0	gas		1	RefAS	20	none	0	none	0
B8	Basecase-all-elec	1	0	1900	90	2	22.8035	13.6821	8.5	0	ele		1	RefAS	20	none	0	none	0
B8	EE-retrofit-package	1	0	2020	90	2	22.8035	13.6821	8.5	1	ele	2017	1	RefAS	20	none	0	none	0
B9	Basecase-as-built	2	1	1898	90	2	38.4491	23.0695	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B9	Basecase-all-elec	2	1	1898	90	2	38.4491	23.0695	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B9	EE-retrofit-package	2	1	2020	90	2	38.4491	23.0695	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B10	Basecase-as-built	2	3	1980	90	2	35.8934	21.536	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B10	Basecase-all-elec	2	3	1980	90	2	35.8934	21.536	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B10	EE-retrofit-package	2	3	2020	90	2	35.8934	21.536	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B11	Basecase-as-built	1	2	1980	90	1	32.914	19.7484	8.5	0	gas		1	RefAS	20	none	0	none	0
B11	Basecase-all-elec	1	2	1980	90	1	32.914	19.7484	8.5	0	ele		1	RefAS	20	none	0	none	0
B11	EE-retrofit-package	1	2	2020	90	1	32.914	19.7484	8.5	1	ele	2017	1	RefAS	20	none	0	none	0
B12	Basecase-as-built	3	6	1933	90	2	45.1848	27.1109	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B12	Basecase-all-elec	3	6	1933	90	2	45.1848	27.1109	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B12	EE-retrofit-package	3	6	2020	90	2	45.1848	27.1109	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B13	Basecase-as-built	2	4	2004	90	2	48.3046	28.9828	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B13	Basecase-all-elec	2	4	2004	90	2	48.3046	28.9828	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B13	EE-retrofit-package	2	4	2020	90	2	48.3046	28.9828	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B14	Basecase-as-built	3	4	1920	90	2	28.8675	17.3205	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B14	Basecase-all-elec	3	4	1920	90	2	28.8675	17.3205	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B14	EE-retrofit-package	3	4	2020	90	2	28.8675	17.3205	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B15	Basecase-as-built	1	2	1900	90	1	52.1536	31.2922	8.5	0	gas		1	RefAS	20	none	0	none	0
B15	Basecase-all-elec	1	2	1900	90	1	52.1536	31.2922	8.5	0	ele		1	RefAS	20	none	0	none	0
B15	EE-retrofit-package	1	2	2020	90	1	52.1536	31.2922	8.5	1	ele	2017	1	RefAS	20	none	0	none	0
B17	Basecase-as-built	1	3	1926	90	1	38.5141	23.1084	8.5	0	gas		1	RefAS	20	none	0	none	0
B17	Basecase-all-elec	1	3	1926	90	1	38.5141	23.1084	8.5	0	ele		1	RefAS	20	none	0	none	0
B17	EE-retrofit-package	1	3	2020	90	1	38.5141	23.1084	8.5	1	ele	2017	1	RefAS	20	none	0	none	0

BuildingID	Model Case	Unit Count	Occ. Count	Last Year Constr.	House Orient.	Stories Above Ground	Dimension 1	Dimension 2	Ceiling Height	Air Sealing Present	HW Fuel	HW Year	Refrig. Count	First Fridge Type	First Fridge Size	Second Fridge Type	Second Fridge Size	Third Fridge Type	Third Fridge Size
B18	Basecase-as-built	1	3	1918	90	1	41.6733	25.004	8.5	0	gas		1	RefAS	20	none	0	none	0
B18	Basecase-all-elec	1	3	1918	90	1	41.6733	25.004	8.5	0	ele		1	RefAS	20	none	0	none	0
B18	EE-retrofit-package	1	3	2020	90	1	41.6733	25.004	8.5	1	ele	2017	1	RefAS	20	none	0	none	0
B20	Basecase-as-built	2	6	1910	270	3	33.3333	20	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B20	Basecase-all-elec	2	6	1910	270	3	33.3333	20	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B20	EE-retrofit-package	2	6	2020	270	3	33.3333	20	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B21	Basecase-as-built	2	1	1941	270	2	30.0278	18.0167	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B21	Basecase-all-elec	2	1	1941	270	2	30.0278	18.0167	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B21	EE-retrofit-package	2	1	2020	270	2	30.0278	18.0167	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B22	Basecase-as-built	3	5	1980	270	2	46.7529	28.0517	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B22	Basecase-all-elec	3	5	1980	270	2	46.7529	28.0517	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B22	EE-retrofit-package	3	5	2020	270	2	46.7529	28.0517	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B23	Basecase-as-built	2	3	1908	270	1	53.135	31.881	8.5	0	gas		2	RefAS	20	RefAS	20	none	0
B23	Basecase-all-elec	2	3	1908	270	1	53.135	31.881	8.5	0	ele		2	RefAS	20	RefAS	20	none	0
B23	EE-retrofit-package	2	3	2020	270	1	53.135	31.881	8.5	1	ele	2017	2	RefAS	20	RefAS	20	none	0
B24	Basecase-as-built	1	2	1912	270	2	48.9898	29.3939	8.5	0	gas		1	RefAS	20	none	0	none	0
B24	Basecase-all-elec	1	2	1912	270	2	48.9898	29.3939	8.5	0	ele		1	RefAS	20	none	0	none	0
B24	EE-retrofit-package	1	2	2020	270	2	48.9898	29.3939	8.5	1	ele	2017	1	RefAS	20	none	0	none	0
B25	Basecase-as-built	3	2	1908	270	3	35.9861	21.5917	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B25	Basecase-all-elec	3	2	1908	270	3	35.9861	21.5917	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B25	EE-retrofit-package	3	2	2020	270	3	35.9861	21.5917	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B26	Basecase-as-built	3	4	1995	270	2	42.1011	25.2606	8.5	0	gas		3	RefAS	20	RefAS	20	RefAT	20
B26	Basecase-all-elec	3	4	1995	270	2	42.1011	25.2606	8.5	0	ele		3	RefAS	20	RefAS	20	RefAT	20
B26	EE-retrofit-package	3	4	2020	270	2	42.1011	25.2606	8.5	1	ele	2017	3	RefAS	20	RefAS	20	RefAT	20
B27	Basecase-as-built	1	2	1925	270	2	25.8199	15.4919	8.5	0	gas		1	RefAS	20	none	0	none	0
B27	Basecase-all-elec	1	2	1925	270	2	25.8199	15.4919	8.5	0	ele		1	RefAS	20	none	0	none	0
B27	EE-retrofit-package	1	2	2020	270	2	25.8199	15.4919	8.5	1	ele	2017	1	RefAS	20	none	0	none	0

BuildingID	Model Case	Dish Washer E-STAR	Dish washer Total Loads	Clothes Dryer Fuel	Clothes Dryer Weekly Loads	Clothes Washer Loads Warm Cold	Cooling Type	Heating Type	Heating Sys. Year	Window Area Back	Window Area Front	Window Area Left	Window Area Right	Window Types Differ By Side	Window Type Front	Walls Same All Sides	Wall Constr. Front	Attic
B1	Basecase-as-built	no	6	elec	10	12	non	gfn		62.3	46.7	66.3	66.3	0	dcaw	1	ewwf00wo	uncon
B1	Basecase-all-elec	no	6	elec	10	12	non	ehp		62.3	46.7	66.3	66.3	0	dcaw	1	ewwf00wo	uncon
B1	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	62.3	46.7	66.3	66.3	0	dseaaw	1	ewps21wo	uncon
B2	Basecase-as-built	no	12	elec	20	24	non	gfn		72.8	72.8	19.2	11.5	0	dcaa	1	ewwf00st	uncon
B2	Basecase-all-elec	no	12	elec	20	24	non	ehp		72.8	72.8	19.2	11.5	0	dcaa	1	ewwf00st	uncon
B2	EE-retrofit-package	yes	12	elec	20	24	non	ehp	2017	72.8	72.8	19.2	11.5	0	dseaaw	1	ewwf13st	uncon
B3	Basecase-as-built	no	9	elec	15	18	non	gfn		34.3	41.1	10.9	14.5	0	dcaw	1	ewwf00st	uncon
B3	Basecase-all-elec	no	9	elec	15	18	non	ehp		34.3	41.1	10.9	14.5	0	dcaw	1	ewwf00st	uncon
B3	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	34.3	41.1	10.9	14.5	0	dseaaw	1	ewwf13st	uncon
B4	Basecase-as-built	no	6	elec	10	12	non	gfn		57.2	61.3	32.1	32.1	0	dcaw	1	ewwf00st	uncon
B4	Basecase-all-elec	no	6	elec	10	12	non	ehp		57.2	61.3	32.1	32.1	0	dcaw	1	ewwf00st	uncon
B4	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	57.2	61.3	32.1	32.1	0	dseaaw	1	ewwf13st	uncon
B5	Basecase-as-built	no	6	elec	10	12	non	gfn		26.5	33.1	52.6	52.6	0	dcaa	1	ewwf00st	uncon
B5	Basecase-all-elec	no	6	elec	10	12	non	ehp		26.5	33.1	52.6	52.6	0	dcaa	1	ewwf00st	uncon
B5	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	26.5	33.1	52.6	52.6	0	dseaaw	1	ewwf13st	uncon
B6	Basecase-as-built	no	12	elec	20	24	non	gfn		35.6	71.3	74.3	94.1	0	dcaw	1	ewwf00st	uncon
B6	Basecase-all-elec	no	12	elec	20	24	non	ehp		35.6	71.3	74.3	94.1	0	dcaw	1	ewwf00st	uncon
B6	EE-retrofit-package	yes	12	elec	20	24	non	ehp	2017	35.6	71.3	74.3	94.1	0	dseaaw	1	ewwf13st	uncon

BuildingID	Model Case	Dish Washer E-STAR	Dish washer Total Loads	Clothes Dryer Fuel	Clothes Dryer Weekly Loads	Clothes Washer Loads Warm Cold	Cooling Type	Heating Type	Heating Sys. Year	Window Area Back	Window Area Front	Window Area Left	Window Area Right	Window Types Differ By Side	Window Type Front	Walls Same All Sides	Wall Constr. Front	Attic
B7	Basecase-as-built	no	9	elec	15	18	non	gfn		171.6	308.9	254.2	36.3	0	scnw	1	ewwf00wo	uncon
B7	Basecase-all-elec	no	9	elec	15	18	non	ehp		171.6	308.9	254.2	36.3	0	scnw	1	ewwf00wo	uncon
B7	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	171.6	308.9	254.2	36.3	0	dseaaw	1	ewps21wo	uncon
B8	Basecase-as-built	no	3	elec	5	6	non	gfn		86.9	86.9	58.1	58.1	0	scnw	1	ewwf00wo	uncon
B8	Basecase-all-elec	no	3	elec	5	6	non	ehp		86.9	86.9	58.1	58.1	0	scnw	1	ewwf00wo	uncon
B8	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	86.9	86.9	58.1	58.1	0	dseaaw	1	ewps21vi	uncon
B9	Basecase-as-built	no	6	elec	10	12	non	gfn		153.4	153.4	98	98	0	dcaw	1	ewwf00wo	uncon
B9	Basecase-all-elec	no	6	elec	10	12	non	ehp		153.4	153.4	98	98	0	dcaw	1	ewwf00wo	uncon
B9	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	153.4	153.4	98	98	0	dseaaw	1	ewps21vi	uncon
B10	Basecase-as-built	no	6	elec	10	12	non	gfn		142.5	171.1	122	122	0	dseaaw	1	ewwf11wo	uncon
B10	Basecase-all-elec	no	6	elec	10	12	non	ehp		142.5	171.1	122	122	0	dseaaw	1	ewwf11wo	uncon
B10	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	142.5	171.1	122	122	0	dseaaw	1	ewps21wo	uncon
B11	Basecase-as-built	no	3	elec	5	6	non	gfn		77.9	77.9	56	56	0	dseaaw	1	ewwf00wo	uncon
B11	Basecase-all-elec	no	3	elec	5	6	non	ehp		77.9	77.9	56	56	0	dseaaw	1	ewwf00wo	uncon
B11	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	77.9	77.9	56	56	0	dseaaw	1	ewps21wo	uncon
B12	Basecase-as-built	no	9	elec	15	18	non	gfn		109.2	109.2	53.8	15.4	0	dcaw	1	ewwf11wo	cath
B12	Basecase-all-elec	no	9	elec	15	18	non	ehp		109.2	109.2	53.8	15.4	0	dcaw	1	ewwf11wo	cath
B12	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	109.2	109.2	53.8	15.4	0	dseaaw	1	ewps21wo	cath
B13	Basecase-as-built	no	6	elec	10	12	non	ehp		93.7	93.7	41.1	8.2	0	scnw	1	ewwf11wo	uncon
B13	Basecase-all-elec	no	6	elec	10	12	non	ehp		93.7	93.7	41.1	8.2	0	scnw	1	ewwf11wo	uncon
B13	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	93.7	93.7	41.1	8.2	0	dseaaw	1	ewps21wo	uncon
B14	Basecase-as-built	no	9	elec	15	18	non	gfn		54.1	54.1	24.5	24.5	0	scna	1	ewwf00st	uncon
B14	Basecase-all-elec	no	9	elec	15	18	non	ehp		54.1	54.1	24.5	24.5	0	scna	1	ewwf00st	uncon
B14	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	54.1	54.1	24.5	24.5	0	dseaaw	1	ewwf13st	uncon
B15	Basecase-as-built	no	3	elec	5	6	non	gfn		84.7	84.7	44.3	44.3	0	dcaw	1	ewwf00wo	uncon
B15	Basecase-all-elec	no	3	elec	5	6	non	ehp		84.7	84.7	44.3	44.3	0	dcaw	1	ewwf00wo	uncon
B15	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	84.7	84.7	44.3	44.3	0	dseaaw	1	ewps21wo	uncon
B17	Basecase-as-built	no	3	elec	5	6	non	gfn		30.7	30.7	32.7	65.5	0	dcaw	1	ewwf00wo	uncon
B17	Basecase-all-elec	no	3	elec	5	6	non	ehp		30.7	30.7	32.7	65.5	0	dcaw	1	ewwf00wo	uncon
B17	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	30.7	30.7	32.7	65.5	0	dseaaw	1	ewps21wo	uncon

BuildingID	Model Case	Dish Washer E-STAR	Dish washer Total Loads	Clothes Dryer Fuel	Clothes Dryer Weekly Loads	Clothes Washer Loads Warm Cold	Cooling Type	Heating Type	Heating Sys. Year	Window Area Back	Window Area Front	Window Area Left	Window Area Right	Window Types Differ By Side	Window Type Front	Walls Same All Sides	Wall Constr. Front	Attic Typ
B18	Basecase-as-built	no	3	elec	5	6	non	gfn		33.4	33.4	70.8	53.1	0	dcaw	1	ewwf00wo	uncond_a
B18	Basecase-all-elec	no	3	elec	5	6	non	ehp		33.4	33.4	70.8	53.1	0	dcaw	1	ewwf00wo	uncond_a
B18	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	33.4	33.4	70.8	53.1	0	dseaaw	1	ewps21wo	uncond_a
B20	Basecase-as-built	no	6	elec	10	12	non	gfn		39.5	59.3	42.5	42.5	0	scnw	1	ewwf00wo	cath_ce
B20	Basecase-all-elec	no	6	elec	10	12	non	ehp		39.5	59.3	42.5	42.5	0	scnw	1	ewwf00wo	cath_ce
B20	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	39.5	59.3	42.5	42.5	0	dseaaw	1	ewps21wo	cath_ce
B21	Basecase-as-built	no	6	elec	10	12	non	gfn		14.1	14.1	40.8	10.2	0	scna	1	ewwf00st	uncond_a
B21	Basecase-all-elec	no	6	elec	10	12	non	ehp		14.1	14.1	40.8	10.2	0	scna	1	ewwf00st	uncond_a
B21	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	14.1	14.1	40.8	10.2	0	dseaaw	1	ewwf13st	uncond_a
B22	Basecase-as-built	no	9	elec	15	18	non	gfn		56.6	56.6	39.7	39.7	0	scnw	1	ewwf11wo	uncond_a
B22	Basecase-all-elec	no	9	elec	15	18	non	ehp		56.6	56.6	39.7	39.7	0	scnw	1	ewwf11wo	uncond_a
B22	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	56.6	56.6	39.7	39.7	0	dseaaw	1	ewps21wo	uncond_a
B23	Basecase-as-built	no	6	elec	10	12	non	gfn		64.7	64.7	22.6	22.6	0	scnw	1	ewwf00wo	uncond_a
B23	Basecase-all-elec	no	6	elec	10	12	non	ehp		64.7	64.7	22.6	22.6	0	scnw	1	ewwf00wo	uncond_a
B23	EE-retrofit-package	yes	6	elec	10	12	non	ehp	2017	64.7	64.7	22.6	22.6	0	dseaaw	1	ewps21wo	uncond_a
B24	Basecase-as-built	no	3	elec	5	6	non	gfn		59.5	59.5	16.7	8.3	0	scnw	1	ewwf11wo	uncond_a
B24	Basecase-all-elec	no	3	elec	5	6	non	ehp		59.5	59.5	16.7	8.3	0	scnw	1	ewwf11wo	uncond_a
B24	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	59.5	59.5	16.7	8.3	0	dseaaw	1	ewps21wo	uncond_a
B25	Basecase-as-built	no	9	elec	15	18	non	gfn		42.9	51.5	18.4	18.4	0	scna	1	ewwf00wo	uncond_a
B25	Basecase-all-elec	no	9	elec	15	18	non	ehp		42.9	51.5	18.4	18.4	0	scna	1	ewwf00wo	uncond_a
B25	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	42.9	51.5	18.4	18.4	0	dseaaw	1	ewps21wo	uncond_a
B26	Basecase-as-built	no	9	elec	15	18	non	gfn		50.7	60.8	14.3	14.3	0	scnw	1	ewwf11wo	uncond_a
B26	Basecase-all-elec	no	9	elec	15	18	non	ehp		50.7	60.8	14.3	14.3	0	scnw	1	ewwf11wo	uncond_a
B26	EE-retrofit-package	yes	9	elec	15	18	non	ehp	2017	50.7	60.8	14.3	14.3	0	dseaaw	1	ewps21wo	uncond_a
B27	Basecase-as-built	no	3	elec	5	6	non	gfn		19.9	29.9	8.8	8.8	0	scnw	1	ewwf00wo	uncond_a
B27	Basecase-all-elec	no	3	elec	5	6	non	ehp		19.9	29.9	8.8	8.8	0	scnw	1	ewwf00wo	uncond_a
B27	EE-retrofit-package	yes	3	elec	5	6	non	ehp	2017	19.9	29.9	8.8	8.8	0	dseaaw	1	ewps21wo	uncond_a

APPENDIX D: THE OAKLAND ECO-BLOCK PROJECT: A GENERAL SURVEY AND ASSESSMENT OF PROPOSED BUILDING MATERIALS AND THEIR CONSTITUENT CHEMICALS PROPOSED BY THE WATER AND ENERGY SUB-GROUPS

The Oakland Eco-Block Project: A General Survey and Assessment of Proposed Building Materials and Their Constituent Chemicals proposed by the Water and Energy Sub-groups

Berkeley Center for Green Chemistry
Draft December 11, 2017

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Table of Contents

Introduction

This report is a general review of the building materials currently proposed for a sustainability retrofit of a 100-person neighborhood in West Oakland, California. The purpose of this report is to identify and assess for intrinsic chemical hazard material options for the types of building improvements being proposed. The goal is to provide a first set of general guidelines for reducing or eliminating chemicals of concern from the building materials that will be specified for this project. It is our intent that this first assessment will form the basis for a more detailed chemical hazard evaluation and ranking of the materials specified in the later design phases of this project.

The materials reviewed here are typical options available in the commercial market for the improvements proposed by two subgroups, Water and Energy, belonging to a larger team led by Dr. Dan Kammen and Mr. Harrison Fraker, of the

Energy and Resources Group (ERG) of the College of Natural Resources, University of California at Berkeley. The team is competing for selection by the City of Oakland to design and manage construction of the revitalized neighborhood as part of Oakland's participation in the 100 Resilient Cities program.

This report comprises the following:

- a general review of the current improvements proposed by the two subgroups
- a listing of the typical materials options available for these improvements
- an identification of possible chemicals of concern found within the materials
- general recommendations for avoiding or mitigating hazardous chemicals found in these products.

A summary matrix of all proposed material systems is provided in Appendix A. This matrix includes the type of building system (windows), the components (frame, glazing), the material options available, and notes about chemicals of concern. This matrix does not include appliances, HVAC machinery or lighting.

This report also includes a more detailed description of material options available for building insulation and possible chemical hazards associated with each option. This assay is divided into three basic categories of insulation: fiber, rigid panel, and spray foam types. Each of these is then divided into material types and chemicals of concern are identified for three basic stages in the life cycle: manufacture, use and disposal. This is summarized in a matrix in Appendix B.

We anticipate that the next step toward the goal of reducing hazardous chemicals from this design and construction project will be to perform a more detailed chemicals hazard assessment. In this type of assessment, specific chemicals identified by CAS number are evaluated across a number of toxicological endpoints using curated lists such as the International Agency for Research on Cancer (IARC), Global Harmonized System of Classification and Labeling of Chemicals (GHS), and the substances of very high concern by European Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) program of the European Union, and ranked for relative safety. Appendix C contains a model of this approach.

Energy Production

Photovoltaics (PV)

Photovoltaic systems are a fast-growing alternative energy technology branded for their environmental friendly energy production. While that is true and its use phase does not pose an environmental or human health harm (since the PV compounds are encapsulated between thick layers of plastic or glass), the PV manufacturing process includes many hazardous and toxic materials. The five main types of PV module materials are crystalline silicon, amorphous silicon, cadmium telluride, copper indium gallium diselenide and gallium arsenide [1].

During the manufacturing process of crystalline silicon, hydrofluoric acid is used that can cause chemical burns, silane is produced as a byproduct that is flammable; toxic gaseous effluents are also generated from dopant gases and vapors that should not be inhaled and lead solder is used which poses a concern during disposal. During the amorphous silicon production process, silane gas is the main safety hazard. It has a low spontaneous ignition range and is flammable and explosive.

The other PV materials in cadmium telluride, copper indium gallium diselenide and gallium arsenide, are toxic and carcinogenic. In comparison, cadmium telluride has the highest acute toxicity due to the cadmium and causes pneumonitis, edema and can lead to death. Hazards to workers may arise from feedstock preparation, fume leaks and waste handling. Copper indium selenide solar cells have copper, indium and selenide toxicity yet are mild in comparison to the feedstock material, hydrogen selenide. Hydrogen selenide is highly toxic and has an Immediately Dangerous to Life and Health concentration of 1 ppm [1]. Finally, the manufacturing process of gallium arsenide also requires toxic feedstocks of arsine and phosphine. The process also uses hydrogen that is flammable and arsenic that is carcinogenic.

Therefore, these manufacturing impacts should be taken into consideration when choosing the safest product. In addition, all five of these PV materials pose environmental concerns if not handled and disposed of properly at their end of life. Since the materials are rare, they are often recycled. Yet if they are landfilled or incinerated, the heavy metals such as cadmium and lead (found in the crystalline silicon PV system) will gasify and be released in the atmosphere and cause environmental hazard concerns due to leaching in soils and water bodies [1].

Recommendations for PV Modules: Although all PV modules are generally safe for residents during use, they all pose some level of hazard during manufacture and end of use. The two materials that present the most concern during manufacturing are cadmium telluride and gallium arsenide due to the toxic hazards of the metals and feedstocks used. The two PV modules that present the highest end of life concerns are those that contain cadmium telluride and crystalline silicon due to the metals present. Not all intrinsic hazard can be avoided when choosing these types of modules, so team specifiers should require additional management and engineering controls associated with the products chosen. This includes worker safety precautions taken during the manufacturing process and recycling, rather than landfilling or incineration, at the end of use.

Water System Improvements

Water Pipes

Water pipes are used to transport water to homes for drinking, cooking and cleaning and to carry away waste. The US EPA has set limits on over 90 contaminants in drinking water and they can be grouped by contaminant types: physical, chemical, biological (or also known as microbiological or microbes) and radiological contaminants [2]. Thus, it is important to know what materials the pipes can be made of and their environmental and health impacts.

Galvanized Steel or Galvanized Iron

Galvanized steel pipes are steel pipes that have a zinc protective coating to prevent corrosion and rust. They were commonly used in homes built prior to 1960 as an alternative to lead pipes. Yet after decades of water exposure, galvanized pipes corrode and rust on the inside that can release iron and/or zinc into the drinking water. Iron is persistent and an endocrine disruptor whereas zinc has multiple hazards such as respiratory irritation, endocrine disruptor, persistence, and is toxic to the aquatic environment. In addition, the zinc that the pipes were typically dipped in may have contained lead. Lead is a neurotoxin that accumulates in soft tissues and bones, damages the nervous system, and causes blood disorders. It can cause permanent brain damage in children exposed to it. The zinc could also contain other chemicals such as cadmium [3] that could harm inhabitants) [4].

Galvanized iron pipes are iron pipes that also have a zinc protecting coating. These pipes have the same health hazards as galvanized steel pipes already mentioned [5].

Copper

The biggest concern with copper pipes is corrosion. Copper pipes that are corroded can release copper into the water to levels higher than the US Environmental Protection Agency's Safe Drinking Water Act accepted level and cause the water to taste bitter or metallic. The concentration of copper in the water is affected by the level of corrosion of the copper pipes, variations in PH, hardness, dissolved oxygen among others. Copper is an essential micronutrient and present at low concentrations and thus the US EPA developed a healthy level of 1.3 mg/L of copper for drinking water in 1999. This level of copper has no adverse health effects, yet if humans are exposed to high levels of copper toxic effects include skin sensitization, organ toxicity, acute mammalian toxicity and persistence. At much higher levels, copper can cause death [6]. In addition, copper's extraction and manufacturing process is energy intensive and thus has a poor environmental life cycle analysis. Copper pipes are generally used for hot water.

Cast Iron

Cast iron pipes have historically been coated with coal tar and bitumen to protect the pipe from corrosion. Coal tar and bitumen are made of a mixture of polycyclic aromatic compounds that vary depending on the source of coal or petroleum used and the processing techniques. Thus, as the lining deteriorates, polycyclic aromatic hydrocarbons (PAH) can leach out of the coatings into the drinking water. PAH are known to be a very high hazard for cancer and are persistent, bioaccumulative and toxic [7].

Polyvinyl chloride (PVC)

According to a study in the Journal of Environmental Engineering, polyvinyl pipes allow polyvinyl chloride (a carcinogen) to leach into drinking water at levels above the maximum allowed. In addition, the US Centers for Disease Control and Prevention notes that phthalates are also found in PVC pipes and leach into water and cause liver and reproductive toxicity, endocrine disruption. Long-term exposure can be hazardous. In addition, the manufacturing of PVC uses polyvinyl chloride, as well as stabilizers and plasticizers like phthalates, which may contain heavy metals that are toxic. End of life incineration may cause hydrochloric acid formation. This is a corrosive material and can cause respiratory damage. [8]. End of life incineration also produces dioxins, mentioned below. PVC pipes are susceptible to physical damage if exposed to UV light and should not be placed close to water heaters and heat sources as they can expand and contract with heat therefore soften and deform the pipe.

Chlorinated PVC (CPVC)

CPVC pipes are made similarly to PVC pipes, yet undergo an extra chlorination process to increase the chlorine content in order to withstand higher temperatures. Therefore, the same toxic chemicals that leach out of PVC are found in CPVC. In addition, CPVC uses toxic manufacturing intermediaries and toxic synthetic adhesives such as epoxies, polyurethanes, cyanoacrylates and acrylic polymers. These are carcinogenic and are made of harsh solvents such as benzene, toluene, methanol, acetone. Other chemicals that may leach from the CPVC into the water include chloroform, tetrahydrofuran, methyl ethyl ketone, organotins and acetate that may cause cancer and other serious health impacts as well as ozone pollution. During incineration at the end of life of CPVC pipes, highly toxic dioxins (most toxic chemicals known to science) are generated [9]–[11]. CPVC pipes can be used for cold and hot water distribution.

Cross Linked Polyethylene (PEX)

PEX piping has gained popularity in the green building industry due to its flexibility, ease of installation, and cost. LCA studies have also demonstrated that PEX required 25-60% less energy and produced 50-75% less CO_2 than copper pipes. Although PEX pipes do not require solvents for installation, in a year after installation and use, additives and degradation products have been detected in the water carried by the pipe. In addition, PEX has been linked to chemical leaching, high total organic carbon levels, and in some cases, it is oxygen permeable so chemicals can penetrate the tube when in contact with contaminated soil. According to a study by Kelley et al, 158 contaminants a year were found in a PEX plumbing system for drinking water. [9],[12].

HDPE

High-density polyethylene pipes are widely approved for cold water applications and can be fused together to form a joint therefore eliminating sources of leaks and contamination. Although considered a safe plastic alternative, as with other plastics, chemicals can leach from HDPE pipes and include specific ketones, phenols and hydrocarbons [13], [14].

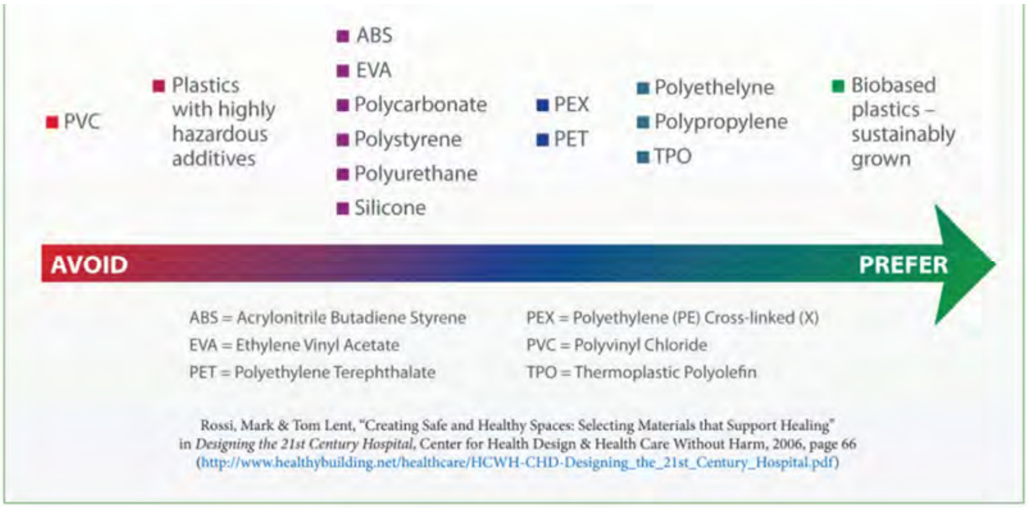

Figure 1 *Plastic Environmental Preference from Rossi, Mark & Tom Lent "Creating Safe and Healthy Space: Selecting Materials that Support Healing"*[15]

Insulation for Hot Water Pipes

Some homeowners and builders choose to insulate their hot water pipes in order to reduce heat loss and raise water temperatures. The most commonly used insulation are polyethylene or neoprene foam sleeves. Other options include fiberglass. Both polyethylene and neoprene are known to be persistent but do not have any direct hazards associated with their use. They both have hazards associated with their process chemistry in order to be made. Polyethylene produces resin dusts during its manufacturing and gases during the heating process that cause skin, eye and respiratory system irritation [16]. Neoprene produces butadiene as a gas during its production that is considered a toxic pollutant by the US Environmental Protection Agency. Low exposure causes eye, throat and respiratory irritation whereas high exposure can cause damage to the nervous system. In addition, neoprene uses adhesives such as rosin (or colophony) that is a skin sensitizer and its use (over 0.1%) must be reported to the European Union Dangerous Preparations Directive [17]. Fiberglass has very high respiratory and skin irritation associated with it and may have a resin binder that is carcinogenic.

Waste Water Pipes

Plastic such as PVC and CPVC are most commonly used for wastewater pipes yet other materials such as galvanized steel or iron and copper can be used [2], [18]. These pipes present the same health issues mentioned above. Cast iron pipes were also used before 1970s yet these pipes create hydrogen sulfide gasses when they carry waste that can then oxidize into sulfuric acid that is corrosive to the pipes and causes them to rust from the inside out [19]. Finally concrete or reinforced concrete pipes can be used for waste water as these pipes can withstand tensile and compressive stress yet also easily corrode and decompose, releasing hydrogen sulfide gas that then oxidizes to form sulfuric acid [20], [21]. Hydrogen sulfide is a flammable gas and causes eye and respiratory irritation. It may cause acute or chronic toxicity and inhaling large amounts can result in death [22].

Recommendations for Water Pipes: Water carrying pipes can be divided into water supply distribution (incoming) and waste removal (outgoing). These can be further divided into hot or cold supply pipes, and grey or black water waste pipes. Copper pipe is recommended for hot water supply pipes, and polypropylene or high-density polyethylene (HDPE) for cold water supply. PEX, PVC and CPVC should not be used for water supply. High density polyethylene (HDPE) is recommended for waste pipes as a balance between cost, availability and relative hazard. Please refer to Figure 1 to determine the environmental safety preference when choosing between plastic water pipes.

Energy Efficiency Improvements

Roofing Systems

A sloped roof is made typically of several layers of structural and protective materials. These layers include sheathing, underlayment, flashing, roof material and gutters and downspouts [23]. Sheathing is a supportive and stabilizing surface that secures the roof shingles and other roof framing members.

Sheathing

Typical roof sheathing materials include plywood, oriented strand board (OSB), paper fiber used for commercial applications, and tongue-and-groove board (used in homes built prior to 1950) [23]. Plywood is made of multiple layers of wood veneer stacked in alternating direction and glued together. The adhesives used in plywood may be of concern yet differ widely and individual products need to be investigated to evaluate hazard. Often formaldehyde has been used in plywood adhesives because of its superior cross-linking performance. Formaldehyde is used as a liquid in the adhesive resin but can vaporize at room temperature, becoming a gas linked to a variety of health problems including eye, nose throat and skin irritation, and allergic reactions. Long-term exposure has been linked to cancer in humans. Phenol-formaldehyde (PF) is less hazardous than urea-formaldehyde (UF) In addition, plywood may contain phenolic resins that make it impervious to moisture. Phenolic resin is persistent and may cause respiratory irritation. OSB is made from wood scraps pressed and glued into panels. It also contains formaldehyde used as an adhesive binder. OSB tends to retain moisture if gotten wet and can harbor mold resulting in significant chronic health problems for those exposed to it. Tongue and groove is made of cut wood stock, whereas paper fiber is made up of 100% waste paper. If the wood is considered sustainable when purchasing plywood or tongue and groove, the wood will be stamped with a Forest Stewardship Council (FSC) certification logo. This independent organization develops standards for responsible environmental and social forestry practice.

Underlayment

Roofing underlayment and flashing protect a home from water damage by preventing water from entering the sheathing and causing leaks. Underlayment may be one of three typical types: asphalt impregnated felt, rubberized asphalt, and non-bitumen synthetic [23]. Standard underlayment is roofing felt in 30 or 15 pound weights, also known as tar paper. This was historically made from paper fibers saturated with asphalt, yet is also made from fiberglass today. The asphalt has caused multiple hazards for installers as it has acute toxicity effects and skin, eye and respiratory irritation. Fiberglass causes skin and respiratory irritation as well. Rubberized asphalt products are made from a wide variety of materials including non-skid polyethylene or polyester top layers, mineralized surfaces, fiberglass reinforcement, and synthetic polymer films. Synthetic membranes are made of uncoated spun-bonded polypropylene multiple ply barriers or high density polyethylene (HDPE) that work as an alternate to traditional building paper under metal, tile and wood shake roofs. HDPE is generally considered safe but has been linked to leaching endocrine disrupting chemical nonylphenol used as a stabilizer [24]. Polypropylene (PP) is also generally considered safe although it has been shown to leach plastic additives [25], may be linked to occupational asthma upon heating [26], and is persistent.

Flashing

Flashing is used in areas vulnerable to leaks such as openings like chimneys and edges like eaves and valleys. Traditionally these are bent metal pieces that act as a watertight barrier and are made up of galvanized steel, copper or lead [23]. Copper and lead are persistent metals that naturally occur in the environment yet are harmful in high concentrations. The toxicity of lead is the same whether inhaled or swallowed and attacks the nervous system. Lead exposure damages the brain and kidneys and causes anemia and miscarriages [27]. Exposure to copper dust can cause nose, mouth and eye irritation as well as headaches, dizziness and nausea. High intakes of copper can cause liver and kidney damage [28]. Both lead and copper are also harmful to aquatic life. These hazards are much more likely for people working with the materials during installation and disposal than for the residents during the use phase [29]. Newer, safer materials include powder-coated aluminum or steel or stainless steel.

Self-adhered flashing strips are also used extensively for flashing, and are made of a wide variety of materials. A typical example (DuPont Flexible Flashing) comprises a flexible, textured polyethylene laminate barrier backed by a butyl-based adhesive layer, protected by a siliconized paper which is removed at installation. Butyl rubber is produced by polymerization of about 98% of isobutylene with about 2% of isoprene. U.S. Occupational Safety and Health Administration (OSHA) rules, European Union regulations and the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (UN GHS) consider this material to be non-hazardous during use.

Finally drip edges such as gutters and downspouts are installed along the perimeter of the roof and can be made up of the same components as flashing, or more commonly aluminum, or PVC (polyvinyl chloride). Unpainted and ungalvanized gutters leach zinc into rainwater and rust over time.

PVC is made from vinyl chloride, which is listed as a human carcinogen in the Fourteenth Report on Carcinogens published by the National Toxicology Program [30]. Dioxins, phthalates (used as a plasticizer), and BPA are suspected to be endocrine disruptors, which are chemicals that may interfere with the production or activity of hormones in the human endocrine system [31]. TCDD dioxin is listed as a human carcinogen, and di(2-ethylhexyl) phthalate is listed as "reasonably anticipated to be a human carcinogen" in the Fourteenth Report on Carcinogens published by the National Toxicology Program. Dioxins are released during the manufacturing, burning or landfilling of PVC. Exposure to PVC dust may cause asthma and affect the lungs.

Roof Material

The roofing material is the top layer in the assembly. It is the layer that determines the appearance of the roof, its longevity and maintenance, and water repellency. Below are the different roofing material options and the EHS concerns associated with them.

Fiber Cement

Fiber cement is made of cement and cellulose fiber to add reinforcement and reduce weight. The silica in the cement causes respiratory irritation and is a concern if the dust formed during mechanical machining is inhaled.

Clay

Clay tiles are made of mineral clay and are shaped when they are wet then dried through kiln firing. They are not harmful generally to human health or the environment, and can be reused. Clay is a natural resource thus is a sustainable option yet clay tiles are considered to be heavy, more brittle and labor intensive as a roofing installation option.

Plastic/ Polymer

Synthetic polymer roofs are lightweight, durable, require minimal maintenance, and last a very long time yet cost more initially than other roofing options such as asphalt. They may come in the form of shingles, flat or corrugated panels. Additives such as plasticizers, UV protectors and dyes may be combined with a base polymer to improve performance. There are a wide variety of these substances, but dyes and plasticizers in particular can be of concern. Thermoplastic polymers like polypropylene are persistent and durable for long exterior wear if protected from UV degradation. Polycarbonates are another thermoplastic used in the construction industry. The main material for this is produced by a reaction of bisphenol A with phosgene. Bisphenol A has been linked to asthma and neurodevelopmental problems such as hyperactivity, anxiety, depression, and aggression after early life exposure. In adults, it is associated with obesity, type 2 diabetes, heart disease, decreased fertility, and prostate cancer [32]–[34].

Metal

Copper roofs are energy intensive and costly to produce and install. Copper leaches from roofs and is toxic to aquatic environments, thus also causing rainwater to be unsuitable for landscape use.

Aluminum roofing could come in shake, shingle, or tile form. It is pressed then coated or painted into various colors [23]. It is energy intensive to produce aluminum yet the final product is durable, long-lasting, is safe for water-quality, and can reduce attic heat gains by up to 34%. Aluminum with anodized finishes form a protective layer that is bonded to the metal and is preferable to other coating options. Aluminum shingles are available with 100% recycled content.

Steel roofing is made of steel, an alloy of iron and carbon, and comes in a variety of forms, including corrugated and standing seam. It is sealed with liquid or powder coated finishes to avoid rust. Factory cut and finished roofing is less likely to rust than field cut. Powder coated at the factory has less of an impact on air pollution than liquid applied finishes. Galvanized steel has typically a zinc protective layer that is also harmful. The zinc used to prevent rust can get carried away with rainwater runoff to storm sewers and waterways and is toxic to aquatic life. Aluminized steel also exists where aluminum is applied to the steel sheet to form a protective layer. If the aluminum finish is scratched, however, the steel surface will rust. Weathering or Cor-ten steel (US Steel Corporation) is an alloy steel that rusts to a designed depth and forms a protective surface obviating the need for protective paints. Elements added to the iron include manganese, copper, chromium, vanadium and nickel. All of these metals are persistent. Manganese, Chromium VI and vanadium are toxic to humans. They can be inhaled during their use in manufacturing (typical for this use case), from drinking in water or by eating it in foods. Manganese affects the cardiovascular, nervous, and respiratory systems along with the liver [35]. Chromium VI affects the immune system, urinary system and kidneys, respiratory system and is known to cause lung cancer [36]. Vanadium affects the cardiovascular system, digestive system, urinary system and kidneys, reproductive system, and respiratory system and is known to cause lung cancer [37]. The International Agency for Research on Cancer (IARC) has determined that vanadium is possibly carcinogenic to humans.

Slate

Slate is a fine-grained homogeneous metamorphic rock composed mainly of clay minerals. It is fashioned into roof tiles and requires minimal processing. It is considered safe for human health and the environment. It is expensive to produce and install yet lasts long with a 100-year warranty for many offered products [23]. Most slate comes from the northeastern United States or from abroad thus transportation and carbon costs are considerations.

Asphalt

Asphalt shingles are made of asphalt fiber topped with a layer of mineral granules. Some products contain built-in moss inhibitors that contain zinc, copper and other toxicants that are harmful to aquatic life. In addition, asphalt tar and adhesives used during the installation emit large amounts of volatile organic compounds (VOCs) that can cause respiratory, skin and eye irritation, as well as dizziness, nausea and headaches. Some studies indicate the tar may also cause cancer [38], [39].

Concrete

Concrete tiles are made of cement, sand and limestone. They require a large amount of energy to produce yet require minimal maintenance and have a long-life expectancy. The Portland cement in concrete has constituents that produce both irritant contact dermatitis and corrosive effects (from alkaline ingredients such as lime) and sensitization, leading to allergic contact dermatitis (from ingredients such as chromium) [40].

Wood
Wood shakes are made of naturally rot-resistant wood such as cedar and the wood itself is considered to be safe for human health and the environment. They may, however, be treated with preservatives (petroleum distillates, fungicides and insecticides) and moss inhibitors (copper or other metals). Many wood preservatives contain cancer causing ingredients and are skin sensitizers and harmful to aquatic life.

Recycled content
Recycled content roof shakes are made of various materials such as recycled plastic, cellulose fibers, tires and industrial rubber [23]. Not all of the recycled content shakes have been tested for EHS impact since the material used varies from supplier to supplier. The potential health and environmental impact for these products will have to be determined on an individual basis.

Recommendations for Roofing System Materials: There is a wide variety of choices for the components of a roofing system and often installation methods will dictate the extent to which one can mix materials specified. Here are our general recommendations for preferred components: sheathing should be formaldehyde-free plywood, underlayment should be polypropylene or high-density polyethylene (HDPE); asphalt underlayment should be avoided. Flashing should be polyethylene with butyl-based adhesive. Gutters and downspouts should be aluminum and not PVC. The roofing top layer should be polypropylene if more natural products like clay or fiber cement are too costly or impractical. Metal roofs should also be considered, but asphalt roofing should be avoided. All individual product candidates should be reviewed for hazard on a case-by-case basis, particularly synthetic polymers, as often additives like UV blockers, dyes and plasticizers present significant and overlooked hazards. Recognizing that most products represent some hazard, specifiers should require management and engineering controls during manufacture and end of use. This is particularly true for the polyethylene, butyl and polypropylene materials cited here as worker safety and environmental harm during manufacture are significant concerns.

House Wrap & Flashing Paper

House wrap is a synthetic material installed as a barrier to protect a house from moisture. It also improves a house's energy efficiency by acting as an airflow barrier by sealing and preventing air infiltration or leaks and helps protect against mold, insects and UV radiation. In addition to house wrap, flashing paper is used on the edges of windows and doors to protect a house from moisture and water intrusion.

A wide variety of materials exist for house wrap and flashing paper. A typical product will comprise a water-resistant layer and an adhesive backing. Most house wrap products are made from polyolefins, high molecular weight hydrocarbons and the two most common are polyethylene and polypropylene. A variety of adhesive polymers form the backing which is protected by a strip-off paper sheet prior to installation. This backing may be coated with silicone.

High density polyethylene (HDPE) is generally considered safe during use but has been linked to leaching endocrine disrupting chemical nonylphenol used as a stabilizer [24]. Polypropylene (PP) is also generally considered safe during use although it has been shown to leach plastic additives (such as the stabilizing agent oleamide) when PP labware was used in scientific experiments [25] and heated PP may be linked to occupational asthma based on the exposure of a worker in a PP factory [26].

A note on UV Stabilizers in polymers [41] -

When UV light hits a polymer, photodegradation occurs and causes the polymer chains in the - plastic to break down. This results in a loss of impact and tensile strength, elongation, - discoloration and cracking. There are three types of UV stabilizers or additives that are added to - a polymer to inhibit photodegradation. -

1. - UV absorbers can be added that act to absorb and dissipate the radiation and heat through thermal energy in the polymer. Examples of these are carbon black, rutile titanium oxide, benzophenones, and hydroxyphenyl triazines to name a few. These materials are carcinogenic, persistent and have multiple hazards such as endocrine and organ toxicity.
2. - Quenchers can be added that transfer energy from the excited state to the ground state. Commonly used quenchers are made of nickel yet are not used as often because nickel is a heavy metal and has high health and environmental hazards associate with it.
3. - Hindered Amine Light Stabilizers (HALS) may also be used. They trap the free radicals that form when the UV hits the polymer and therefor limit the photodegratation process. All HALS, though they may have different structures, will share a 2,2,6,6-tetramethylpiperidine ring structure that is known to be flammable and acutely toxic.

Below is a list of house wraps and their compositions based on Material Safety Data Sheets. These wraps were chosen for review from the EcoBlock draft materials list received on November 6, 2017:

DuPont's Tyvek and Stucco Wrap are made of high density nonwoven polyethylene fibers. No other data is given although the MSDS sheet indicated proprietary UV stabilizers are used in the Stucco Wrap. Polyethylene is persistent and may cause respiratory irritation.

Pactiv GreenGaurad RainDrop is made of cross-woven polyolefin. Polyolefins are any class of polymers (or plastics) produced from an olefin monomer. This is not enough information to determine the hazards associated with this house wrap and therefore the general health and safety of its use cannot be stated.

Barricade Drainage Wrap is a non-perforated, non-woven polyolefin membrane. This is not enough information to determine the hazards associated with this house wrap and therefore the general health and safety of its use cannot be stated.

Barricade Weather Trek is made of a micro-perforated polyethylene. Polyethylene is persistent and may cause respiratory irritation.

Valeron Vortec is made of a UV enhanced, cross-laminated HDPE. HDPE is generally considered safe during use but has been linked to leaching endocrine disrupting chemical nonylphenol used as a stabilizer [24].

Fortifiber Hydro Tex is made of an asphalt-saturated kraft paper with a polypropylene layer. Kraft paper is made from paper pulp or recycled cardboard and does not have any reported hazards associated with it while asphalt is a carcinogen, persistent, gene and organ toxicant. Polypropylene is persistent, has shown to leach plastic additives, and linked to occupational asthma upon heating.

Home Slicker Plus Typar is made of 40% polypropylene, along with nylon 6 and polyester. Polypropylene and nylon 6 are persistent and polypropylene also causes lung irritation. There are no direct hazards with polyester and polypropylene is generally considered safe during use, but both polyester and polypropylene have very high hazards associated with their production. Polypropylene is persistent, has shown to leach plastic additives, and linked to occupational asthma upon heating.

Benhamine Odyke HdroGap is made of polypropylene trilmaninate polyolefin resin with additives that are not mentioned. Polypropylene is persistent, has shown to leach plastic additives, and linked to occupational asthma upon heating. It also has very high hazards associated with its production. Not enough information is given for the additives therefore a recommendation cannot be made.

Delta Dry is made of high density polyethylene (HDPE). HDPE is generally considered safe during use but has been linked to leaching endocrine disrupting chemical nonylphenol used as a stabilizer [24] and is persistent.

Although none of the house wraps indicated what type of materials are used in their UV stabilizers, it is important to note the possibility of these hazards being present.

Below is a list of flashing paper and their compositions based on Material Safety Data Sheets. These were chosen for review from the EcoBlock draft materials list received on November 6, 2017:

Fortifiber Moistop- Is made of a multilayer composite of woven polypropylene fabric coated with UV resistant polypropylene and other polymeric components [42]. Polypropylene is persistent, has shown to leach plastic additives, and is linked to occupational asthma upon heating.

Fortifiber Moistop EZ Seal- Is made of a reinforced woven polymer membrane coated with a trade-secret adhesive formula. Not enough information is provided to identify the hazardous or non-hazardous materials in this product. Yet it is known that butyl rubber is typically used as an adhesive which is persistent. The making of butyl rubber is highly hazardous as its process chemistry includes chemicals that are known to cause cancer, developmental, reproductive and organ toxicity along with respiratory, eye and skin irritation yet after its manufacturing, it is safe to install and use as indicated by (OSHA) rules, European Union regulations and the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (UN GHS) .

House Wrap Recommendations: Non-perforated or micro-porous and non-woven products are preferred as they allow sufficient vapor migration while still resisting water (woven products compromise water resistance) [43], [44]. Polypropylene or high-density polyethylene (HDPE) is recommended for the house wrap with the same qualifications as above under roofing: case-by-case review for complete materials list and chemical hazard assessment, requirements for engineering and management controls during manufacturing and end of use stages when intrinsic hazard cannot be avoided.

Flashing Paper Recommendations: Solvent-free solid or modified acrylic pressure sensitive adhesives (PSA) have a low environmental burden and bond well to most substrates at a wide range of temperatures and moisture levels without primers. Individual products should be reviewed for materials composition and chemicals hazard assessment before being specified.

Caulks/Sealants

Caulking compounds are used to seal cracks and holes around windows and other openings. Many caulks contain hazardous hydrocarbon compounds such as acrylic, neoprene, polysulfides, polyurethanes, and silicon that can cause respiratory, skin and eye irritation, nausea, low blood pressure and lightheadedness while long term exposure can be hazardous [45]. Caulking compounds may include phthalates as plasticizers. Phthalates have been linked with asthma, allergies, and cognitive and behavioral problems after early life exposure. They may also affect reproductive development in boys and phthalates are associated with reduced fertility in men [46], [47].

Below is a list of caulks and sealants that were chosen for review from the EcoBlock draft material list:

Polyurethane expandable spray foam contains isocyanates which cause respiratory irritation and are carcinogenic and are harmful to the environment. Its production requires a variety of highly hazardous intermediary chemicals such as formaldehyde and phosgene. Formaldehyde, when present in the air at a concentration above 0.1 part per million, can cause watery eyes, nausea, coughing, chest tightness, wheezing, skin rashes, allergenic reactions, and burning sensations in the eyes, nose, and throat. Formaldehyde has been shown to cause cancer in laboratory animals and may cause cancer in humans. It also may cause birth defects. It is highly toxic if swallowed, inhaled, or absorbed through skin or mucous membranes. Formaldehyde reacts vigorously with oxidizers and, at its highest concentrations, is a combustible liquid. In addition, formaldehyde reacts with hydrochloric acid (HCl) to produce bis (chloromethyl) ether vapor, a very potent carcinogen [48].

Mastic caulking is a liquid sealant that cures in an elastic state therefore it is flexible and can adhere to any surface. Typical mastic caulks are made of limestone, aluminum silicate or aluminum hydroxide and titanium oxide or zinc oxide. These chemicals are persistent.

Aerosol sealing can be solvent or water based. Solvent based formulas typically have a polymeric rubber and hydrocarbon resin with a solvent while water based have a mastic polymer in water.

Recommendations for Caulks: Caulks used should have low VOC and reduced chemicals of concern. Silicon, acrylic, acrylic-latex, neoprene, polyurethane, polysulfides and vulcanized butyl rubber caulks are examples and should be avoided [45]. Water based caulks and sealants, also known as latex, are less harmful, easy to apply and have little odor associated with them yet do not last as long as the non-water caulks and sealants.

Recommendations for Sealants: Low VOC products such as silyl-modified polymers (hybrids of polyurethane and silicone) are best because they are solvent and isocyanate free [44]. VOC content should not exceed 4% by weight or 50 g/L according to NAHB National Green Building Standard. Water based aerosol sealants are less harmful than solvent based sealants. GreenGuard Certified aerosol sealants can be found that meet LEED requirements, are UV stable and are non-volatile. Polyurethane expandable spray foam should be avoided.

Windows

Windows are composed of two major components: the frame and the glass. Each of these require different materials choices by specifiers.

Frame

Vinyl windows are made with polyvinyl chloride (PVC) with a UV stabilizer [49]. Structural and energy performance is comparable with wood yet expands and contracts with temperatures therefore loosens seals and causes cracks. PVC may contain and/or leach a variety of toxic chemicals including, but not limited to: bisphenol A (BPA), phthalates, lead, dioxins, mercury, and cadmium. Phthalates are used commonly as plasticizers, are endocrine disruptors, and have been linked to asthma and allergic symptoms, ADHD, and breast cancer [46]. The vinyl chloride monomer used in manufacturing is a known carcinogen and represents a worker hazard. If burned at disposal, PVC produces dioxins, which are known human carcinogens, persistent organic pollutants and one of the most toxic chemicals tested [46].

Aluminum has good structural strength yet is thermally conductive so is not as energy efficient as other materials [49]. It is safe during its use and can be recycled yet the manufacturing of the raw material (if not using recycled content) is very energy intensive.

Wood frames are natural and a renewable product that does not impose health concerns. The paints, sealants and caulks necessary for protecting the wood and making the window weather tight, however, may contain chemicals of concern.

Composite wood frames are also available and have many combinations of materials [49]. The health hazards of this type of window frame would have to be determined for each individual product. In general, a wide variety of adhesives are used during the manufacturing process of composite wood frames and can emit VOCs that are harmful to inhale.

Fiberglass is durable and strong and is considered to be the highest performing window frame (its coefficient of performance is close to that of glass) yet is unstable with UV radiation therefore would need UV stabilizers [49]. In addition, the manufacturing of fiberglass resin emits styrene (possible human carcinogen) and VOCs that are harmful to the human health and environment and recycling at its end of use is difficult [30].

Glass

Insulated glass (also known as double glazing) consists of two or three glass panels separated by a low conductivity gas fill between the spaces to reduce heat transfer. The most commonly used gas is argon which is inert and inexpensive. Krypton, another inert gas, can also be used for better performance but costs more [49]. Both these gasses are noble gases and therefore are considered safe to use, yet overtime they are known to leak and are persistent in the environment.

Low-emissivity coatings on glass have been used more recently. A thin transparent layer of a metallic oxide such as (tin, silver, titanium, zinc oxide) is applied on the glass and allows short wavelength sunlight to pass through the glass yet blocks long-wavelength heat radiation [49]. These metals are persistent in the environment. Titanium dioxide, for example, has been labeled a possible cancer-causing agent (Group 2B carcinogen) by the International Agency for Research on Cancer (IARC). High concentrations of powdered titanium dioxide dust caused respiratory tract cancer in rats, and the agency determined that similar biological events were present in workers.

Recommendations for Windows: Vinyl windows should be avoided. Aluminum or wood frames with double glazing with argon gas in between are recommended. Composite wood frames could also be considered on a case-by-case product basis. All low-emissivity coatings researched comprised environmentally persistent metals and potential worker hazard, so despite the energy savings possible, we do not recommend these coatings without additional scrutiny of individual products and requirements for engineering and manufacturing controls during manufacturing and end of use stages.

Paint

Paints can be a source of VOC's and other toxic contaminants and can be categorized into natural paints, zero VOC, low VOC or high VOC paints. Natural paints are made of plant oils and plant dyes along with other natural minerals such as clay, chalk, talcum and bees wax to name a few. Zero VOC paints can have 5g/L of VOC or less according to the EPA Reference Test Method 24. Although they have very low VOC emissions, they may still have colorants, biocides, fungicides and other toxic chemicals. Low VOC paints do not exceed 50g/L (but EPA allows up to 200g/L) of VOC emissions and are usually water based whereas high VOC paints are usually petroleum based or oil based and contain formaldehyde, toluene and other alcohols and ketones [50]. Some paints also include cadmium and chromium for use as pigments which are toxic and carcinogenic.

Typical paint strippers have methylene chloride as an active ingredient that is a potential carcinogen. Biodegradable paint strippers are water soluble and noncaustic yet have N-Methyl-2-pyrrolidone (NMP) as an active ingredient organic solvent [50]. NMP is known to have reproductive toxicity.

Recommendations for Paints: Low VOC content that also uses low VOC tints and meet the MPI Green Performance criteria or is Green Sealed Certified. Paint coatings made from natural and minimally processed materials that contain no chemicals of concern are best.

Detailed Comparison: Insulation

The conservation of energy is one of the main strategies for greater sustainability in retrofitting buildings and other urban infrastructure. This is typically done through passive devices that improve the efficiency of space heating and cooling performance. One common tactic is that of moderating temperature fluctuations (reducing the need for turning on heating or cooling devices) by the use of insulation. We examined by literature search the types of insulation available, the chemicals of concern typically found in them, and the resultant environmental, health and safety (EHS) concerns. We focused our attention on those EHS concerns associated with three stages in a typical life-cycle of these products, manufacture/installation, use within the home, and disposal. We did not perform a life-cycle analysis, nor was any testing done on products.

Insulation Types

There are different types of insulation and each method of installation presents varying health hazards. We have divided this section into three basic forms of insulation material: fiber, rigid panel and spray foam. Each type is then further divided into options by material stock used, for example whether cotton or fiberglass fiber is used. We note where a material is manufactured in different physical forms and may be included in more than one category. For consistency, the R-values reported below for each insulation material were obtained from the Department of Energy- Insulation Materials website [51] except for Mycelia which was obtained from a building insulation report [52].

Fiber Insulation

Blanket (or also known as batts or rolls) insulation is a compressible, spun material that comes in strips dimensioned for installation between wall studs and roof rafters. It causes the least number of airborne particles, but is the least energy efficient. Loose-fill (or blown in) insulation consists of small particles or materials that are delivered into crevices by a mechanical blower without any adhesives and causes the most amount of airborne particles [53].

Fiber Glass (R Value: 2.2 – 3.8/inch)

Fiber glass insulation is composed mainly of glass (silica, limestone) and a resin binder. This insulation has a high respiratory hazard due to the fine particles of glass, and can cause skin, lung and eye irritation during the manufacturing and installation process [54]. The resin binder used may have other health hazard effects. Formaldehyde, which is typically the binder used in fiber glass insulation, is highly toxic and carcinogenic. Companies such as Johns Manville Corporation and Knauf have developed fiber glass insulation product lines certified to be free of formaldehyde. Fiberglass is installed as a blanket or loose-fill blown in.

Manufacturing/ Installation

- High respiratory hazard
- Skin, lung, eye irritant
- Toxic and carcinogenic if formaldehyde is used as a binder

Use (Residents)

- Often building air ducts are wrapped in insulation and if they are leaky, the inhabitant will also be exposed to the same airborne hazards cited during manufacturing and installation. Residents can also be exposed when in areas like attics where the material is not contained by interior walls.
- If installed by blown loose insulation, airborne particles may still be in the house (especially if HVAC was turned on during installation).

End of Life

- Demolition of buildings leads to widespread airborne dissemination unless strict engineering controls are practiced.
- Can only be reused and recycled or landfilled. No health hazards have been reported, yet that does not mean there are no health hazards associated with landfilling fiberglass. Formaldehyde and the chemicals used in the adhesives may leach out over time and be of environmental concern.

Cellulose (R Value: 3.2 – 3.8/inch)

Cellulose insulation is composed of roughly 80% recycled paper (usually newspaper) and 20% boric acid, ammonium sulfate and aluminum sulfate that are present as fire retardants and insecticides. It is installed loose by blower usually. The ink in recycled newspaper is typically made of soy-based or vegetable-base ink and is therefore non-hazardous. If the newspaper ink is made of a petroleum-based ink, however, it will be very toxic to human health and the environment as is releases high amounts of VOCs that include toluene, benzene (a carcinogen) and xylene [55].

Although cellulose insulation is made of recycled material, is relatively cheap, easy to work with and is useful in energy conservation, it is not without chemicals of concern. It is treated heavily with fire retardants such as boric acid, ammonium sulfate and/or aluminum sulfate. These fire retardants are toxic to human health and are considered to be endocrine disruptors, persistent and may cause reproductive and developmental hazards.

Manufacturing/ Installation

- Toxic and carcinogenic if petroleum-based ink is used in the newspaper
- Fire retardants are toxic: reproductive and developmental toxicity, endocrine disruptor, persistent

Use (Residents)

- If loose material is not contained, the inhabitant will also be exposed to the same hazards cited during manufacturing and installation.

End of Life

- Demolition of buildings leads to widespread airborne dissemination unless strict engineering controls are practiced.
- Can only be reused and recycled or landfilled. No health hazards have been reported yet that does not indicate that health hazards are not a concern [56]. Cellulose typically has fire retardants that are toxic to the human health, environment and to the aquatic environment.

Cotton (R Value: 3.4/inch)

Cotton insulation is made mostly of cotton, some polyester and a flame retardant such as boron [57]. Although it is fairly inert, the cotton used in insulation is typically recycled and contains large volumes of residual pesticides. Cotton insulation is not as effective as other types of insulation thus would require thicker and more layers of insulation to achieve an R-value comparable to polyurethane for example. Cotton insulation can be used in the form of batts or loose fill.

Manufacturing/ Installation

- Installation and manufacturing of cotton insulation is fairly safe yet if the cotton contains pesticide, it is considered toxic to inhale.

Use (Residents)

- Safe to residents.

End of Life

- Can be reused and recycled, landfilled or incinerated. Is safe generally.

Mineral Wool (R Value: 3.0 – 3.3/inch)

Mineral wool is made of rock wool or slag wool. It is made by spinning or drawing fibers from minerals. It is considered fairly inert and efficient at insulating [58]. During installation, the mineral wool may cause respiratory and skin irritation yet is considered safe. Some mineral wool may contain phenol-formaldehyde as a binder which is harmful to indoor air quality for residents, is a high respiratory sensitizer, persistent, and a carcinogen [59]. Mineral wool does not require additional fire retardant chemicals. It is available as blankets and loose-fill insulation.

Plastic Fiber Insulation (R Value: 3.8/inch – 4.3/inch)
Polyethylene terephthalate (PET) comes in batt form. See below under rigid panel insulation.

Rigid Panel Insulation

Foam boards (or rigid foam) are rigid panels used for insulation and sold in different thicknesses and sizes. Although the boards themselves do not present hazards, the manufacturing process of the boards does and is discussed below.

Polystyrene (R Value: 3.8 - 5.0/inch)
There are two types of polystyrene insulation, extruded polystyrene insulation (XPS) and expanded polystyrene insulation (EPS). The difference between these two insulations lies in their manufacturing process. XPS is produced by melting a plastic resin along with other ingredients into a liquid and continuously extruding it through a die and expanding it during the cooling process thus forming a closed cell rigid insulation board. EPS, on the other hand, is manufactured using a mold where small foam beads are heated and expanded in the mold to fuse together, the large block is then cut into sheets based on the shape and size necessary.

In general, both types of polystyrene insulation are composed of polystyrene resin, benzene ethylbenzene, toluene, styrene, and hexabromocyclododecane (HBCD) flame retardant (or TCPP). These chemicals are hazardous and are known to be carcinogenic, endocrine disruptors, developmental and reproductive toxins, and persistent and bioaccumlative. HBCD is classified as a substance of very high concern by European Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) program of the European Union [60]. Blowing agents are typically used with polystyrene and can vary from methyl formate (reproductive toxin and endocrine disruptor), pentane (eye, skin and respiratory irritant, persistent, developmental toxicity, flammable, global warming potential), hydrochloroflourocarbons (HCFC) (ozone depletion, respiratory irritation, carcinogen), or water [61].

In addition, XPS generally contains hydroflorocarbons (HFCs) that are potent greenhouse gasses contributing to climate change and contains color dies in order to market or brand the products. EPS on the other hand, has never contained HFCs, CGCs, formaldehyde or color dies. EPS may also contain up to 15% recycled content. EPS has a better overall environmental impact in comparison to XPS [62], [63].

Manufacturing/ Installation

- Toxic and hazardous as indicated above. In addition, XPS has HFCs that significantly contribute to global warming through the addition of greenhouse gasses to the atmosphere.

Use (Residents)

- After installation, polystyrene is considered relatively inert and safe to residents.

End of Life

- Can only be reused and recycled (typically by the process of pyrolysis) or landfilled. When landfilled, polystyrene is extremely hard to biodegrade and thus remains a solid waste in the environment and to the aquatic environment [64]. During pyrolysis, compounds mainly composed of benzene, toluene, ethylbenzene and styrene are produced [65]. Benzene evaporates into the air very quickly and if inhaled can cause anemia, damage to the immune system and may be poisonous [66]. Toluene can also be inhaled and affects the nervous system at large doses (causes headaches, dizziness or unconsciousness at low doses) [67] whereas ethylbenzene affects the nervous system and organ development [68]. Styrene monomer is hazardous due to its persistence and intrusion into the natural food web since it evaporates easily and dissolves in liquids. It also affects the nervous system [69].

Polyisocyanurate (R Value: 5.8 - 8/inch)

This insulation is very similar to extruded polystyrene and polyurethane foam insulation and is slightly more stable with less toxic flame retardants. It is a rigid foam board with a foil layer as a vapor barrier. It is made from Polyethylene terephthalate PET (usually 9% recycled from plastic bottles) and does not use ozone-depleting HCFCs for blowing agents [57]. As stated below, PET is generally safe to use yet is hazardous during its manufacturing process.

Polyurethane (R Value: 5.5 - 6.5/inch)

Polyurethane insulation is typically manufactured and installed as either a spray foam or rigid foam insulation. It is composed of diphenylmethane diisocyanate (MDI), polyos resin, an amine catalyst, a flame retardant such as TCPP or HBCD and finally a blowing agent such as methyl formate or pentante [58], [70]. As discussed above, the flame retardants and blowing agents are toxic to developmental and reproductive organs, are endocrine disruptors, and cause eye, skin, and respiratory irritation. In addition, the isocyanate (MDI) is highly toxic and can cause cancer, respiratory sensitization, skin and eye irritation, organ toxicity and acute mammalian toxicity.

Manufacturing/ Installation

- Toxic and hazardous as indicated above and inert once cured.

Use (Residents)

- After installation, polyurethane is generally inert but as the material ages, toxic gasses slowly escape into the residence.
- If it does not contain UV inhibitors, polyurethane will degrade in sunlight and will be toxic. Some of the chemicals released may include carbon dioxide and carbon monoxide, nitrogen oxides, hydrogen cyanide, isocyanates (which are highly toxic), among other hydrocarbons and other chemicals. The composition and amount of

chemicals released will vary, yet exposure to them may cause skin, eye and respiratory irritation while prolonged exposure will result in more serious health hazards.

End of Life

- Can be reused and recycled, landfilled or incinerated. Is a large contributor to greenhouse gas emissions [71]. When landfilled or incinerated, polyurethane will degrade into the same components mentioned above and will have the same environmental and human health hazards [72].

Plastic Fiber Insulation (R Value: 3.8/inch – 4.3/inch)

Polyethylene terephthalate (PET) is formed by terephthalates during the reaction of ethylene glycol and terephthalic acid along with catalysts such as zinc, manganese and/or antimony (III) oxides [54]. Terephthalates are unlikely to break down to a toxic monoester unlike other plastics that contain phthalates [54]. PET is used to manufacture synthetic fibers and PET fibers are the most common synthetic fibers for use in making bottles and textile fibers. Although PET's manufacturing process is highly hazardous and has compounds known to be carcinogenic, cause developmental, reproductive, and organ toxicity, along with terrestrial and aquatic toxicity, it is generally considered safe to use after production and is known to be persistent at its end of life [54]. Recycling is considered the best way to reduce PET waste and can therefore be used for insulation. For insulation, PET bottles are washed, shredded, dried and are further milled into granules. The granules are then mixed with proprietary stabilizer, additives, and other agents that are then extruded into rigid panels for insulation treated with flame retardants [51], [73]. PET insulation is considered relatively non-irritating to work with [51]. In April 2010, the Environmental Health Perspective suggested that PET might yield endocrine disruptors and an article published in Journal of Environmental Monitoring in April 2012 concluded antimony concentrations in water or soft drinks in PET bottles may exceed the EU limit after less than a year of storage at room temperature.

Mycelia (R Value: 3.0/inch)

Mycelia is a mushroom based insulating material offered typically as rigid panels with a chemical modulator such as acetic acid, calcium sulfate or glycerol [52]. It is considered benign and safe to manufacture, install and use, yet is not readily available to the market and has a very low R value thus would require more layers and thickness.

Sprayed Foam Insulation

Sprayed foam insulation consists of combining two liquids that undergo a chemical reaction to expand and form a foam insulation that hardens in the place where it is sprayed. This type of installation typically releases toxic fumes from the foam as they contain binders and other harmful chemicals that will be discussed in this report. The adhesives used for spray insulation may also be toxic and of concern, as they are composed of a variety of different chemicals. For example, some adhesives are made of polymeric isocyanate and polyol amines while others are made of dimethyl ether, n-hexane, acetone and/or propane. There is no standard adhesive in use, so further investigation of individual products will be needed to assess the hazards of the material to be used.

Polyurethane
See above under rigid panel insulation.

Polyisocyanurate
See above under rigid panel insulation.

Phenolic (R Value: 4.8/inch)
Phenolic insulation is a foamed in place insulation made of phenol, formaldehyde and pentane as a blowing agent. The chemical composition of phenolic insulation makes it toxic, causing multiple hazards during manufacturing. Short term exposure causes respiratory, skin and eye irritation whereas long term exposure causes liver damage. It is persistent and produces greenhouse gases. Additionally, phenolic foam has been shown to deteriorate in the presence of moisture or UV light.

Cementitious (R Value: 3.9/inch)
Cementitious insulation is applied as a sprayed foam or offered in precast panels. It is composed of magnesium oxide, water, polyvinyl alcohol, tamol for a dispersant and barium metaborate as a crosslinker [74]. It does not contain any formaldehyde and is considered less toxic than other types of insulation. Yet during installation, the fumes from this insulation are considered to be pregnancy and developmental hazards, organ toxicants, eye and skin irritants, and the material is persistent [74]. While comparable to polyurethane foam in cost and r-value, it does not emit VOC’s over time.

Recommendations for Insulation: Insulation presents a challenge to specifiers when they seek to avoid hazardous materials, as the demands of thermal insulation performance and workability within the structure of a typical building interior compete with the requirement for safer materials. For fiber insulation we recommend mineral wool that does not contain phenol-formaldehyde binder, with stipulations for engineering and personal protective gear during installation. For rigid insulation, there are few good choices, particularly during the manufacturing stage, but cementitous material is the least objectionable. For sprayed foam insulation, cementitious material is the preferred choice, with similar engineering and personal protective gear requirements during installation. Materials that contain formadehyde, hydrofluorocarbons, and hydrochlorofluorocarbons should be avoided.

Out of Scope
The following areas were out of scope of this research:
- HVAC upgrades including
    - Equipment upgrades
    - Space heating upgrades
    - Ventilation
- Appliance upgrades
- Lighting: LED

Appendix A: Energy and Water System Material Options

Energy Systems Material Options

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*	*Option 6*	
PV		Crystalline Silicon	Amorphous Silicon	Copper Indium Diselenide or Copper Indium Gallium Diselenide	Cadmium Telluride	Gallium Arsenide	
					Cadmium is toxic and carcinogenic	*Arsenide is toxic and carcinogenic*	
		**The greatest possibility of human health risk is associated with PV devices is during the manufacturing stage due to exposure- toxic gas release & hazardous acids used					
		**Installation hazards: due to leaching of materials from broken PV modules. Primary chemicals of concern are heavy metals such as cadmium and selenium.					
		**Disposal hazards: Landfill disposal can lead to contamination of local ground and surface water.					

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*	*Option 6*	Option 7	*Option 8*	*Option 9*	*Option 10*
Roofing		Asphalt	Plastic/Polymers	Copper	Galvanized Steel	Fiber Cement	Steel	Concrete	Aluminum	Clay/Slate/Wood
		Emits VOCs; Toxic; Eye, Skin & Lung irritant; Potential carcinogenic	Release chemicals that latch on water	Energy intensive to produce and polluting; toxic to aquatic environment	Uses a zinc protective layer- zinc is harmful to aquatic environment	Made of cement & cellulose fiber- respiratory hazard	Coated with powder for rust.	Made of cement, limestone and sand.	Energy intensive to produce but safe	Sustainable & Safe

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*
House Wrap		Asphalt	Polyethylene	Polypropylene	Unidentified Polyolefin
		Carcinogenic; Persistent; Gene & Organ Toxicant	Persistent; Respiratory Irritation	Persistent; Respiratory Irritation; Leaching of chemicals	Not enough information as it can be made of multiple plastic resins

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*	*Option 6*
Windows						
Frame		Vinyl- made of PVC- hazardous during manufacturing due to phthalates	Aluminum- Energy intensive to manufacturing	Wood	Composite Wood- VOCs associated with adhesives	Fiberglass- hazardous during manufacturing
Gas Fills	Argon	Krypton				
Low e- coatings		Metallic Oxide: Titanium, zinc, copper, tin & silver- persistent				
Glass	Double Glazed	Tripe Glazed				

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*
Paint					
Paint		Natural Paints: *Water; plant oils; plant dyes and essential oils; natural minerals: clay, chalk,*	Zero VOC Paint: *Water based. May still contain colorants, biocides, fungicides and toxic chemicals.*	Low VOC Paint: *Water based; latex*	High VOC Paint: *Oil based- white spirit, formaldehyde, toluene and other alcohols, ketones, acetates*
Paint Strippers		Caustic paint strippers: Active ingredient: methylene chloride- potential carcinogen	Biodegradable paint strippers: water-soluble and noncaustic. Active ingredient: N-Methylpyrrolidone (NMP)- organic solvent. Reproductive toxicity based on test animals		

Water Systems Material Options

	Option 1 (as indicated by EcoBlock)	*Option 2*	*Option 3*	*Option 4*	*Option 5*	*Option 6*	*Option 7*
Pipes							
Water	CPVC	PVC	PEX	HDPE	Galvanized Iron/Steel	Cast Iron	Copper
Sanitary	CPVC	PVC	PEX	ABS			

Appendix B: Insulation Comparison

Fiber Insulation

1. Fiber Insulation	R-Values	Health and Safety		
		Resident	Manufacturer/Installer	Disposal
a. Fiberglass	2.2-3.8 per inch	***Respiratory & skin irritation***	***High respiratory hazard; skin & eye irritant; toxic and carcinogenic if formaldehyde is used***	***Recycled or landfill- health hazards associated with formaldehyde***
Silica				
Limestone				
Kaolin clay				
fluorspar				
colemanite				
dolmite				
Metal carbonates (sodium or barium carbonate)				
Formaldehyde Binder		High carcinogen; developmental toxicity; gene mutation; respiratory sensitization; mammalian toxicity; eye and skin irritant; flammable; acute aquatic toxicity		
b. Cellulose	3.2 to 3.8 per inch	***Toxic and carcinogenic***	***Toxic and carcinogenic if petroleum ink is used; Fire retardants are toxic***	***Recycled or landfill- health hazards with fire retardants***
Newspaper (MOST COMMON)		Contains fire retardants	Petroleum in ink: hazardous; releases VOCs that include toluene, benzene and xylene	
Boric acid (or mineral borate/ borax)			Acute toxicity; endocrine disruptor; reproductive and developmental toxicity; persistent	
Ammonium sulfate				
Aluminum sulfate				
Ammonium phosphate				
Zinc chloride				
Other materials instead of newspaper:				
Cardboard				
Cotton	3.4 per inch	***Safe to use***	***Contains pesticides- toxic to inhale***	***Recycled, landfill or incinerated- safe***
Straw	2.4 to 3.0 per inch			
Sawdust				
Hemp	3.5 per inch			
Corncob				
Sheeps Wool	3.5 per inch			
c. Mineral Wool		***Safe unless contains phenol-formaldehyde- high respiratory hazard and persistent***	***Respiratory and skin irritation***	
i. Rock wool (made of basalt or diabase)	3.30-3.3 per inch			
ii. Slag wool (blast furnace slag that forms on surface of molten metal)				
d. Plastic Fiber Insulation	3.8 to 4.3 per inch			
Polyethylene terephthalate (PET)		***Persistent***	***High cancer, mammalian and reproductive toxicity; PBT***	***Recycled***

Rigid Panel Insulation

2. Rigid Panel	R-Value	Health and Safety		
		Resident	Manufacturer/Installer	Disposal
a. Polystyrene	3.8 to 5.0 per inch	***Inert; Safe***	***Toxic and hazardous***	***Recycled or landfilled; Styrene monomers are hazardous***
Monomer styrene			High hazard of cancer and PBT during manufacturing	
Benzene			Carcinogenic	
Flame Retardant: TCPP or HBCD			Endocrine disruptors, PBT, developmental and reproductive toxicity	
Blowing agents: Methyl Formate			Reproductive toxicant and endocrine disruptor	
b. Polyisocyanurate	5.8 to 8 per inch		***Carcinogenic, highly toxic; reproductive hazard, skin, eye and respiratory irritation; acute mammalian toxicity***	
MDI		High persistence and high respiratory sensitization	Very high PBT, toxic and cancer concerns during manufacturing	
Polyester polyol				
Blowing agent: Pentane		Multiple hazards: persistent, developmental, flammable, neurotoxicity, eye and skin irritation, organ toxicant, acute and chronic aquatic, global warming potential		
c. Polyurethane	5.5 to 6.5/inch	***Toxic gasses slowly escape; if degrades from sunlight- toxic***	***Carcinogenic, highly toxic; reproductive hazard, skin, eye and respiratory irritation; acute mammalian toxicity***	***Recycled, landfilled or incinerated- large contributor to greenhouse gas emissions; hazardous decomposition***
Toluene				
Benzene				
Diphenylmethane diisocyanate (MDI)		High persistence and high respiratory sensitization	Very high PBT, toxic and cancer concerns during manufacturing	
Polyos resin				
Flame Retardant: TCPP or HBCD				
Blowing agent: Methyl Formate or Pentane				
d. Plastic Fiber Insulation	3.8 to 4.3 per inch			
Polyethylene terephthalate (PET)		***Persistent***	***High cancer, mammalian and reproductive toxicity; PBT***	***Recycled***
e. Mycelia	3.0 per inch	***Safe***	***May cause allergic reaction***	***Biodegradable***
Mushrooms				
Chemical modulator: acetic acid, calcium sulfate, luaric acid or glycerol			Possibly carcinogenic; skin and eye irritation; has variable feedstock so may be persistent	

Sprayed Foam Insulation

3. Sprayed Foam	R-Value	Health and Safety		
		Resident	Manufacturer/Installer	Disposal
c. Polyurethane	5.5 to 6.5 per inch	***Toxic gasses slowly escape; if degrades from sunlight- toxic***	***Carcinogenic, highly toxic; reproductive hazard, skin, eye and respiratory irritation; acute mammalian toxicity***	***Recycled, landfilled or incinerated- large contributor to greenhouse gas emissions; hazardous decomposition***
Toluene				
Benzene				
Diphenylmethane diisocyanate (MDI)		High persistence and high respiratory sensitization	Very high PBT, toxic and cancer concerns during manufacturing	
Polyos resin				
Flame Retardant: TCPP or HBCD				
Blowing agent: Methyl Formate or Pentane				
b. Polyisocyanurate	5.8 to 8 per inch		***Carcinogenic, highly toxic; reproductive hazard, skin, eye and respiratory irritation; acute mammalian toxicity***	
MDI		High persistence and high respiratory sensitization	Very high PBT, toxic and cancer concerns during manufacturing	
Polyester polyol				
Blowing agent: Pentane		Multiple hazards: persistent, developmental, flammable, neurotoxicity, eye and skin irritation, organ toxicant, acute and chronic aquatic, global warming potential		
		* Some polyisocyanurate insulation contain no CFC, HFC, or HCFC blowing agents so have lower environmental impact, no GWP, zero ozone depletion potential, made of recycled content & recyclable		
c. Cementitious	3.9 per inch	***Safe***	***Fumes are hazardous***	***Persistent***
Magnesium oxide			Pregnancy and developmental hazard from fumes; persistent; cancer; organ toxicant and eye irritation	
Water				
Polyvinyl alcohol (PVA)			Persistent	
Tamol (dispersant)				
Barium metaborate (crosslinker)			Inhalation hazard; High persistence and eye irritation, medium mammalian, terrestrial, and acute aquatic hazard	
d. Phenolic	4.8/inch			
Phenol		Multiple hazards: cancer, reproductive, endocrine, gene mutation, mammalian, eye and skin irritation, organ toxicant, acute & chronic aquatic, terrestrial, reactive		
Formaldehyde		Multiple hazards: cancer, developmental endocrine, gene mutation, respiratory, mammalian, eye and skin irritation, skin sensitization, organ toxicant, flammable, acute aquatic.		
Pentane (blowing agent)		Multiple hazards: persistent, developmental, flammable, neurotoxicity, eye and skin irritation, organ toxicant, acute and chronic aquatic, global warming potential		
Phenol Formaldehyde		High persistence and high respiratory sensitizer		
Generally	**Spray foams have high PBT and cancer hazards during manufacturing phase. Contain heavy metals; toxic; ozone depletion compounds**			

Appendix C: Next Steps

Model Chemical Hazard Assessment

Chemical hazard assessment aims to identify the inherent hazards of a chemical and assess its potential effects on human health and the environment. The inherent hazards depend on the molecular structure of the chemical and are intrinsic properties. A chemical hazard assessment evaluates the hazards associated with a chemical across a range of 18 potential hazard endpoints related to human health and environmental toxicity. Endpoints are adverse specific outcomes such as carcinogenicity, mutagenicity, reproductive toxicity, skin irritation, persistence, bioaccumulation, reactivity and flammability and are defined by the strength of the evidences of that association determined by an authoritative group (such as the International Agency for Research on Cancer for carcinogenic endpoints).

The following outlines the procedure for conducting a chemical assessment:

1. - Identify the chemicals or compounds of interest
    a. - Determine their CAS number
2. - Search for hazard information recognized by authoritative bodies such as governmental, regulatory or international consensus groups
    a. - Search https://www.pharosproject.net/ or comparable curated source to find authoritative evaluations
    b. - From phasors, go to source listings for more details on associated endpoints
    c. - Use GHS guidelines to understand listing based on GHS classifications
        i. Classifications can be determined by exposure route
            1. - Type: Ingestion, Dermal contact, Inhalation
            2. - Intensity of exposure: How much?
            3. - Duration of exposure: How long?
            4. - Frequency of exposure: How often?
3. - Perform a literature review search for information on chemicals not listed by authoritative bodies
4. - For chemicals with little or no hazard data, fill in the gaps by considering function group analysis, chemical class information, and analogies similar to the chemical or compound

In addition to performing a chemical hazard assessment on each chemical or compound, a hazard assessment can be performed based on the life cycle stage of concern. The life cycle includes phases of raw material extraction, production, use and end of life.

Below is an example conducted on electrochromic and thermochromic windows. As can be seen, the health and environmental endpoints of concern are listed in the left column. The materials under investigation are listed in the top row. Exposure routes and life cycle stage are also highlighted for each material. The strength of evidence for each endpoint is noted in each cell. The example was taken from a report on An Alternatives Assessment of Current Smart Window Technologies by Smith, Roee and Hill submitted in May 2015 [75].

	Key Assessment Criteria	Electrochromic Windows							Thermochromic Windows					
		Transparent Conductor			Cathodic EC Layer		Proton Conductor	Anodic EC Layer	Heat Responsive Phase Change Material		Doped Heat Responsive Phase Change Material			
		ITO	GO & Ag nanocomposite	Tungsten Oxide	PANI *	PEDOT	Zirconium Phosphate	Nickel Oxide	Nickel Ion Imidazole	Vanadium Oxide	Iodide	Gold	Tungsten(VI) oxychloride	Titanium Niobium(V) Oxide
	Exposure Route(s) of Greatest Concern	Inhalation, dermal	Inhalation, dermal	Inhalation	Inhalation, dermal	Dermal	NI	Inhalation, dermal	Inhalation, dermal	Inhalation	None	Dermal	NI	Inhalation, dermal
Health	Carcinogenicity	NI	May include carcinogenic impurities	NI	Probable Carcinogen	NI	NI	Known Carcinogen	Known Carcinogen	NI	NI	NI	NI	NI
Health	Organ Toxicity	High	NI	NI	Medium	NI	NI	NI	High	High	NI	NI	NI	NI
Health	Central Nervous System Effects	NI	NI	NI	Medium	NI	NI	NI	NI	NI	NI	NI	NI	NI
Health	Reproductive Toxicity	NI	NI	NI	Medium	NI	NI	NI	Possible	NI	NI	NI	NI	NI
Health	Developmental Toxicity	NI	NI	NI	Medium	NI	NI	NI	NI	NI	NI	NI	NI	NI
Health	Acute Toxicity	High	Low	Medium	Very High	Medium	NI	Very High	Very High	High	NI	Low	High	Moderate
	Physical Safety Concerns	No	No	No	Flammable	No	No	No	No	No	No	No	NI	No
Env	Persistence	NI	Very High	Very High	Low	NI	NI	High	NI	NI	Very High	Very High	NI	Very High
Env	Bioaccumulation	NI	NI	NI	Low	NI	NI	Low	NI	NI	NI	NI	NI	NI
Env	Aquatic Toxicity	NI	Very High	No	Very High	NI	NI	Moderate	Very High	Very High	NI	No	NI	No
	Life Cycle Stage(s) of Concern	Processing, Waste	Processing, Waste	Processing	Processing	Waste	Unclear	Processing, waste	Processing, waste	Processing	Processing	Processing, waste	Unclear	Processing
	Notes				Effects are from monomer	Major data gaps	Major data gaps						Major data gaps	

** Both monomer and polymer were assessed*

NI = no indication among the literature. This could imply a knowledge gap, but more often seems to be a sign that there is little reason to suspect an effect.

We do not categorize materials for which data appeared to be lacking for reasons other than a lack of suspicion; such materials are highlighted in gray.

Appendix D: External Resources and Certification Programs

Resources for more information

- Healthy Building Network (https://healthybuilding.net/)
- Pharos Project (www.pharosproject.net)

Indoor Air Quality Certification Programs for Building Materials [15]

- **Collaborative for High Performance Schools (CHPS)-** Provides information and resources for products that meet low emitting materials criteria for use in school such as adhesives, sealants, concrete sealers, acoustical ceilings, wall panels, wood flooring, composite wood boards, resilient flooring and carpet.

- **FloorScore-** Certifies resilient flooring products that meet VOC emissions

- **GreenGuard-** Certifies furniture and indoor finishes with low VOC emissions

- **GreenLabel Plus-** Certifies carpets, adhesives and cushions that meet VOC emission requirements

- **Indoor Advantage Gold-** Certifies wall coverings, systems furniture, casework, insulation and other non-flooring interior products that meet VOC emissions

- **Green Seal Certified**- Certifies paints and coatings that exclude certain chemicals and meet certain performance requirements

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APPENDIX E: ECOBLOCK OAKLAND BASE SCHEME BASED ON REVIEW AND ANALYSIS OF CONCEPT STAGE DOCUMENTS

Eco Block Oakland

Base Scheme
Oakland, CA

Based on review & analysis of:

Concept Stage Estimate

Report Prepared for:

Integral Group and Sherwood Design

March 8, 2018

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TABLE OF CONTENTS

BASIS OF ESTIMATE

REFERENCE DOCUMENTATION

This Construction Cost Estimate was produced from the following documentation. Design and engineering changes occurring subsequent to the issue of these documents have not been incorporated in this estimate.

Document	Date
- EcoBlock Basis of Design	27-Oct-17
- Oakland EcoBlock Illustrations	14-May-17
- Eco Block PV	17-May-17
- Reliable plans and routes	17-May-17
- EcoBlock cost package water team	23-May-17
- Updated Cost Matrix	29-Sep-17
- Updated SDE Water Matrix	30-Sep-17
- Sherwood review/markups of TBD 10-13-17 estimate	27-Oct-17

PROJECT DESCRIPTION

The scope of work includes block level micro grid and water recovery and reuse systems for a residential city block in Oakland, California. Various schemes were evaluated based on cost and constructability to determine viability of a cooperative block level power and water service. Power options include PV's on all rooftops as practicle, flywheel energy storage, PG&E interconnection, EV charging, and microgrid control. Water recovery options include blackwater mining, treatment and reuse within the block for toilet flushing and irrigation if possible.

BASIS FOR PRICING

This estimate reflects the fair construction value for this project and should not be construed as a prediction of low bid. Prices are based on local prevailing wage construction costs at the time the estimate was prepared. Pricing assumes a procurement process with competitive bidding for all sub-trades of the construction work, which is to mean a minimum of 3 bids for all subcontractors and materials/equipment suppliers. If fewer bids are solicited or received, prices can be expected to be higher. Conversely in the current competitive market should a larger number of sub-bids be received (i.e. 6 and above) pricing can expected to be lower than the current estimate.

Subcontractor's markups have been included in each line item unit price. Markups cover the cost of field overhead, home office overhead and subcontractor's profit. Subcontractor's markups typically range from 15% to 25% of the unit price depending on market conditions.

General Contractor's/Construction Manager's Site Requirement costs are calculated on a percentage basis. General Contractor's/Construction Manager's Jobsite Management costs are also calculated on a percentage basis.

Site Requirements	*6.0%*
Jobsite Management	*5.0%*
Phasing	*10.0%*

General Contractor's/Construction Manager's overhead and fees are based on a percentage of the total direct costs plus general conditions, and covers the contractor's bond, insurance, site office overheads and profit.

Insurance & Bonding	*1.5%*
General Contractor Bonding	
Sub-Contractor Bonding	
OSIP	
Fee (G.C. Profit)	*4.0%*

Unless identified otherwise, the cost of such items as overtime, shift premiums and construction phasing are not included in the line item unit price.

This cost estimate is based on standard industry practice, professional experience and knowledge of the local construction market costs. TBD Consultants have no control over the material and labor costs, contractors methods of establishing prices or the market and bidding conditions at the time of bid. Therefore TBD Consultants do not guarantee that the bids received will not vary from this cost estimate.

CONTINGENCY

Design Contingency	*15.0%*

BASIS OF ESTIMATE

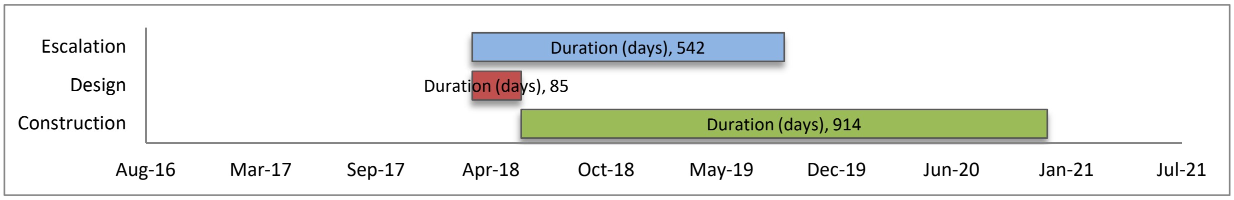
The Design Contingency is carried to cover scope that lacks definition and scope that is *anticipated* to be added to the Design. As the Design becomes more complete the Design Contingency will reduce.

Construction Contingency	*0.0%*	*Carried else where in owners budget*

The Construction Contingency is carried to cover the unforeseen during construction execution and Risks that do not currently have mitigation plans. As Risks are mitigated, Construction Contingency can be reduce, but should not be eliminated.

An owners contingency has not been included in this construction cost estimate, but it is advised that the owner carry additional contingency to cover scope change, bidding conditions, claims and delays.

CONSTRUCTION SCHEDULE



Construction Start Date	Jun-2018	Construction End Date	Dec-2020
Mid-date of Construction	Sep-2019	Construction Duration	30 months
Escalation Period	18 months		

ESCALATION

Escalation is required to the midpoint of construction which is assumed to be 27 months from March 2018

Escalation:	*25.0%*	*Simple Rate*	*Based on cumulative escalation over 5 Years*
Year 1	*5.0%*		
Year 2	*5.0%*		
Year 3	*5.0%*		
Year 4	*5.0%*		
Year 5	*5.0%*		

This calculation does not account for adverse bidding conditions and a separate Bid Contingency should be carried if there are limited qualified bidders or if a market research study indicates.

EXCLUSIONS

- Land acquisition, feasibility studies, financing costs and all other owner costs
- All professional fees and insurance
- Site surveys, existing condition reports and soils investigation costs
- Items identified in the design as Not In Contract [NIC]
- Hazardous materials investigations and abatement
- Utility company back charges, including work required off-site and utilities rates
- Work to City streets and sidewalks
- Items defined as Vendor / Owner supplied and Vendor / Owner installed
- Permits
- Owners contingency
- Overtime, 2nd shift and lost productivity premiums
- Design Fees
- PG & E Fees
- Sustainability Fees (LEED)
- Furniture, fixtures and equipment (FF&E)

KEY CRITERIA

BLDG TABULATION

Floor	GFA	Unit Count				COMMENTS
EcoBlock Base Systems		**Unit count**	**Bathroom count**	**Washer/dryer count**	**Dishwasher count**	
Unit 1	1,823	1	2			
Unit 2	2,448	4	4			
Unit 3	2,184	3	3			
Unit 4	1,525	2	2			
Unit 5	2,042	2	2			
Unit 6A and 6B	2,036	2	2			
Unit 7	2,191	1	2			
Unit 8	624	1	1			
Unit 9	1,774	2	2			
Unit 10	1,546	1	2			
Unit 11	650	1	1			
Unit 12	2,450	3	3			
Unit 13	2,800	2	2			
Unit 14	1,000	3	3			
Unit 15	1,632	1	2			
Unit 16	890	1	1			
Unit 17	1,042	1	1			
Unit 18	2,000	2	2			
Unit 19	1,082	1	1			
Unit 20	2,623	3	3			
Unit 21	1,694	1	2			
Unit 22	2,880	1	2			
Unit 23	2,331	1	2			
Unit 24	2,127	3	3	Allow	Allow	
Unit 25	800	1	1			
				26	44	
Multi family units:						
Unit 26 (8 units)	6,500	8	8	3	8	
Unit 27 (11 units)	8,946	11	12	3	12	
		Unit count	Bathroom count	W/D Allow	Dishwasher Allow	
Subtotal	**59,640**	**63**	**71**	**32**	**64**	

Site assumptions 47,000 SF of permeable surface

Properties
26 Single family structures
2 Multi family structures

GRAND SUMMARY

	TOTAL	COMMENTS
EcoBlock Options:		
Base Estimate:		
Costs consistent to all options	6,405,366	
Electrical Scenarios:		
Scenario 1: Standard PV and storage at home scale	2,976,921	
Scenario 2: Community DC Collection, Distribution and Storage at Block scale	13,444,458	
Scenario 3a: Community DC Collection, Distribution and Storage at Block scale with home DC loads	14,707,470	
Scenario 3b: Right scaled Community DC Collection, Distribution and Storage at Block scale, with home DC loads	11,608,458	Assume only 50% participation
Water and wastewater options:		
Water Option 1: Rainwater collection and reuse, non-potable	175,059	
Water Option 2: Irrigation contol, raingarden, shared well plus distribution, permeable paving	2,784,924	
Water Option 3a: Irrigation contol, raingarden, shared well plus distribution, permeable paving	3,085,008	
Water Option 3b: Irrigation contol, raingarden, permeable paving, blackwater mining	5,020,016	
Miscellaneous options:		
Window replacement Option:	3,594,893	

Option 1

	SECTION	%	TOTAL	COMMENTS
	10 FOUNDATIONS			
	20 BASEMENT CONSTRUCTION			
A	**SUBSTRUCTURE**			
	10 SUPERSTRUCTURE			
	20 EXTERIOR ENCLOSURE	12.0%	419,039	
	30 ROOFING	31.2%	1,087,661	
B	**SHELL**	**43.2%**	**1,506,700**	
	10 INTERIOR CONSTRUCTION	1.7%	59,640	
	20 STAIRS			
	30 INTERIOR FINISHES	0.9%	29,820	
C	**INTERIORS**	**2.6%**	**89,460**	
	10 CONVEYING			
	20 PLUMBING	4.7%	163,726	
	30 HVAC	25.9%	903,440	
	40 FIRE PROTECTION			
	50 ELECTRICAL	10.7%	375,000	
D	**SERVICES**	**41.3%**	**1,442,166**	
	10 EQUIPMENT	4.0%	138,560	
	20 FURNISHINGS			
E	**EQUIPMENT + FURNISHINGS**	**4.0%**	**138,560**	
	10 SPECIAL CONSTRUCTION			
	20 SELECTIVE BUILDING DEMOLITION			
F	**SPECIAL CONSTRUCTION + DEMOLITION**			
	10 SITE PREPARATION			
	20 SITE IMPROVEMENTS	6.4%	223,700	
	30 SITE MECHANICAL UTILITIES			
	40 SITE ELECTRICAL UTILITIES	2.6%	90,000	
	50 OTHER SITE CONSTRUCTION			
G	**BUILDING SITEWORK**	**9.0%**	**313,700**	
DIRECT COSTS			**3,490,585**	
	SITE REQUIREMENTS	6.0%	209,435	$6,989 per month
	JOBSITE MANAGEMENT	5.0%	174,529	$5,824 per month
	PHASING	10.0%	349,059	$11,648 per month
	ESTIMATE SUB-TOTAL		**4,223,608**	
	INSURANCE + BONDING	1.5%	63,354	
	FEE	4.0%	168,944	
	ESTIMATE SUB-TOTAL		**4,455,907**	
	DESIGN CONTINGENCY	15.0%	668,386	
	CONSTRUCTION CONTINGENCY			
	ESTIMATE SUB-TOTAL		**5,124,293**	
	ESCALATION	25.0%	1,281,073	
ESTIMATE TOTAL			**6,405,366**	total add-ons 83.5%

Base scope consistent thru all options

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
1							
2		**Foundations**					
3							
4		Standard Foundations		NA			
5							
6		**FOUNDATIONS**					
7							
8		**Basement Construction**		NA			
9		no work anticipated					
10							
11		**BASEMENT CONSTRUCTION**					
12							
13		**Superstructure**					
14		no work anticipated		NA			
15							
16		**SUPERSTRUCTURE**					
17							
18		**Exterior Enclosure**					
19							
20		Sub floor insulation					
21		Crawl space insulation under lower level					
22		All single family dwellings combined area	44,194	SF	3.00	132,582	
23		Multi family units:					
24		Unit 26 (8 units)	3,250	SF	3.00	9,750	
25		Unit 27 (11 units)	4,473	SF	3.00	13,419	
26							
27		Exterior Walls					
28		Insulate and seal exterior walls of single family dwellings	66,700	SF	2.50	166,750	
29		Multi family units:					
30		Unit 26 (8 units)	16,250	SF	2.50	40,625	
31		Unit 27 (11 units)	22,365	SF	2.50	55,913	
32							
33		Windows					
34		Replace exterior windows of all single family dwellings		NA			not included with this option
35		Multi family units:					
36		Unit 26 (8 units)		NA			not included with this option
37		Unit 27 (11 units)		NA			not included with this option
38							
39		Replace exterior doors allowance		NA			not included with this option
40							
41		**EXTERIOR ENCLOSURE**				**419,039**	
42							
43		**Roofing**					
44							
45		Roof Coverings					
46		Reroofing of existing structures, non-asphalt, for water reclaimation, all single family dwellings	54,359	SF	15.00	815,379	
47		Multi family units:					
48		Unit 26 (8 units)	3,998	SF	15.00	59,963	
49		Unit 27 (11 units)	5,502	SF	15.00	82,527	
50							
51		Attic insulation					
52		Attic insulation upper level					
53		All single family dwellings combined area	44,194	SF	2.50	110,485	
54		Multi family units:					
55		Unit 26 (8 units)	3,250	SF	2.50	8,125	
56		Unit 27 (11 units)	4,473	SF	2.50	11,183	
57							
58		**ROOFING**				**1,087,661**	
59							

Base scope consistent thru all options

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
60		**Interior Construction**					
61							
62		Partitions					
63		Cutting and patching allowance single family residences	44,194	SF	1.00	44,194	
64		Cutting and patching allowance multi family	15,446	SF	1.00	15,446	
65							
66		**INTERIOR CONSTRUCTION**				**59,640**	
67							
68		**Stairs**					
69		no work anticipated		NA			
70							
71		**STAIRS**					
72							
73		**Interior Finishes**					
74							
75		Wall Finishes					
76		Sheet rock repairs and paint touchup, single family dwellings	44,194	SF	0.50	22,097	
77		Sheet rock repairs and paint touchup, multi family dwellings	15,446	SF	0.50	7,723	
78							
79		**INTERIOR FINISHES**				**29,820**	
80							
81		**Conveying**					
82		No work anticipated		NA			
83							
84		**CONVEYING**					
85							
86		**Plumbing**					
87		Upgrade residential fixtures with low water consumption fixtures					
88		Replace water closets, minimal repiping	71	EA	880.00	62,480	
89		Replace lavatory faucets	71	EA	531.00	37,701	
90		Replace shower heads	71	EA	895.00	63,545	
91							
92		Replace existing plumbing at homes:		NA		Excluded	
93							
94		Greywater diversion and treatment:		NA		Excluded	
95							
96		**PLUMBING**				**163,726**	
97							
98		**HVAC**					
99							
100		Air handling equipment upgrades					
101		Allow replacement of existing furnace AHU and hydronic coil (Single family)	44	EA	4,000.00	176,000	
102		Allow replacement of existing furnace with AHU and hydronic coil (Multi family, 8 unit)	1	LS	28,000.00	28,000	
103		Allow replacement of existing furnace with AHU and hydronic coil (Multi family, 11 unit)	1	LS	42,000.00	42,000	
104		Upgrade natural ventilation, add HRV (Single family)	44	EA	3,250.00	143,000	
105		Upgrade natural ventilation, add HRV (Multi family, 8 unit)	1	LS	20,000.00	20,000	
106		Upgrade natural ventilation, add HRV (Multi family, 11 unit)	1	LS	30,000.00	30,000	
107		Allow replacement of existing exhaust fan with high efficiency ECM (Single family)	44	EA	1,000.00	44,000	
108		Allow replacement of existing exhaust fan w/high efficiency ECM (Multi family, 8 unit)	1	LS	8,000.00	8,000	
109		Allow replacement of existing exhaust fan with high efficiency ECM (Multi family, 11 unit)	1	LS	12,000.00	12,000	
110							
111		Hydronic equipment additions					

Base scope consistent thru all options

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
112		Allow for new air to water heat pump units, serves hydronic heating hot water systems	44	EA	4,900.00	215,600	
113		Allow for new air to water heat pump units, serves hydronic heating hot water systems (multi family, 8 unit)	1	LS	27,423.20	27,423	
114		Allow for new air to water heat pump units, serves hydronic heating hot water systems (multi family, 11 unit)	1	LS	38,196.60	38,197	
115		Hydronic hot water distribution to new heating water coil	44	EA	1,500.00	66,000	
116		Hydronic hot water distribution to new heating water coil (multi family, 8 unit)	1	EA	8,400.00	8,400	
117		Hydronic hot water distribution to new heating water coil (multi family, 11 unit)	1	EA	11,700.00	11,700	
118							
119		Thermostat upgrades					
120		Replace thermostat with web connected type and smart meters	44	EA	517.50	22,770	
121		Replace thermostat with web connected type and smart meters, muti-family 8-unit	1	LS	4,140.00	4,140	
122		Replace thermostat with web connected type and smart meters, multi-family 11-unit	1	LS	6,210.00	6,210	
123							
124		**HVAC**				**903,440**	
125							
126		**Fire Protection**					
127							
128		Sprinklers		NA			
129							
130		**FIRE PROTECTION**					
131							
132		**Electrical**					
133							
134		Electrical Service & Distribution		NA			See Electrical Scenarios
135							
136		Lighting and Branch Wiring					
137		Allow for LED lighting upgrades at residences plus ceiling fans, single family	44	EA	5,000.00	220,000	
138		Allow for LED lighting upgrades at residences, multi family/condo's	20	EA	4,000.00	80,000	
139		Upgrade lighting controls, single family	44	EA	1,250.00	55,000	Add combination OS/switch
140		Upgrade lighting controls, multi family/condo's	20	EA	1,000.00	20,000	Add combination OS/switch
141							
142		Other Electrical Systems					
143		Standalone PV arrays, complete systems at each bldg, include inverters		NA			See Electrical Scenarios
144							
145		**ELECTRICAL**				**375,000**	
146							
147		**Equipment**					
148							
149		Vehicular Equipment					
150		Electric vehicle charging stations		NA			not applicable this option
151							
152		Upgrade appliances to energy star rated					
153		Replace Washer/Dryers	32	EA	1,730.00	55,360	All options
154		Replace Dishwashers	64	EA	1,300.00	83,200	All options
155							
156		**EQUIPMENT**				**138,560**	
157							
158		**Furnishings**		NA			
159							
160		**FURNISHINGS**					
161							
162		**Special Construction**		NA			

Base scope consistent thru all options

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
163							
164		**SPECIAL CONSTRUCTION**					
165							
166		**Selective Building Demolition**		NA			
167							
168		**SELECTIVE BUILDING DEMOLITION**					
169							
170		**Site Preparation**					
171							
172		Site Clearing					
173		Clear and grub industrial plot for new CUP		NA			not applicable this option
174							
175		Site Demolition and Relocations					
176		Demo existing sidewalk		NA			not applicable this option
177		Demo existing street corners		NA			not applicable this option
178		Demo existing curb/gutter at new bulbout locations		NA			not applicable this option
179							
180		Site Earthwork		NA			
181							
182		Hazardous Waste Remediation		NA			
183							
184		**SITE PREPARATION**					
185							
186		**Site Improvements**					
187							
188		Pedestrian Paving					
189		Replace sidewalk		NA			not applicable this option
190		Install stormwater cell bulb outs with new curbs, 7' x 20'		NA			not applicable this option
191		New ADA curb ramps		NA			not applicable this option
192							
193		Site Development					
194		Equipment pad for central plant equipment		NA			not applicable this option
195		Fencing, security		NA			not applicable this option
196		CUP building if required, CMU, unconditioned		NA			not applicable this option
197							
198		Landscaping					
199		Plantings in stormwater infiltration bulb outs		NA			not applicable this option
200		18" bioretention soil		NA			not applicable this option
201		12" class II premeable rock		NA			not applicable this option
202		Tree allowance add as many as possible in existing sidewalk planting areas	20	EA	875.00	17,500	not applicable this option
203		Replace landscaped areas with new drought tolerant planting		NA			not applicable this option
204							
205		Irrigation systems:					
206		Upgrade to drip irrigation systems at single family residences, include moisture sensor/irrigation controllers, 900SF	26	EA	2,700.00	70,200	
207		Upgrade to drip irrigation systems at multi-family buildings, include moisture sensors/irrigation controllers, 900 SF	2	EA	5,000.00	10,000	
208		Rainbarrel installation at single family residences (allow 1000 gallon)		NA			See upgrade options
209		Rainbarrel installation at multi-family buildings (allow 2000 gallon)		NA			See upgrade options
210							
211		Plantings at individual residences					
212		Private: Replace landscaped areas with new drought tolerant planting, 900SF	26	EA	4,500.00	117,000	
213		Multi-family: Replace landscaped areas with new drought tolerant planting, 900SF	2	EA	4,500.00	9,000	
214		Private raingardens, 150SF x 18" deep		NA			See upgrade options
215		Multi-family raingardens, 300SF x 18" deep		NA			See upgrade options
216							

Base scope consistent thru all options

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
217		**SITE IMPROVEMENTS**				**223,700**	
218							
219		**Site Mechanical Utilities**					
220							
221		Water Supply		NA			Use existing potable supply
222							
223		Sanitary Sewer		NA			Use existing sewer system
224							
225		Storm Sewer		NA			
226							
227		Fuel Distribution		NA			
228							
229		Other Site Mechanical Utilities		NA			
230							
231							
232		**SITE MECHANICAL UTILITIES**					
233							
234		**Site Electrical Utilities**					
235							
236		Electrical Distribution					
237		Maintain existing pole mounted electrical distribution, replace feeders as necessary		NA			not required this option
238							
239		Site Lighting					
240		Upgrade steet lighting to LED type (allow)		NA			See upgrade options
241		Lighting controls		NA			See upgrade options
242		Building exterior lighting					
243		Allow for LED lighting upgrades at single family dwellings	26	EA	3,000.00	78,000	
244		Allow for LED lighting upgrades at residences, multi family/condo's	2	EA	6,000.00	12,000	
245							
246		Site Communications & Security		NA			
247							
248		Other Site Electrical Utilities		NA			
249							
250		**SITE ELECTRICAL UTILITIES**				**90,000**	
251							
252		**Other Site Construction**					
253							
254		Other Site Systems & Equipment		NA			
255							
256							
257		**OTHER SITE CONSTRUCTION**					

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
1							
2		Electrical Scenario 1					
3							
4		Electrical Service & Distribution					
5		Allow for new AC load centers at 25% of 30 units	8	EA	3,500.00	28,000	
6		Allow for new main service panels at multi family bldgs	2	EA	8,500.00	17,000	
7							
8		Lighting and Branch Wiring		NA			See upgrade options
9							
10		Other Electrical Systems					
11		Standalone PV arrays, complete systems at each bldg, include inverters					
12		Single family PV systems, average size 8.9 kw, 231kw/26 homes	26	EA	35,600.00	925,600	
13		Multi family (8 unit) PV system (allow 4kw/unit)	32	KW	3,800.00	121,600	
14		Multi family (11 unit) PV system (allow 4kw/unit)	48	KW	3,800.00	182,400	
15		Single family battery storage allowance	26	EA	11,450.00	297,700	
16		Multi family (8 unit) battery storage	1	EA	20,000.00	20,000	
17		Multi family (11 unit) battery storage	1	EA	30,000.00	30,000	
18							
19		Markups 83.5%			83.50%	1,354,621	
20							
21		**Electrical Scenario 1**				**2,976,921**	
22							
23		Electrical Scenario 2					
24							
25		Electrical Service & Distribution					
26		Allow for new AC load centers at 25% of 30 units	8	EA	3,500.00	28,000	
27		Allow for new main service panels at multi family bldgs	2	EA	8,500.00	17,000	
28		AC/DC inverter residential level	29	EA	6,210.00	180,090	
29		AC/DC inverter multi family residential level	1	EA	12,150.00	12,150	
30		AC/DC inverter multi family residential level	1	EA	17,220.00	17,220	
31							
32		Lighting and Branch Wiring		NA			See upgrade options
33							
34		Other Electrical Systems					
35		Block level PV array				See below	
36		Electric vehicle and charging stations, (1) per single family dwelling, (2) per multifamily	30	EA	45,000.00	1,350,000	
37							
38		Site Elecric					
39		DC Micro-grid					
40		Duct bank in joint, 2' x 2' concrete encased, (8) 6"conduits	1,800	LF	400.00	720,000	
41		DC/DC converter	11	EA	65,000.00	715,000	
42		Central flywheel, 800VDC (5) 40kw, 250A	1	EA	350,000.00	350,000	
43		Sub grade DC switch	1	EA	85,000.00	85,000	
44		Feeders:					
45		380V DC, 250A from Flywheel	1,800	75	75.00	135,000	
46		380V DC, from PV arrays	1,800	90	90.00	162,000	
47		Distribution panels vehicle charging	2	EA	18,650.00	37,300	
48		Sectionalizing switches, residential	4	EA	130,000.00	520,000	
49		Sectionalizing switches, EV charging	2	EA	75,000.00	150,000	
50		Distribution panels residential, 1200A	4	EA	35,000.00	140,000	
51		Distribution panels residential, 200A	2	EA	18,000.00	36,000	
52		Electrical equipment pads serving TX, switches and panels	6	EA	5,000.00	30,000	
53		380V DC feeders, residential, 100A	1,650	LF	125.00	206,250	
54		380V DC feeders, PV array	1,800	LF	95.00	171,000	
55		Microgrid controls	1	LS	350,000.00	350,000	
56							

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
57		Site Lighting					
58		Upgrade steet lighting to LED type, redistribute to DC power source	32	EA	5,000.00	160,000	
59		Lighting controls	1	LS	35,000.00	35,000	
60							
61		Other Site Electrical Utilities					
62		Power poles	7	EA	30,000.00	210,000	
63		PV array, 364 KW, 910 panels	1	LS	1,061,970.00	1,061,970	
64		DC switches, serve PV array	8	EA	12,500.00	100,000	
65		Battery storage	1	LS	347,700.00	347,700	
66							
67		Markups 83.5%			83.50%	6,117,778	
68							
69		**Electrical Scenario 2**				**13,444,458**	
70							
71		Electrical Scenario 3a					
72							
73		Electrical Service & Distribution					
74		Allow for new AC load centers at 25% of 30 units	8	EA	3,500.00	28,000	
75		Allow for new main service panels at multi family bldgs	2	EA	8,500.00	17,000	
76		Allow for new DC load centers and service feeders to residences 3bed/2bath	44	EA	4,500.00	198,000	
77		Allow for new DC load centers and service feeders to residences 8 plex	1	EA	10,000.00	10,000	
78		Allow for new DC load centers and service feeders to residences 11 plex	1	EA	15,000.00	15,000	
79							
80		Lighting and Branch Wiring		NA			See upgrade options
81							
82		Other Electrical Systems					
83		Block scale PV				see below	
84		DC appliance upgrades		NA			
85		Electric vehicle and charging stations, (1) per single family dwelling, (2) per multifamily	30	EA	45,000.00	1,350,000	
86							
87		Site Electric					
88		DC Micro-grid					
89		Duct bank in joint, 2' x 2' concrete encased, (8) 6"conduits	1,800	LF	400.00	720,000	
90		AC Primary switch	1	EA	154,000.00	154,000	
91		Transformer, 365 KVA, 12.47KV - 480V, 3P, 3W	1	EA	85,000.00	85,000	
92		AC/DC inverter, 365KW, 480VAC, 2625A	1	EA	80,000.00	80,000	
93		DC/DC converter	11	EA	35,000.00	385,000	
94		Central flywheel, 800VDC (5) 40kw, 250A	1	EA	350,000.00	350,000	
95		Sub grade DC switch	1	EA	85,000.00	85,000	
96		Feeders:					
97		380V DC, 250A from Flywheel	1,800	75	75.00	135,000	
98		380V DC, from PV arrays	1,800	90	90.00	162,000	
99		12.47 KVA, 600A	1,800	200	200.00	360,000	
100		Transformers, 12.47KV - 240V 50KV vehicle charging	2	EA	18,650.00	37,300	
101		Transformers, 12.47KV - 240V 300KV, residential AC loads	4	EA	33,000.00	132,000	
102		Sectionalizing switches, residential	4	EA	130,000.00	520,000	
103		Sectionalizing switches, EV charging	2	EA	75,000.00	150,000	
104		Distribution panels residential, 1200A	4	EA	35,000.00	140,000	
105		Distribution panels residential, 200A	2	EA	18,000.00	36,000	
106		Electrical equipment pads serving TX, switches and panels	6	EA	5,000.00	30,000	
107		380V DC feeders, residential, 100A	2,400	LF	125.00	300,000	
108		380V DC feeders, PV array	1,800	LF	95.00	171,000	
109		Microgrid controls	1	LS	450,000.00	450,000	
110							

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
111		Site Lighting					
112		Upgrade steet lighting to LED type, redistribute to DC power source	32	EA	5,000.00	160,000	
113		Lighting controls	1	LS	35,000.00	35,000	
114							
115		Other Site Electrical Utilities					
116		Power poles	7	EA	30,000.00	210,000	
117		PV array, 364 KW, 910 panels	1	LS	1,061,970.00	1,061,970	
118		DC switches, serve PV array	8	EA	12,500.00	100,000	
119		Battery storage	1	LS	347,700.00	347,700	
120							
121		Markups 83.5%			83.50%	6,692,500	
122							
123		**Electrical Scenario 3a**				**14,707,470**	
124							
125		Electrical Scenario 3b					
126							
127		Electrical Service & Distribution					
128		Allow for new AC load centers at 25% of 30 units	8	EA	3,500.00	28,000	
129		Allow for new main service panels at multi family bldgs	2	EA	8,500.00	17,000	
130		Allow for new DC load centers and service feeders to residences 3bed/2bath	22	EA	4,500.00	99,000	
131		Allow for new DC load centers and service feeders to residences 8 plex	1	EA	5,000.00	5,000	
132		Allow for new DC load centers and service feeders to residences 11 plex	1	EA	7,500.00	7,500	
133							
134		Lighting and Branch Wiring		NA			See upgrade options
135							
136		Other Electrical Systems					
137		Block scale PV				see below	
138		DC appliance upgrades		NA			
139		Electric vehicle and charging stations, (1) per single family dwelling, (2) per multifamily	15	EA	45,000.00	675,000	
140							
141		Site Electric					
142		DC Micro-grid					
143		Duct bank in joint, 2' x 2' concrete encased, (8) 6"conduits	1,800	LF	400.00	720,000	
144		AC Primary switch	1	EA	154,000.00	154,000	
145		Transformer, 182 KVA, 12.47KV - 480V, 3P, 3W	1	EA	55,000.00	55,000	
146		AC/DC inverter, 182KW, 480VAC, 2625A	1	EA	50,000.00	50,000	
147		DC/DC converter	11	EA	35,000.00	385,000	
148		Central flywheel, 800VDC (5) 40kw, 250A	1	EA	350,000.00	350,000	
149		Sub grade DC switch	1	EA	85,000.00	85,000	
150		Feeders:					
151		380V DC, 250A from Flywheel	1,800	75	75.00	135,000	
152		380V DC, from PV arrays	1,800	90	90.00	162,000	
153		12.47 KVA, 600A	1,800	200	200.00	360,000	
154		Transformers, 12.47KV - 240V 50KV vehicle charging	2	EA	18,650.00	37,300	
155		Transformers, 12.47KV - 240V 300KV, residential AC loads	4	EA	33,000.00	132,000	
156		Sectionalizing switches, residential	4	EA	130,000.00	520,000	
157		Sectionalizing switches, EV charging	2	EA	75,000.00	150,000	
158		Distribution panels residential, 1200A	4	EA	35,000.00	140,000	
159		Distribution panels residential, 200A	2	EA	18,000.00	36,000	
160		Electrical equipment pads serving TX, switches and panels	6	EA	5,000.00	30,000	
161		380V DC feeders, residential, 100A	1,300	LF	125.00	162,500	
162		380V DC feeders, PV array	1,800	LF	95.00	171,000	
163		Microgrid controls	1	LS	450,000.00	450,000	
164							

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
165		Site Lighting					
166		Upgrade steet lighting to LED type, redistribute to DC power source	32	EA	5,000.00	160,000	
167		Lighting controls	1	LS	35,000.00	35,000	
168							
169		Other Site Electrical Utilities					
170		Power poles	7	EA	30,000.00	210,000	
171		PV array, 182 KW, 455 panels	1	LS	530,985.00	530,985	
172		DC switches, serve PV array	8	EA	12,500.00	100,000	
173		Battery storage	1	LS	173,850.00	173,850	
174							
175		Markups 83.5%			83.50%	5,282,323	
176							
177							
178		**Electrical Scenario 3b**				**11,608,458**	
179							
180		Water option 1					
181							
182		No well, existing potable water source					
183		Irrigation via standard sprinklers and hose					
184		Rainwater collection cistern, treatment					
185							
186		Irrigation systems:					
187		Upgrade to drip irrigation systems at single family residences, 900SF		NA			See option 2 and 3
188		Upgrade to drip irrigation systems at multi-family buildings, 900 SF		NA			See option 2 and 3
189		Rainbarrel installation at single family residences (allow 1000 gallon)	26	EA	3,180.00	82,680	
190		Rainbarrel installation at multi-family buildings (allow 2000 gallon)	2	EA	6,360.00	12,720	
191							
192		Plantings at individual residences					
193		Private: Replace landscaped areas with new drought tolerant planting, 900SF		NA			With base, all options
194		Multi-family: Replace landscaped areas with new drought tolerant planting, 900SF		NA			With base, all options
195		Private raingardens, 150SF x 18" deep		NA			See option 2 and 3
196		Multi-family raingardens, 300SF x 18" deep		NA			See option 2 and 3
197							
198		Markups 83.5%			83.50%	79,659	
199							
200							
201		**Water option 1**				**175,059**	
202		Water option 2					
203							
204		Irrigation systems:					
205		Irrigation meters and controls, single family	26	EA	1,500.00	39,000	
206		Irrigation meters and controls, multi family	2	EA	1,500.00	3,000	
207		Rainbarrel installation at single family residences (allow 1000 gallon)	26	EA	3,180.00	82,680	
208		Rainbarrel installation at multi-family buildings (allow 2000 gallon)	2	EA	6,360.00	12,720	
209		Pumping, treatment and potable reuse equipment	1	LS	182,000.00	182,000	
210							
211		Plantings at individual residences					
212		Private: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
213		Multi-family: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
214		Private raingardens, 150SF x 18" deep	26	EA	2,250.00	58,500	
215		Multi-family raingardens, 300SF x 18" deep	2	EA	4,500.00	9,000	
216							
217		Shared groundwater well improvements, develop existing wells, distribution purple pipe		NA			See option 3a
218							
219		Site/block improvements					

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
220		Install stormwater cell bulb outs with new curbs, 7' x 20'		NA			See option 3a and 3b
221							
222		Site Clearing					
223		Clear and grub industrial plot for new CUP	3,335	SF	2.00	6,670	
224							
225		Site Demolition and Relocations					
226		Demo existing parking lane	17,600	SF	3.00	52,800	
227		Demo existing street corners	4	EA	1,000.00	4,000	
228		Demo existing curb/gutter at new bulbout locations	220	LF	20.00	4,400	
229							
230		Site Development					
231		Equipment pad for central plant equipment	1	LS	50,000.00	50,000	
232		Fencing, security	300	LF	85.00	25,500	
233		CUP building if required, CMU, unconditioned	3,000	SF	120.00	360,000	
234		Parking aisle permeable paving	17,600	SF	20.00	352,000	
235							
236		Landscaping					
237		Plantings in stormwater infiltration bulb outs		NA			See option 3a and 3b
238		18" bioretention soil		NA			See option 3a and 3b
239		12" class II premeable rock		NA			See option 3a and 3b
240		Tree allowance (3/bulb out)		NA			See option 3a and 3b
241							
242		Other Site Systems & Equipment					
243		Trench excavation and backfill, 4' wide, 4' deep	1,800	LF	100.00	180,000	
244							
245		Markups 83.5%			83.50%	1,187,595	
246							
247							
248		**Water option 2**				**2,784,924**	
249							
250		<u>Water option 3a</u>					
251							
252		Irrigation systems:					
253		Irrigation meters and controls, single family	26	EA	1,500.00	39,000	
254		Irrigation meters and controls, multi family	2	EA	1,500.00	3,000	
255		Rainbarrel installation at single family residences (allow 1000 gallon)	26	EA	3,180.00	82,680	
256		Rainbarrel installation at multi-family buildings (allow 2000 gallon)	2	EA	6,360.00	12,720	
257		Pumping, treatment and potable reuse equipment	1	LS	182,000.00	182,000	
258							
259		Plantings at individual residences					
260		Private: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
261		Multi-family: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
262		Private raingardens, 150SF x 18" deep	26	EA	2,250.00	58,500	
263		Multi-family raingardens, 300SF x 18" deep	2	EA	4,500.00	9,000	
264							
265		Shared groundwater well improvements, develop existing wells, distribution purple pipe	1	LS	108,000.00	108,000	
266							
267		Site/block improvements					
268		Install stormwater cell bulb outs with new curbs, 7' x 20'	11	EA	2,500.00	27,500	
269							
270		Site Clearing					
271		Clear and grub industrial plot for new CUP	3,335	SF	2.00	6,670	
272							
273		Site Demolition and Relocations					
274		Demo existing parking lane	17,600	SF	3.00	52,800	
275		Demo existing street corners	4	EA	1,000.00	4,000	
276		Demo existing curb/gutter at new bulbout locations	220	LF	20.00	4,400	
277							

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
278		Site Development					
279		Equipment pad for central plant equipment	1	LS	50,000.00	50,000	
280		Fencing, security	300	LF	85.00	25,500	
281		CUP building if required, CMU, unconditioned	3,000	SF	120.00	360,000	
282		Parking aisle permeable paving	17,600	SF	20.00	352,000	
283							
284		Landscaping					
285		Plantings in stormwater infiltration bulb outs	1,540	SF	15.00	23,100	
286		18" bioretention soil	86	CY	100.00	8,556	
287		12" class II premeable rock	57	CY	75.00	4,278	
288		Tree allowance (3/bulb out)	100	EA	875.00	87,500	
289							
290		Other Site Systems & Equipment					
291		Trench excavation and backfill, 4' wide, 4' deep	1,800	LF	100.00	180,000	
292							
293		Markups 83.5%			83.50%	1,403,805	
294							
295							
296		**Water option 3a**				**3,085,008**	
297							
298		Water option 3b					
299		Irrigation systems:					
300		Irrigation meters and controls, single family	26	EA	1,500.00	39,000	
301		Irrigation meters and controls, multi family	2	EA	1,500.00	3,000	
302		Rainbarrel installation at single family residences (allow 1000 gallon)	26	EA	3,180.00	82,680	
303		Rainbarrel installation at multi-family buildings (allow 2000 gallon)	2	EA	6,360.00	12,720	
304		Pumping, treatment and potable reuse equipment	1	LS	182,000.00	182,000	
305							
306		Plantings at individual residences					
307		Private: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
308		Multi-family: Replace landscaped areas with new drought tolerant planting, 900SF		NA			Included with base estimate
309		Private raingardens, 150SF x 18" deep	26	EA	2,250.00	58,500	
310		Multi-family raingardens, 300SF x 18" deep	2	EA	4,500.00	9,000	
311							
312		Water Supply					
313		Non-potable water distribution in joint trench, 4"	1,700	LF	95.00	161,500	
314		NP service laterals to single family residences, includes trenching, valves	780	LF	55.00	42,900	
315		Metering and backflow preventers	26	EA	1,500.00	39,000	
316		NP service laterals to multi family apartment/condo's, includes trenching, valves	60	LF	85.00	5,100	
317		Metering and backflow preventers	2	EA	3,500.00	7,000	
318							

ALTERNATES DETAIL

REF	MF	DESCRIPTION	QUANTITY	UoM	UNIT RATE	TOTAL	COMMENTS
319		Sanitary Sewer					
320		Forced main from sewer mining to CUP, route in joint trench, 4"	500	LF	95.00	47,500	
321		Sewer mining manhole and pump vault	1	LS	125,000.00	125,000	
322		Blackwater treatment equipment, 5000 gpd, aquacell, 5000 gal tank	1	LS	600,000.00	600,000	
323		Sanitary waste overflow distribution	100	LF	95.00	9,500	
324		Waste branches to residences, includes trenching, valves, metering and backflow preventers		NA			Homeowner expense
325							
326		Other Site Mechanical Utilities					
327		Allow for miscellaneous utility modifications and relocations	1	LS	125,000.00	125,000	
328		Groundwater well improvements, develop existing wells, distribution purple pipe		NA			See option 3a
329							
330		Site/block improvements					
331		Install stormwater cell bulb outs with new curbs, 7' x 20'	11	EA	2,500.00	27,500	
332							
333		Site Clearing					
334		Clear and grub industrial plot for new CUP	3,335	SF	2.00	6,670	
335							
336		Site Demolition and Relocations					
337		Demo existing parking lane	17,600	SF	3.00	52,800	
338		Demo existing street corners	4	EA	1,000.00	4,000	
339		Demo existing curb/gutter at new bulbout locations	220	LF	20.00	4,400	
340							
341		Site Development					
342		Equipment pad for central plant equipment	1	LS	50,000.00	50,000	
343		Fencing, security	300	LF	85.00	25,500	
344		CUP building if required, CMU, unconditioned	3,000	SF	120.00	360,000	
345		Parking aisle permeable paving	17,600	SF	20.00	352,000	
346							
347		Landscaping					
348		Plantings in stormwater infiltration bulb outs	1,540	SF	15.00	23,100	
349		18" bioretention soil	86	CY	100.00	8,556	
350		12" class II premeable rock	57	CY	75.00	4,278	
351		Tree allowance (3/bulb out)	100	EA	875.00	87,500	
352							
353		Other Site Systems & Equipment					
354		Trench excavation and backfill, 4' wide, 4' deep	1,800	LF	100.00	180,000	
355							
356		Markups 83.5%			83.50%	2,284,312	
357							
358							
359		**Water option 3b**				**5,020,016**	
360							
361		Upgrade Option 1: Replace windows					
362							
363		Windows					
364		Replace exterior windows of all single family dwellings	8,000	SF	150.00	1,200,000	
365		Multi family units:					
366		Unit 26 (8 units)	1,950	SF	150.00	292,500	
367		Unit 27 (11 units)	2,684	SF	150.00	402,570	
368							
369		Replace exterior doors allowance	64	EA	1,000.00	64,000	
370							
371		Markups 83.5%			83.50%	1,635,823	
372							
373							
374		**Upgrade Option 1: Replace windows**				**3,594,893**	

APPENDIX F: LIFECYCLE ASSESSMENT REPORT

CE 268E Civil Systems and the Environment

Life-Cycle Assessment of Block-Scale Sustainability Retrofitting: Case Study of the Eco-Block in Oakland, CA

November 30, 2017

Borna Poursheikhani, Daniel Herron, Martin Folkedal Hjelle, Camille Salem and Sarah Hermine Fossum Simonsen

Abstract

This paper investigates the environmental impact of a series of sustainability retrofits on a residential block in Oakland, CA. The block consists of 44 households in 26 houses. The Eco-Block Project aims to reduce the greenhouse gas emissions associated with residential buildings through a community approach to sustainable living. Life-cycle assessments (LCA) of the main components of the proposed electric system, including photovoltaic panels and flywheels, along with building efficiency and transportation system retrofits are compiled, with a focus on global warming potential (GWP) as the impact category. We also consider the displaced (avoided operational) emissions due to PV electricity generation, building efficiency retrofits, and an EV car sharing system. The GWP of the energy system (transportation + electricity) was –0.34 kg CO_2eq/kWh for an Eco-Block with the EV car sharing system and –0.18 kg CO_2eq/kWh for the scenario without the EV car sharing system. The assessment of building efficiency retrofits proved minimally beneficial relative to the impact of the energy system. In addition, vertical axis wind turbines (VAWT) and Tesla Powerwalls are considered as potential additions/alternatives to the PV + Flywheel system. We recommend not including the VAWTs as they will provide a near negligible amount of electricity relative to the PV system. The Powerwall vs. Flywheel comparison however resulted inconclusively given the similarity in results and the uncertainty associated with the embodied emission calculations of the two systems.

Executive Summary

This report is a Lifecycle assessment of the proposed sustainability renovations for the Eco-Block project in Oakland, California. We aim to highlight the most environmentally significant components in the current design and explore some potential alternatives to the current electricity generation and storage plans. We focus our attention on the GWP, both embodied and operational, of the added energy systems, building efficiency retrofits, and EV car sharing system. The planning horizon used in this report is 15 years.

The most significant component of the Eco-Block design from an environmental impact perspective is the energy system retrofit (broken into electricity and transportation subcomponents later on in the report). In our analysis, we account for the embodied emissions of the solar panels, inverter, flywheels, EV chargers, and EVs as well as the avoided operational emissions associated with home electricity consumption, EV charging, and return of residual electricity to the grid. We anticipate a total of 12 GWh of electricity generation from the solar panels with an upper bound of 28 GWh and a lower bound of 1.1 GWh. In our assessment we consider 3 fates for this generated electricity: home electricity use, EV charging, and return to the grid. The operational emissions of our energy system are in the form of avoided operational emissions only: the home electricity use and the electricity returned to the grid are said to "avoid" or "displace" electricity that would have otherwise come from the PG&E electricity fuel mix. Similarly, the EV fleet's solar electricity consumption has zero operational emissions, instead we calculate the avoided operational emissions associated with the displaced use of gasoline powered vehicles. After factoring in the impact of embodied and avoided operational emissions, we found that the Eco-Block has a lifecycle GWP of –4,400 tonnes CO_2eq if an EV car sharing system is included and -1,300 tonnes CO_2eq if the final design does not include an EV car sharing system. Our calculations for this section operate under the assumption that all electricity for home and EV charging come solely from the solar panels. This assumption is based on our analysis of the estimated electricity generation and consumption of the Eco-Block.

This paper also looks at the environmental impact of building efficiency retrofits including installation of efficient home and street lighting, blow-in cellulose wall insulation, and replacement of windows with low-E double paned windows. We factor in the embodied emissions of the lights, windows, and blow-in cellulose as well as the avoided operational emissions associated with the resulting reduced natural gas heating demand and the electricity saved by switching from incandescent to LED lights. We estimate a life cycle GWP of –100 tons CO_2eq for the building efficiency retrofits. This value excludes window retrofits as we found that the embodied emissions of the new windows negatively outweigh the added insulation. For this section we used an energy flux equation to correlate the added insulation to the amount of heat saved. Though this method proved sufficient for our calculations, we recommend doing a more extensive building efficiency assessment before deciding whether or not to replace the windows.

To help inform decisions regarding potential alternatives and additions, we explored the potential use of Tesla Powerwalls and vertical axis wind turbines (VAWT) for electricity storage and generation respectively. We do not advise the use of VAWTs due to their relatively negligible electricity production and minimal performance documentation. The storage alternatives assessment proved inconclusive due to the similarity of the two systems' resulting GWPs. We accounted for the embodied emissions of the storage systems and the energy losses associated with the roundtrip efficiency. The Powerwall had an associated lifecycle GWP of 9.4 g/kWh and the flywheel had a lifecycle GWP of 16 g/kWh.

Below is the resulting GWP associated with switching to the Eco-Block, discounting the storage and electricity generation alternatives:

GWP of energy system with EV car sharing system = -0.34 kg CO_2eq/kWh of generation

GWP of energy system (without EV car sharing system) = -0.18 kg CO_2eq/kWh of generation

Total GWP (with EV car sharing system) = -4500 tons CO_2eq

Total GWP (without EV car sharing system) = -1400 tons CO_2eq

Please note that these values do not reflect the DER-CAM analysis; the subcomponents of this report were scaled and modified to create a custom DER-CAM LCA.

Table of Contents

List of Figures

List of Tables

1. Introduction

According to the Union of Concerned Scientists, the United States is the second largest emitter of greenhouse gases (GHG) in the world, second only to China. Buildings are responsible for 40% of the total GHG emissions in the U.S. They consume 70% of total electricity, which is associated with a host of GHGs and hazardous air pollutants alike (USGBC, 2006). Together, these GHGs are responsible for a myriad of environmental and health concerns including, but not limited to, climate change, serious respiratory ailments, increased cancer rates, and millions of premature deaths across the globe every year (Chu, 2013). The Eco-Block aims to provide an alternative, scalable solution to this problem by creating a micro-grid community with shared on-site renewable energy generation, water recycling/reuse, and improved building energy efficiency.

Self-sufficiency for a single house can be both expensive and infeasible. The Eco-Block takes advantage of the financial and environmental benefits associated with the development of a community scale system by distributing the burden across 26 houses. By creating an interconnected system as opposed to a single unit, the Eco-Block allows each house to contribute its abundant resources, and consume resources that it lacks, namely captured water and onsite electricity generation.

This report is a second-generation life-cycle assessment of the Eco-Block project. The goal of this LCA is to build on the previous report by assessing more granularly the cradle to grave greenhouse gas emissions associated with energy system upgrades, building efficiency retrofits, and supplementary EV Car sharing infrastructure. The new energy system infrastructure is composed primarily of photovoltaic electricity generation, flywheel storage, and inverters. The building efficiency retrofits consist of added cellulose insulation, replacement of single paned windows with low-E double panes windows, and switching to efficient in home and street-side LED lighting. We have also included the GHG impact of some alternative/additional system options that may be considered, namely vertical axis wind turbines and lithium-ion battery storage. The life-cycle emissions associated with the project construction and water system upgrade is assumed to be unchanged, therefore we have not conducted any additional assessment of those systems.

2. Problem Statement

At the conclusion of this project there are a few key questions the team would like to answer. Most fundamentally, will these "sustainability retrofits" actually be good for the environment? In addition, what electricity production is necessary to supply the Eco-Block's demand, and what production can be expected from the given conditions? What is the global warming potential of production, installation and operation of the proposed technical equipment at the scale needed for a block-wide retrofitting project? Are there alternatives to the proposed solutions that make smaller environmental footprints? Answering these questions is a step towards later determining whether environmental retrofits are more effective from a GWP standpoint on a block scale compared to individual sustainable houses.

The team will seek to quantify the lifetime greenhouse gas emissions, in terms of kg CO2eq, associated with the proposed retrofit. This analysis will examine the manufacturing, distribution, and operational emissions of each of the major components of the Eco-Block system. Namely, the installed energy generation, storage, and transformer equipment along with the building retrofit materials and transportation elements will be the primary focus. The minor electrical components would have little impact on the overall emissions, so they are assumed to be negligible for the purpose of this study.

Finally, the team will explore several identified opportunities to improve upon the proposed system. For instance, could additional generation capacity, more efficient storage options, and alternative transportation systems help the project achieve its overarching goal of reducing the block’s carbon footprint? This will be determined through a series of comparative analyses on the aforementioned components.

3. Background – A Literary Review

A previous lifecycle assessment of the Eco-Block was carried out in fall 2016. The report "Life Cycle Assessment of Retrofitting Water and Electricity Systems on a Block Scale – Case Study of the Oakland Eco-Block" looked at the GWP of the water system retrofit, electricity system retrofit, and construction as well as some construction costs. The following is a summary of the results and findings of the report (Eid, Porter, Shih, & Techangam, 2016).

3.1. Water Retrofit

The water retrofit life-cycle assessment included the assessment of three water technology alternatives: Blackwater reused for irrigation, greywater reused as indoor non-potable water, and rainwater reused as indoor non-potable water. Although combinations of these technologies might be used, the study considered the three as separate alternatives for comparative purposes. The modeling approach for assessing the three alternatives considered the materials/manufacturing, operation, installation (only for rainwater), and methane release associated with operation (only for blackwater).

As shown in the Figure 1, the results of the assessment show that the global warming potential (GWP) ranges between 1 and 2 kg CO_2eq/m^3: Blackwater has a GWP of 1.5 kg CO_2eq/m^3, greywater has 1.2 kg CO_2eq/m^3, and rainwater has GWP of 2 kg CO_2eq/m^3.

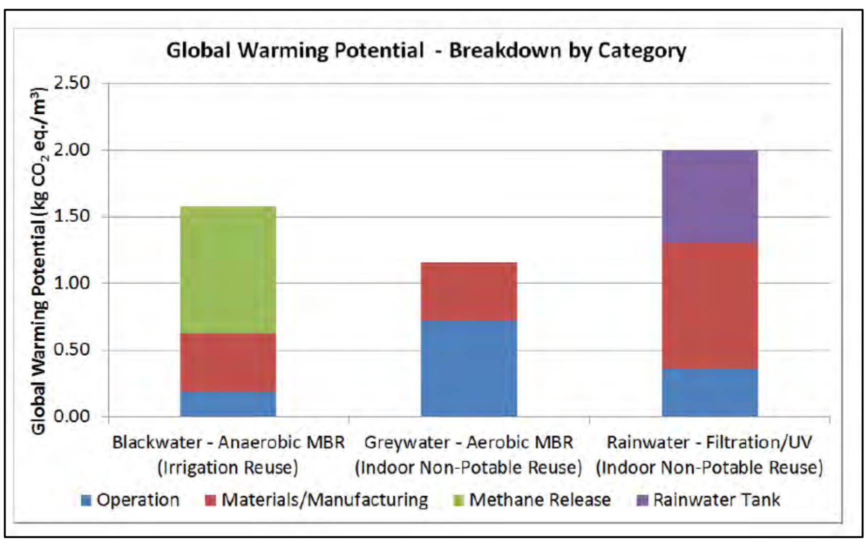


Figure 1 - GWP of water technology alternatives broken down by category (Eid, Porter, Shih, & Techangam, 2016)

3.2. Electricity Retrofit

The electricity retrofit lifecycle assessment includes two different components of the electrical system; photovoltaic panels and flywheels. The modelling approach considered the materials and manufacturing, installation, and operation of the two components. Figure 2 compares the emissions associated with getting electricity using the Eco-Block electrical system (i.e. photovoltaic panels (PVs) and flywheels) and the emissions associated with getting electricity from PG&E. As shown in Figure 2, the emissions associated with the Eco-Block microgrid (i.e. PVs, and flywheels) are around 200 g CO_2eq/kWh, whereas the emissions associated with PG&E are 370 g CO_2eq/kWh.

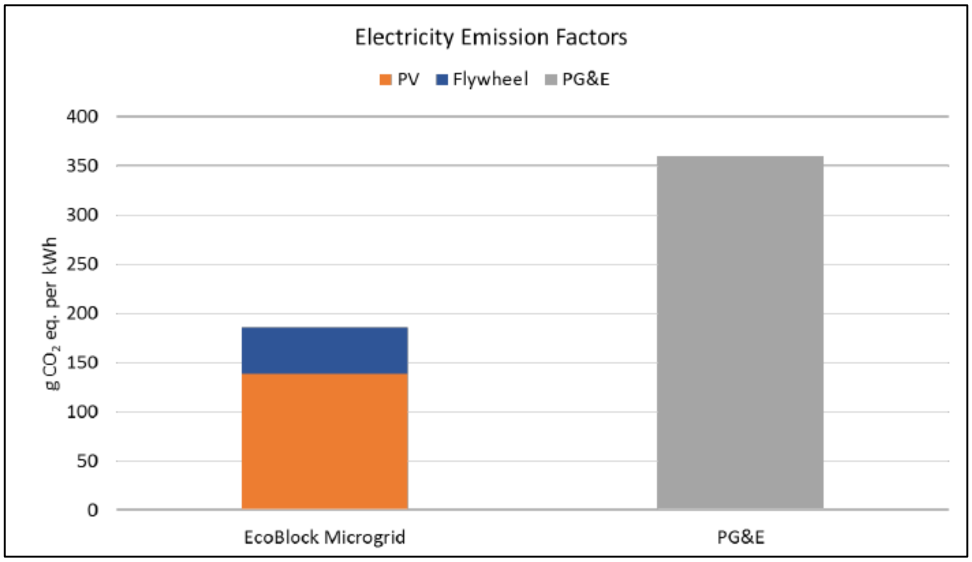


Figure 2 - Emission Comparison between Proposed Eco-Block Micro grid and PG&E (Eid, Porter, Shih, & Techangam, 2016)

We did not use these values for the second generation LCA. A separate set of electrical LCA calculations were done using new Eco-Block data that was not available to the first generation Eco-Block team.

3.3. Construction

The emissions associated with the construction of pavement retrofiting and piping were assessed in the report. They considered the pavement placing method as well as different percentages of recycled material (5%, 15%, and 50%) used in the pavement. For the water and electrical infrastructure, they considered the pipe/conduit diameter and material.

Piping for Water and Electricity

The piping assessment considered the pipe diameter and material for the water, wastewater and electrical infrastructure. Table 1 shows the scenarios of the water and electrical systems that were studied along with the total GWP associated with each scenario.

Table 1 - CO2 Emissions from pipe material selection (kg CO2eq) (Eid, Porter, Shih, & Techangam, 2016)

Diameter Case	Water system material + Electrical system material	Total GWP (kg CO_2 eq.)
Diameter I: Water ϕ = 0.5' Wastewater ϕ = 1.5' Electrical ϕ = 0.5'	DICL + Steel	156,300
	DICL + PVC	142,742
	PVC+ Steel	47,056
	PVC + PVC	33,497
Diameter II: Water ϕ = 1' Wastewater ϕ = 1.5' Electrical ϕ = 0.5'	DICL + Steel	189,616
	DICL + PVC	176,057
	PVC+ Steel	54,988
	PVC + PVC	41,430
Diameter III: Water ϕ = 1" Wastewater ϕ = 2" Electrical ϕ = 0.5"	DICL + Steel	238,560
	DICL + PVC	225,001
	PVC+ Steel	54,446
	PVC + PVC	40,888

It is evident from Table 1 that using PVC + PVC material for the water and electrical system material with a Diameter 1 case has the lowest total GWP as CO_2eq.

Pavement Retrofit

The emissions associated with pavement replacement are affected by several factors, including the pipe diameters, the configuration of the pipes, the type of asphalt to be put in place, and pavement placement method.

- Diameter of Pipes: The diameter of the pipes affects the bedding layers thickness and were considered in three cases (Diameter I, Diameter II, and Diameter III), previously discussed in the water retrofit.
- Configuration of Pipes: The pipes can be placed in two different configurations:
    - Case I: water, wastewater, and electrical pipes are placed next to one another in the same cross-section.
    - Case II: water and wastewater pipes are placed in the same cross-section whereas the electrical pipes are placed in a different section.

- Type of Asphalt: The condition of the existing asphalt layer is not known, so three different asphalt cross sections were considered: Type C, Type D, and Asphalt Concrete Sheet:
  - Type C: 4 inches of asphalt layer with the other pavement layers varying depending on pipe diameter and placement.
  - Type D: 3 inches asphalt layer with the other pavement layers varying depending on pipe diameter and placement.
  - Asphalt Concrete Street: 6 inches asphalt layer with the other pavement layers varying depending on pipe diameter and placement.
- Pavement Placement Method: Two placement methods were considered: cold in place and traditional placement method. The report details the methodology of each method, but the main difference is that the cold in place method uses recycled material while the traditional placement method does not. The cold in place pavement method was considered for three different pavement materials according to the percent recycled material used in the pavement, 5%, 15%, and 50% recycled material.

A sensitivity analysis was completed for emissions associated with pavement retrofit for a combination of pipe diameters, pipe configurations, asphalt types, and pavement placement methods. In total, 36 different cases were considered. The results of this analysis are shown in Figure 3 where the error bars represent 5% recycled material for the higher value of the emissions and 50% recycled material for the lower value of the emissions. The 15% recycled material represent the height of the bar itself.

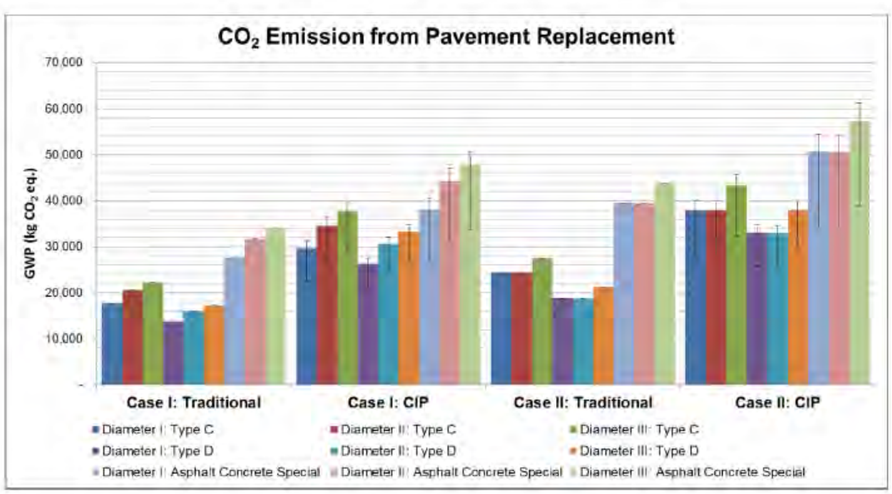


Figure 3 - Emission of with different pavement retrofit combinations (Eid, Porter, Shih, & Techangam, 2016)

The results of the assessment show that the CO_2 equivalent emissions for the traditional placement case are lower than the Cold in Place (CIP) method. Using recycled material decreases the emissions for each type of placement method. It showed that Case I pipe configuration produces less emissions from Case II pipe configuration. Moreover, the pipe diameters configuration Diameter I shows either lower emissions than other pipe combinations or the same emissions as combination as Diameter II combination. Finally, Type D asphalt showed the lowest emissions among other types of asphalts. As a combination, the Case I configuration of pipes with Diameter I pipes placed in the traditional method using Type D asphalt produced the lowest emissions between the 36 scenarios.

3.4. Construction Costs

Cost estimating was done for the pavement retrofit and the utility pipe replacement with an underground rainwater storage tank installation. The total cost was calculated for different combinations of pipe configuration, asphalt type, and pipe material. Figure 4, Figure 5, and Figure 6 show the total cost for each of the three diameter combinations with the error bars representing a 20% contingency on the computed cost. The results show that the cost range for each diameter case as listed below:

- Diameter I: \$460,340 - \$1,211,637
- Diameter II: \$497,760 - \$1,411,150
- Diameter III: \$511,484 - \$1,429,244

The report recommended the use of PVC pipes for the water and electrical systems. Moreover, that constructing the electrical pipe with the water and wastewater pipes is recommended.

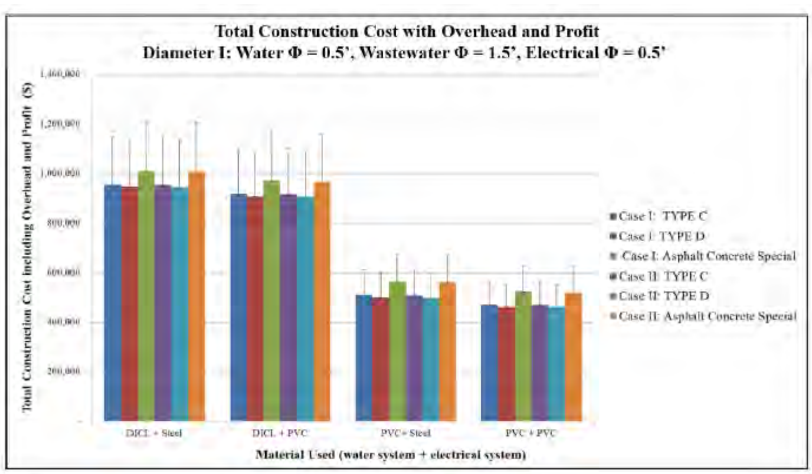


Figure 4 - Construction Cost of Water and Electrical System retrofits for Diameter I (Eid, Porter, Shih, & Techangam, 2016)

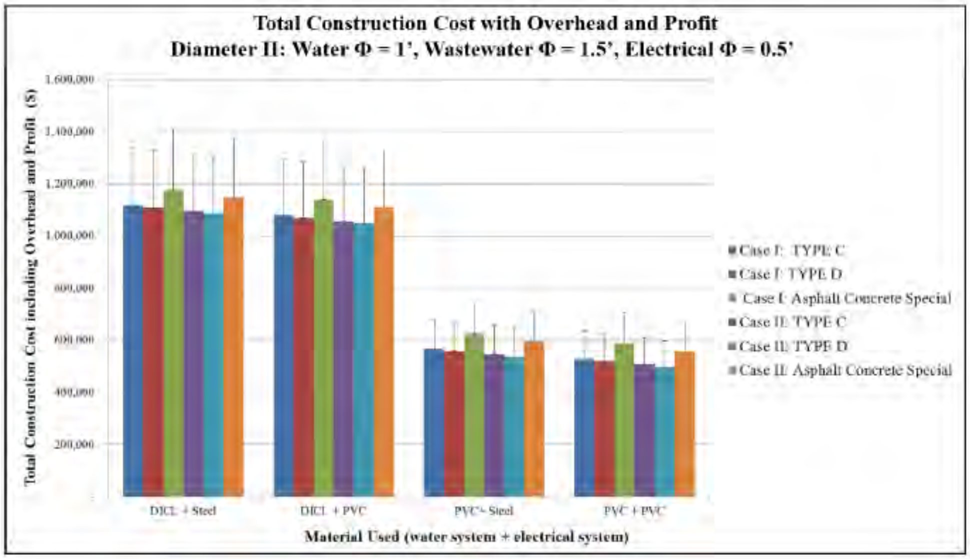


Figure 5 - Total Construction Cost of Water system and Electrical System retrofit for Diameter II (Eid, Porter, Shih, & Techangam, 2016)

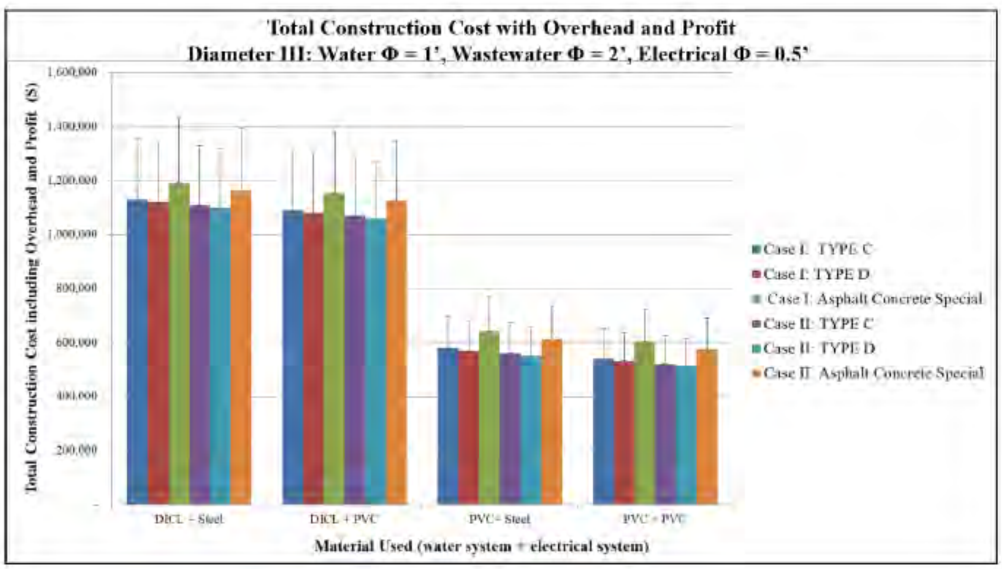


Figure 6 - Total Construction Cost of Water system and Electrical System retrofit for Diameter III (Eid, Porter, Shih, & Techangam, 2016)

4. Modelling Approach and Data – A General Overview

For the purpose of this report, we have decided to use a planning horizon of 15 years-- beyond 15 years the uncertainty is too high to provide reliable estimates.

The Eco-Block is in Oakland, California, bounded by Powell, Marshall, Fremont, and 59th Street. Location is a huge factor in the overall environmental performance of the Eco-Block as it will decide the electricity fuel mix, rain volumes, and available solar insolation. PG&E is one of the cleaner utilities in the U.S., thus an Eco-Block in an area with dirtier electricity can be expected to have a magnified impact relative to our Oakland case. For calculations based on electricity from the grid, we use PG&E's power mix for California. Electricity from the solar panels are assumed to be clean, and won't have any operational emissions.

From the Eco-Block project files, several of the components had proposed product models with specifications. For these we tried to find LCAs or EPDs for the same or similar products, but some components are less documented than others. Individual assumptions and methods are mentioned for each component in its respective subsection.

Three main functional units are used throughout the report, all centered around the impact category of GWP: kg CO_2eq/kWh, kg CO_2eq and kg CO_2eq/therm. All emissions are calculated as total mass of CO_2eq for each product or system over the planning horizon of 15 years, and then normalized.

5. Electricity

The goal of this portion of the LCA is to assess the life-cycle emissions associated with electrical infrastructure changes that will enable the Eco-Block to function as a self-sufficient, microgrid community powered almost completely by renewable energy. The Eco-Block's electricity system will be composed of 4 main components: the photovoltaic panels, flywheel energy storage, transformers, and inverters. We are also considering vertical axis wind turbines and lithium-ion battery storage as alternatives or potential complementary additions to the current design. In our assessment we assume that the PV electricity is sent through the flywheel 25% of the time before being distributed to homes or the transportation system.

Given the roofing configurations on the block, known solar panel efficiencies, Oakland average climate data, and the anticipated electricity loads, we believe that the block will generate up to 20% more energy than it currently consumes. We consider the scenario where this extra generation is used to power a shared EV (electric vehicle) fleet for the block.

All of the PV generated electricity that is consumed by the Eco-Block houses or returned to the grid will contribute to an aggregated avoided operational emissions value by comparing the emissions of the PV system to that of PG&E's fuel mix. The avoided operational emissions of the EVs will be separately calculated using the base case of a gasoline powered 2017 Toyota Camry— this is explored further in the transportation section.

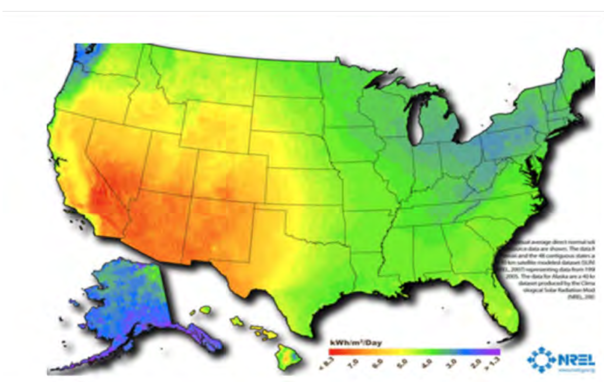
We anticipate a total of 12 GWh generated by the PV system over a planning horizon of 15 years. This generated electricity is used to power the Eco-Block homes and fuel the EV car sharing fleet which we discuss in section 7 – the remaining electricity is pushed back onto the grid. The embodied emissions of the flywheel, inverter, and solar panels are 970,000 kg CO2eq**.** The lifecycle GWP of the electricity system for the scenario without an EV car sharing system comes out to –0.18 kg CO2eq/kWh. The analyses which lead to these results in addition to emission factors for each component are discussed in the following sections.

5.1. Solar Photovoltaic (PV) Array

5.1.1. Introduction

PV generated electricity is currently the main option for onsite power generation which we anticipate will be highly effective given California's consistently high solar insolation, the moderately cool temperature in Oakland, and the ample open roof space available on the Eco-Block for PV installations.

California's solar insolation regularly ranks among the highest in the country, meaning that solar panels are capable of generating more electricity in California than in much of the U.S. Figure 7 shows the disparity between California and the rest of the countries' solar insolation. Oakland's insolation ranges at about 5.4 kWh/m^2-day whereas the rest of the country operates at around 4 kWh/m^2-day (NREL, 2017). In addition to its consistently high insolation, Oakland California's cool-warm climate is highly conducive to achieving high photovoltaic cell efficiency as a result of a temperature that hovers around 15˚C (U.S. Climate Data, 2017). Figure 8 highlights the inverse relationship between cell temperature and open-circuit voltage; typically, colder days allow the PV arrays to perform better than hotter days. Also, the majority of the houses on the Eco-Block have north/south slanted gable roofs which is generally to optimal for maximum aggregate year-round generation (Traber, 2017).



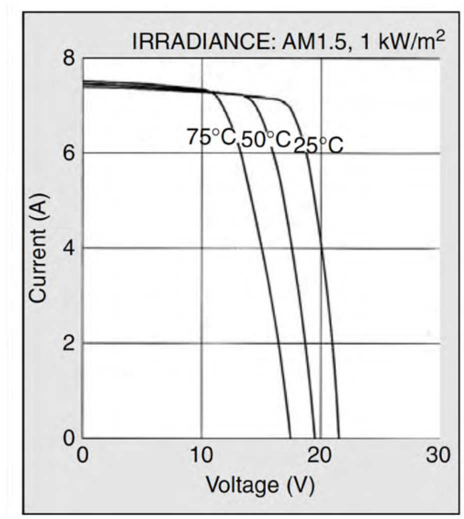


Figure 7 – U.S. Solar Insolation (NREL, 2008)

Figure 8 – Temperature impact on PV voltage (Masters, 2004)

We estimate a total PV electricity generation of 12 GWh over the planning horizon of 15 years. The total embodied emissions of the solar panels came out to **713,000 kg CO2eq** with an embodied emission factor of **0.059 kg CO2eq/kWh.**

5.1.2. Modelling Approach and Data

The Eco-Block provides a communal approach to energy generation that allows houses that are suboptimal PV candidates, or perhaps houses with underperform panels to still power their lives with clean energy from their neighbors' excess generation. This situation is ideal for consumers who want guaranteed clean power. It is also an ideal preparation for an inevitable future where net metering is no longer in existence. Communities that use this sort of sharing of behind the meter generation will be able to maximize future financial and environmental rewards and security regardless of if they have energy storage or not.

Due to their high efficiency panels, SunPower is the most likely supplier of Eco-Block's solar panels. As such, we have performed an LCA on the panels, taking in to account their embodied emissions and their operational emission displacement.

We assume that the Solar Panels have an efficiency of 20.1% and were manufactured at SunPower's facility in the Philippines. SunPower claims a 40-year lifetime for their panels but for the sake of our analysis we assume a 15 year planning horizon (Fthenakis, 2012). We used an average daily solar insolation of 5.4 kWh/m^2-day in Oakland for our PV generation estimates. We assumed 1309 panels at 77" x 39" each (Brown, 2017) and that the panels were stationary (non-tilt) and therefore multiplied them by a factor of 80% to account for non-optimal directionality throughout the day.

5.1.3. Results and Findings

<u>kWh Generated by the PV system over 15 years:</u>

Insolation in Oakland $= 5{,}400\ Wh/m^2day \times 365\ days/year \div 1{,}000 = 1{,}971\ Wh/m^2year$

Generation from our Panels $= 1{,}971\ Wh/m^2year\ \times 0.201 \times 15\ years = 5{,}942\ Wh/m^2$

Ideal generation $= 5{,}942\ Wh/m^2\ \times \frac{(77'' \times 39'')/panel}{1550in^2/m^2} \times 1{,}309\ panels = \mathbf{15 \times 10^6\ kWh}$

Actual Generation = $15 \times 10^6 \times 80\% = 12\ GWh$ *this value is used in later calculations

Embodied Emissions translated to kWh:

281 kg CO2eq/m^2 (Fthenakis, 2012)

GWP per kWh over 15 years = $\frac{281\ kg\ CO_2/m^2}{5{,}942\ kWh/m^2} = 0.04729\ kg\ CO_2/kWh$

Total Embodied GWP over 15 years $= 0.04729\ kg\ CO_2/kWh \times 15.07 \times 10^6\ kWh = 713{,}000\ kg\ CO_2$

5.1.4. Sensitivity Analysis

The main points of variation that we take into account in our sensitivity analysis are the Oakland specific solar insolation, the total area of PV coverage, the efficiency of the PV modules, and the embodied emissions.

We begin by varying our insolation values by 50% in the positive and negative direction giving us a range from 2,700 Wh/m^2-day to 8,100 Wh/m^2-day. Solar insolation is an uncontrollable and highly variable factor in the performance of the overall system. Thus, to truly understand the potential GHG impact of our system we must consider a range of solar insolation values. We also vary the efficiency of our solar panels by 50% in the negative direction down to 10.05% and allow them a slightly higher maximum efficiency of 22.8% – the highest efficiency currently offered by SunPower (SunPower, 2017). This range of efficiency helps us take into account environment-specific inhibiting factors as well as the potential degradation/improvement of solar panel efficiency. The total kWh generated is currently based on an assumption that only 75% of the roof space will be covered in solar panels. For the sake of our sensitivity analysis we will vary this from 25% - 100%. The lower bound accounts for the uncertain level of cooperation that is expected from the Eco-Block residents; this lower bound may also be used to account for suboptimal panel placement (i.e. north facing roofs). The upper bound represents the potential for more modular solar panels in the near future to cover virtually the entire roof e.g. solar shingles.

Given such variability we see that the total kWh generated by our system was estimated to be 15.1 GWh with an error range from 1.1 GWh and 28 GWh (See Appendix A). The operational emissions associated with this electricity generation is calculated at the end of the electricity systems analysis to account for the losses associated with the inverters, flywheel, and transformers.

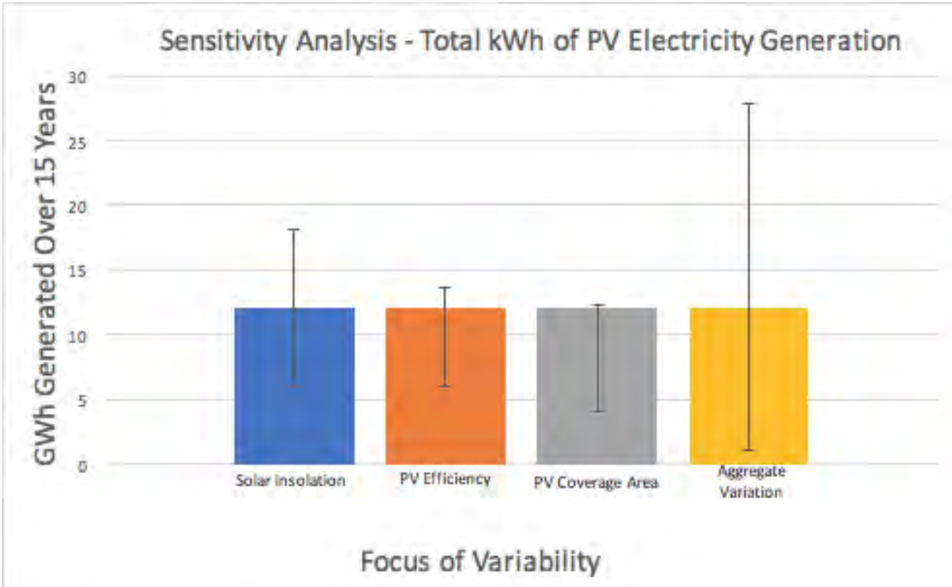


Figure 9 - Result of sensitivity analysis of PV Electricity Generation

In Figure 9 we see the impact of varying a specific variable on the total electricity generation of the PV system.

Our estimate for total embodied emissions was 713 tons CO2eq over the 15-year planning horizon. For the sensitivity analysis, we vary our embodied emissions by 50% in the positive and negative directions to get a range from 356 tons CO2eq to 1,069 tons CO2eq.

5.1.5. Uncertainty Assessment and Management

The uncertainty associated with the GWP analysis of our PV system lies primarily in the PV roof coverage area and the solar insolation calculations. The roof coverage area is a function of community buy-in from the residents of the Eco-Block as well as the speed of technological development and cost decline of solar roofing providers like Tesla and Powerhouse. Sunlight is a natural resource; therefore, solar insolation predictions are inherently uncertain. Our analysis uses a single average solar insolation value with a 50% error range. In Table 2 we have visualized the data quality of the PV system's LCA via a pedigree matrix.

Table 2 - Data Quality Assessment Matrix for the PV Array

Item	Temporal Correlation	Geographical Correlation	Independence of Data Supplier	Acquisition Method	Further Technological Correlation
Solar Insolation	1	1	1	3	N/A
Solar Panel Efficiency	1	1	N/A	1	1
PV Coverage Roof Coverage	1	1	N/A	4	N/A
Embodied Emissions	3	2	1	3	1

*Maximum Quality = 1

*Minimum Quality = 5

5.2. Flywheel

5.2.1. Introduction

Energy storage with the use of flywheels is currently the main option chosen for the Eco-Block project. The flywheel will use excess electric energy created by the photovoltaic systems as input, and stored in the form of kinetic energy. In this case, the kinetic energy is in the form of a spinning rotor in a near frictionless enclosure. When needed, the kinetic energy is converted to electric energy via a motor-generator, which is connected to the grid (Energy Storage Association (2017). The flywheels will be placed in parallel to achieve a higher power output.

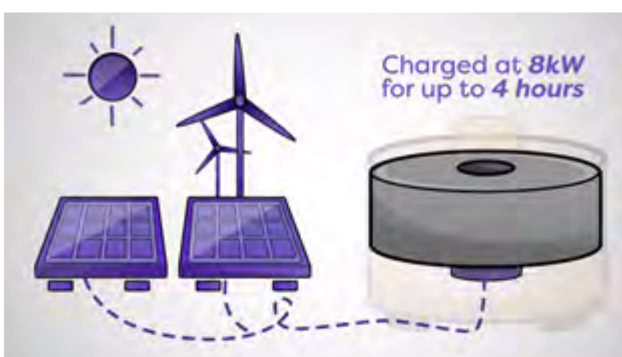


Figure 10 - Illustration of how flywheels work (Amber Kinetics, 2016)

5.2.2. Modelling Approach and Data

The projected capacity of the energy storage is a total of 200kW over 4 hours. Currently, the product listed in the Eco-Block project, a 40kW Flywheel from Amber Kinetics, is still under development. In other words, there is still very little information on this until it becomes commercially available. Instead, we will model the system with twenty-five 8 kW flywheels from the same manufacturer with specs as shown in Figure 11 and Figure 12, to reach the desired storage capacity. These flywheels are reported to have a lifetime of 30 years, whereas manufacturer warranty is 10 years. We will assume a lifetime of 15 years in this assessment. As the flywheels' transportation and maintenance account for a very small portion of the total environmental impact, both will be ignored for the purpose of this study. Additionally, the end-of-life emissions are not considered. The flywheel efficiency is claimed to be greater than 88%, as shown in Figure 11, but we will assume it is exactly 88% for the purpose of this assessment.

Amber Kinetics' utility-scale energy storage systems are composed of multiple interlinked flywheel units	MODEL 32
Power	8 kW
Energy	32 kWh
Duration	4.0 hours
Cooling	Passive
Round-trip Efficiency (DC)	>88%
Daily Cycling Limitation	None
Design Life	30 years
Input / Output Voltage	800 Vdc
Full Power Response Time	< 1 sec
Self Discharge (Avg.)	65 W

Figure 11 - Operational specs of 8kW flywheel (Amber Kinetics, 2017)

Operating Temperature Range	-40 to 50C
Electrical Enclosure:	NEMA3
Seismic Rating:	Zone 4 USUBC
Humidity:	100% Cond.
Dimensions:	52"H x 54"W
Weight:	~10,000 lbs
Communications: Set up to receive operator signal, SCADA (compliant with NERC standards)	

Figure 12 - Physical specs of 8kW flywheel (Amber Kinetics, 2017)

5.2.3. Results and Findings

<u>Manufacturing:</u>

No lifecycle emissions information was available for the 8 kW flywheel from Amber Kinetics selected for modeling in the Eco-Block project. Instead we use data from Schneider Electric which provides numbers on a similar flywheel. Table 3 shows the materials used in the flywheel, as well as the amount. With this information, we can find the weighted average of embodied CO_2eq and calculate the total amount for the units we have.

Table 3 - Raw materials carbon emissions of flywheels (Torell, 2015)

Element	Content [%]	Assumed [%]	Embodied emissions [kg CO2eq/kg]
Iron, Fe	95.195 – 96.33	95.5	1.91
Nickel, Ni	1.65 – 2.00	1.83	12.4
Chromium, Cr	0.70 – 0.90	0.80	5.4
Manganese, Mn	0.60 – 0.80	0.70	3.5
Carbon, C	0.37 – 0.43	0.00	0
Molybdenum, Mo	0.20 – 0.30	0.25	32.2
Silicon, Si	0.15 – 0.30	0.20	13.5
Sulfur, S	0.04	0.00	0.0
Phosphorus,P	0.035	0.00	0.0
Weighted average			2.226

We use the weighted average to determine embodied CO_2 per unit.

$$Embodied\ emissions = 2.226\ kg\ CO_2eq/kg\ \ \times 4{,}536\ \ kg/unit =$$
$$\mathbf{10{,}097\ kg\ \ CO_2eq/unit}$$

In order to achieve the projects capacity requirement of 200 kW, we need 25 flywheels.

$$Total\ Embodied\ emissions = 10{,}097\ kg\ \ CO_2eq/unit\ \ \times 25\ units =$$
$$\mathbf{252{,}425\ kg\ CO_2eq}$$

Operation:

For the purpose of this assignment, some assumptions have been made regarding the operation stage of the flywheels. As we have no good data on the utilization of the energy storage, we make an assumption that 25% of the power passing by the flywheels are stored, while 75% skip the flywheels entirely. From Figure 11 we have that the round-trip efficiency of the flywheel is 88%. This will affect the 25% of power mentioned before, and occurs when the flywheels are charging back up to their capacity of 800 kWh of energy. The solar power generation is assumed to produce more than enough for this, even after taking both EV-chargers and the general power consumption of the block into consideration. For the 75% of power bypassing the flywheels, it is assumed there is no loss. These values are used to calculate the operational emissions of the system as a whole in Section 5.5.

As all the needed power comes from the PVs, the isolated emission factor related to use of the product is effectively zero. Therefore, the total emissions from the flywheels are solely from the manufacturing process, which results in a total GWP of **252,425 kg CO_2eq.**

The total power passing through the flywheels over a period of 15 years, is the sum of household usage, and EV usage. From Section 5.5 we use a value of 3 GWh for the household consumption, and from Section 7.4 we have a total of 1.6 GWh for the EVs. As we assume 25% of this power will pass through the flywheels. Per kWh basis we then get

$$\frac{252{,}425\ kg\ CO_{2eq}}{0.25 \times (1.6\ GWh + 3\ GWh)} = 0.2195\ kg\ CO_{2eq}/kWh$$

5.2.4. Sensitivity Analysis

In the calculations, we have used a 5 times smaller product than proposed in the project, due to unavailability of the product in question. The 40kW flywheel may have substantial differences to the 8kW ones because of its sheer size. There lies uncertainty in the material use in the product, which would have a significant impact on the embodied CO_2eq emissions. For the embodied GWP we made assumptions on the percentage of each material. The lower bound of this calculation would be the scenario with the most amount of steel, as that has the lowest embodied kg CO_2eq/kg.

Table 4 **-** *Upper and lower bounds of flywheel composition (Torell, 2015)*

Element	**Lower Bound**	**Upper Bound**	**Embodied**	**Upper**	**Lower**
Iron, Fe	96.33	95.195	1.91	1.840	1.818
Nickel, Ni	1.65	2.00	12.40	0.205	0.248
Chromium, Cr	0.70	0.90	5.40	0.038	0.049
Manganese, Mn	0.60	0.80	3.50	0.021	0.028
Carbon, C	0.37	0.43	0.00	0.000	0.000
Molybdenum, Mo	0.20	0.30	32.20	0.064	0.097
Silicon, Si	0.15	0.30	13.50	0.020	0.041
Sulphur, S	0.00	0.04	0.00	0.000	0.000
Phosphorus, P	0.00	0.035	0.00	0.000	0.000
Weighted Average				**2.188**	**2.280**

Lower bounds:

$$Embodied\ emissions = 2.188\ kg\ CO_2eq/kg\ \times 4{,}536\ kg/unit = 9{,}925\ kg\ CO_2eq/unit$$

$$Total\ Embodied\ emissions = 9{,}9255\ kg\ CO_2eq/unit\ \times 25\ units = \mathbf{248{,}119\ kg\ CO_2eq}$$

Upper bounds:

$$Embodied\ emissions = 2.280\ kg\ \ CO_2eq/kg\ \ \times 4{,}536\ \ kg/unit =$$
$$10{,}342\ kg\ \ CO_2eq/unit$$

$$Total\ Embodied\ emissions = 10{,}342\ kg\ \ CO_2eq/unit\ \ \times 25\ units =$$
$$\mathbf{258{,}552\ kg\ CO_2eq}$$

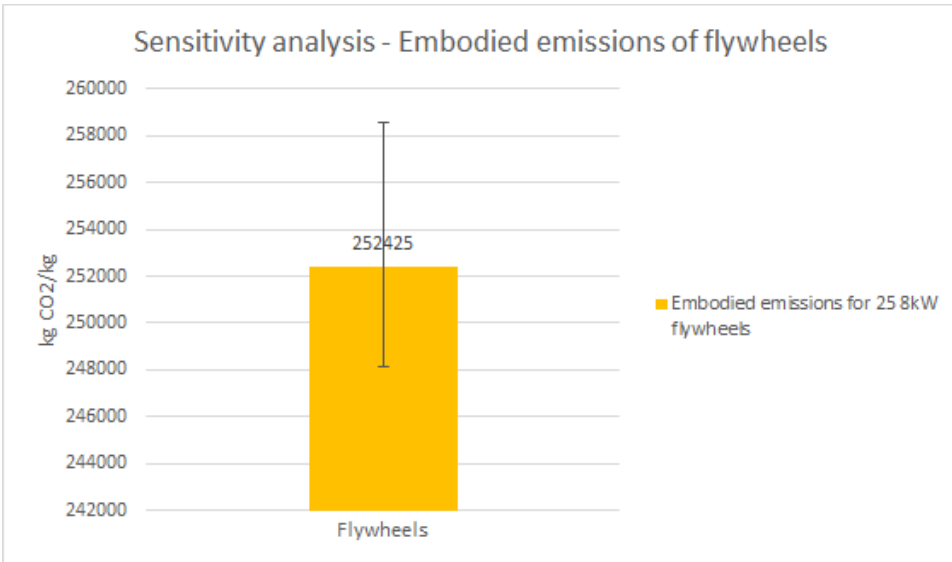


Figure 13 - Sensitivity analysis on embodied emissions of flywheels

As for the use phase of this product there are some variabilities that may affect the needed power input over its lifetime. The efficiency of the flywheel is stated to be over 88%, which means we calculated for the worst-case scenario assuming that number is correct. In addition to that, the assumption made for no losses when power is not being stored is not likely, but it is reasonable to assume that value is very low. Compared to the loss of the power input needed to charge the flywheels, any variations would have limited impact on the total power consumption.

The calculations are done assuming all power is coming from the PV system, and therefore is clean. Depending on the way the system is designed, the flywheels may possibly be charged by power from the grid when the PV-system is offline. Emissions from this scenario would increase the flywheels total GWP during its use phase.

5.2.5. Uncertainty Assessment and Management

As flywheels are a well-known and used technology, the data presented is very reliable. The data on the materials a flywheel consists of, comes from Schneider Electric which is not our provider of flywheels. Other than that, most of the data concerning the specifications of our product comes directly from the manufacturer Amber Kinetics. The biggest uncertainty lies in the fact that our assessment is based on a smaller product, even though it is from the same supplier. Data such as flywheel weight, efficiency and capacity are all collected from the manufacturer of the product we're modeling for, but these parameters don't vary depending on location. A data quality assessment has been done for the parameters involved in the calculations, and is presented in the pedigree matrix in Table 5. The table follows the criteria presented in Appendix D.

Table 5 - Pedigree matrix for data quality assessment for flywheels

Data quality	Acquisition method	Independence of data supplier	Data age	Geographical correlation	Technological correlation
Materials	3	2	1	3	2
Flywheel weight	2	2	1	N/A	4
Flywheel efficiency	2	2	1	N/A	4
Flywheel capacity	2	2	1	N/A	4
Embodied emissions	3	2	1	2	4

*Maximum Quality = 1

*Minimum Quality = 5

5.3. Solar Inverter

5.3.1. Introduction

Another necessary component in the Eco-Block electricity system, is the solar inverter. Its main purpose is to convert the DC power output from the solar panels, to AC that can be used by appliances further downstream.

5.3.2. Modelling Approach and Data

There is very limited information on inverters of the same capacity as the one selected for the Eco-Block project, but also on solar inverters in general. Therefore, some assumptions were made to accommodate this. We used the properties of a notably smaller inverter, with a total weight of 18.5 kg, and made the following assumptions regarding the embodied CO_2eq.

- The printed circuit board is mostly fiberglass, and an emission factor for fiberglass has therefore been used.
- The wire-wound transformers are assumed to be mostly steel, and therefore an emission factor for steel has been used. (City of Winnipeg, 2012)

The product specified in the project, the LV5+ 1500V Solar Inverter from General Electric, has a weight of less than 2000 kg (General Electric Company, 2016). For the purpose of these calculations we will conservatively assume the total weight is exactly 2000 kg. We assume all power from the PV-system goes through this inverter.

5.3.3. Results and Findings

<u>Manufacturing:</u>

Table 6 - Overview of materials in a small inverter and weighted average of kg CO2eq (Fthenaksis & Kim, 2010)

Material	**Embodied emissions [kg CO2eq/kg]**	**Needed for inverter (2500W) [g]**	**Percentage (%)**	**Weighted average [kg CO2eq/kg]**
Steel	1.77	9800	53.0	0.94
Aluminum	8.14	1400	7.6	0.62
Printed circuit board (fiberglass)	2.6	1800	9.7	0.25
Transformers, wire-wound (mostly steel)	1.77	5500	29.7	0.53
Total		18500	100	2.33

$$Embodied\ emissions = 2.33\ kg\ CO_2eq\ /kg\ \times 2000\ kg/unit = 4{,}660\ kg/unit$$

The inverter specified in the project is assumed to have enough capacity for the entire electrical system, and therefore only one unit is needed.

<u>Operation:</u>

The efficiency of the selected inverter is stated to be 99%. (General Electric Company, 2016). This value is incorporated to calculate the avoided operational emissions from the electricity system as a whole in Section 5.5. We assume that the inverter does not have any operational emissions

Total embodied inverter emissions = **4660 kg CO_2eq**

The inverter is responsible for inverting all the power except the power going to the EVs. This equates to a total of

$$12\ GWh - 1.6\ GWh = 10.4\ GWh$$

The emissions per kWh is then

$$\frac{4660\ kg\ CO_{2eq}}{10.4\ GWh} = 0.00045\ kg\ CO_{2eq}/kWh$$

5.3.4. Sensitivity Analysis

The available data on this component was severely limited. The numbers used were for a significantly smaller inverter and scaled up afterwards. There is a big chance the product specified in this project has a different material composition than the one calculated for. Even within the product calculated for, some rather big assumptions were made concerning the composition of materials, and their following emission factor. It is more likely that an inverter on the size we are calculating for have more heavy materials for enclosing the product, and much less printed circuit boards compared to the total material use. However, the impact of the inverter is not of such a scale that it will affect the final calculations for the entire systems GWP in any major way. Because of the great uncertainty surrounding these data, the upper and lower bounds for the calculations has been set to 50% of the calculated emissions.

Lower bounds: 2330 kg CO_2eq/unit

Upper bounds: 6990 kg CO_2eq/unit

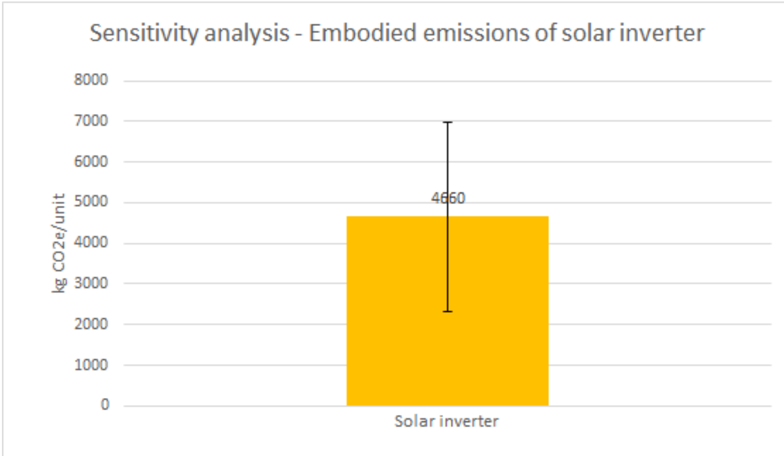


Figure 14 - Sensitivity analysis on embodied emissions of solar inverter

5.3.5. Uncertainty Assessment and Management

The quality of the data presented in the assessment of the solar inverter is highly uncertain. Most of the calculations are based on data from a product which is not very representable for the system we are modeling. This makes the following quality assessment important as it highlights the uncertainty concerning several different criteria. In addition, some of the criteria could not be rated due to lack of information from the source. Table 7 shows a pedigree matrix following the criteria presented in Appendix D.

Table 7 - Data quality assessment matrix for solar inverter

Data quality	**Acquisition method**	**Independence of data supplier**	**Data age**	**Geographical correlation**	**Technological correlation**
Materials in inverter	3	3	3	4	4
Inverter weight	3	2	1	N/A	2
Number of units needed	3	3	1	N/A	3
Emission factors	5	4	3	4	5
Embodied emissions	4	1	2	3	4

*Maximum Quality = 1

*Minimum Quality = 5

5.4. Transformer for AC Load Centers

5.4.1. Introduction

Another key component of the electricity distribution system is the step-down transformer. The transformer's primary function is to decrease incoming voltage before connecting to the household load centers, and there are three relatively simple components that allow this to happen. These include the following: aluminum coils tightly wound to create a magnetic flux that is transferred into the secondary winding, a steel coil allowing the magnetic induction to occur, and the steel tank which encloses and protects the essential parts. A basic schematic is shown in Figure 15.

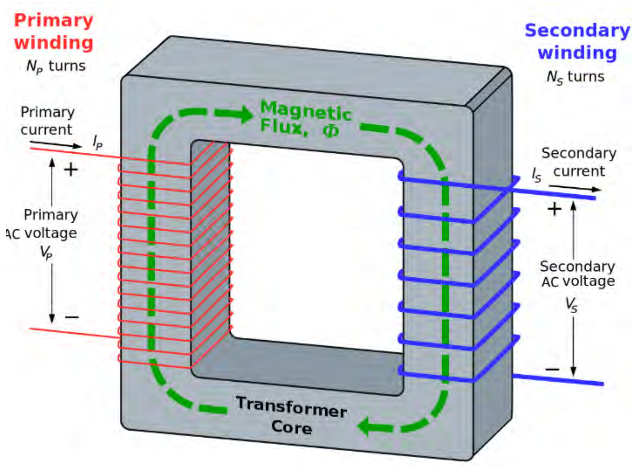


Figure 15 - Basic schematic of key transformer components (Electrical Technology, 2017)

After completing our analysis, we received line diagrams outlining the four different scenarios for the Eco-Block's electricity components and connections. In these diagrams it was assumed that the existing substation transformers would be used to step-down the electricity coming from the grid, and no new transformers would be required for the electricity system. For this reason, we have ignored the transformer's environmental impacts from our final calculations.

5.4.2. Modelling Approach and Data

No lifecycle emissions information was available for the 300 kVA Pad-Mounted Transformer from Schneider Electric selected for use in the Eco-Block project, so a similar 315 kVA Distribution Transformer from ABB Group was modeled instead. ABB's Environmental Product Declaration was completed using the EcoLab software, and considers the production, use-phase, and end-of-life processing associated with the transformer. For the purpose of this study, we will include their production analysis as the primary components do not vary from one transformer to the next, but we will derive our own estimate of use-phase emissions based on the Eco-Block's energy mix and ignore the end-of-life impacts.

5.4.3. Results and Findings

Production:

Table 8 - Transformer material content is replicated from ABB's bill of materials data

Material	**Weight**
Core steel	533
Transformer oil	340
Steel (tank)	324
Aluminum wire	114
Aluminum sheet	86.3
Insulation material	59.9
Porcelain	11
Other	9

Using the EcoLab software, the raw materials and assembly phases were determined to have a total of 19.12 kg atmospheric emissions, 98.23% of which were CO_2eq. This equates to 18.8 kg CO_2eq, which can be distributed over the 15-year planning horizon for an annualized emissions rate of 1.25 kg CO_2eq/year.

In-use Operation:

Transformers are an extremely low-maintenance product, and thus the majority of the use-phase emissions come from the additional generation required to overcome losses. It follows then that these values would be highly dependent on the electricity generation source, which is why we have decided to provide our own emissions estimate based on the Eco-Block's electricity mix. Based on the assumption stated previously that all of the electricity provided to the Eco-Block grid will be come from the block's solar PV and wind capacity, the operational emissions of additional generation are effectively zero.

5.5. Electricity System Overview

After calculating all the emissions related to the different components, we can find the electricity system's total environmental impact. In order to do these calculations, the following assumptions has been made:

- Electricity fuel mix in PG&E territory remains constant for the full lifetime of the project.
- All excess PV energy generation will either be kept in energy storage, or pushed back into the grid.
- We generate enough electricity to meet home energy needs as well as EV charging needs.
- The energy storage provides the system with power for 25% of the time. The last 75% of the time, the power is supplied directly from the solar panels.
- When not passing through energy storage, we assume the efficiency is 100%.

As presented in Appendix A, the total household consumption over 15 years is estimated to be 2,977,140.75 kWh. For the purpose of this assessment, we assume the household consumption is 3 GWh. In order to give an evaluation on the proposed system, we need to calculate the total saved emissions from using solar panels and flywheels compared to only using PG&E's fuel mix. From Appendix B we have an emission factor of 0.277 kg CO_2eq/kWh by pulling power from the grid (including line losses).

Current state estimated emissions over 15 years:

$$3\ GWh \times 0.277\ kg\ CO_{2eq}/kWh = 831{,}000\ kg\ CO_{2eq}$$

The Eco-Block project will use solar power as its main source of power, as well as flywheels for storage. These are the two major components contributing to the systems total embodied emissions, but we are also including the inverter in the calculation.
Estimated embodied emissions in the Eco-Block:

- Solar Panels: 713,000 kg CO_2eq
- Flywheels: 252,425 kg CO_2eq
- Inverter: 4,660 kg CO_2eq
- **Total: 970,085 kg CO_2eq**

Our overall anticipated electricity generation is 12 GWh over 15 years. That 12 GWh of electricity ends up in Eco-Block homes, in the EVs, or is fed back to the grid. In this section we calculate the GWP of the electricity system in the scenario where there is no EV car sharing system. Below are the calculations

PG&E electricity emission factor (appendix B) = 0.26 kg CO_2eq/kWh
PG&E electricity line losses: 6.58%
Transformer efficiency (only for grid electricity): 99% (losses = 0.01)
Inverter efficiency: 99% (losses = 0.01)
Effective flywheel efficiency:
100% efficiency* 75% of time + 88% efficiency*25% of time = 97% (losses = 3%).

Avoided operational emissions of home electricity use over 15 years:

$$3{,}000{,}000\ kWh\ \times 0.26\ kg \frac{CO_{2eq}}{kWh} \times 1.0658 \times 1.01 = 840{,}000\ kg\ CO_2eq$$

Avoided operational emissions of electricity fed back to the grid over 15 years:
Electricity fed back to grid (assuming inverter is needed for all electricity whether it goes to the houses or it is fed back to the grid)

$$[12\ GWh - (3GWh \times 1.01 \times 1.03)] \times 0.99 = 9\ GWh$$

Emissions associated with grid-returned electricity:

$$9{,}000{,}000\ kWh \times 0.26\ kg\ CO_{2eq}/kWh = 2{,}300\ tons\ CO_2eq$$

Lifecycle GWP of Electrical system over 15 years for the scenario without an EV car sharing system:

= embodied – avoided operational

= (970 - 840 – 2,300) tons CO_2eq

= **-2,200 tons CO_2eq** *emissions savings over the 15 year planning horizon

GWP = -2,200 tons CO_2eq/12GWh

GWP = -0.18 kg CO_2eq/kWh

*this calculation indicates kg CO_2eq saved per kWh of PV electricity generation for the scenario without the EV car sharing system

6. Retrofits

The main goal of this portion of the report is to evaluate the environmental impact of retrofitting each of the units within the Eco-Block. Designed to minimize energy consumption and thus environmental footprint, the retrofits will consider changes to two interior building characteristics: (1) wall and window insulation and (2) high-efficiency LED lighting. Operational and embodied emissions will be quantified for each component.

Energy savings associated with the insulation improvements were estimated by comparing the thermal resistance (R) of the existing conditions to the expected value with blow-in cellulose insulation and double-paned, low-emissivity (Low-E) windows. This improved thermal resistance will result in reduced heating load, which equates to reduced natural gas consumption and a smaller environmental footprint.

Similarly, replacing the indoor light sources as well as the streetlights throughout the Eco-Block with high-efficiency LED lamps will decrease energy consumption. Given the change in electricity demand and the emissions factors of the typical PG&E fuel mix we were able to quantify the avoided operational emissions associated with the lighting upgrades.

We estimate that the improved wall and window insulation will result in an avoided operational emissions total of over **180 kg CO_2eq** over the fifteen-year planning horizon. The manufacturing and transportation of the blow-in cellulose and Low-E windows have a net positive, total embodied emissions of **9,600 kg CO_2eq**. Additionally, upgrading the indoor and outdoor lighting to high-efficiency LED lamps is estimated to have an avoided operational emissions total of **94,500 kg CO_2eq** over the fifteen-year planning horizon. In terms of embodied emissions for the lighting retrofit, the base case with incandescent lamps indoor and high-pressure sodium lights outdoor accounted for **8,900 kg CO_2eq** while the LED replacements only produced **2,700 kg CO_2eq**.

6.1. Wall Insulation and Window Replacement

6.1.1. Introduction

To improve the thermal insulation and reduce energy demand, we are assessing the impact of adding blow-in cellulose as a form of insulation to all the buildings on the Eco-Block. Blow-in cellulose is a form of thermal insulant made of cellulose fibers from recycled newspaper, Boric acid, and mineral salts for their flame retardant qualities. Additionally, since windows are typically thermal bridges where the most heat is lost to the exterior, we are considering replacing the old windows with double paned, low-emissivity (Low-E) windows.

6.1.2. Modelling Approach and Data

We considered the life-cycle emissions associated with the treatment, transportation, and avoided use of primary raw materials (wood) and paper processing. The collection and sorting of the wastepaper is attributed to the previous system. For the sake of our analysis, we assume that the blow in cellulose used in the Eco-Block will closely resemble ISOCELL blow in cellulose.

The combined effect of retrofitting insulation and windows is here modelled by steady state horizontal heat flux through a wall, using the equation:

$$q = A \times \frac{T_i - T_e}{R}$$

where q represents the heat flux, A represents the weighted area of walls and windows, T_i represents the interior temperature, T_e represents exterior temperature, and R represents the thermal resistance of the walls and widows, weighted based on window-to-wall ratio. Using this equation twice, for the current state and after the retrofitting, assuming A, T_i and T_e remain constant, we can calculate the percentage change in heat flux (power) to be

$$Percentage\ change = \left(1 - \frac{R_{before}}{R_{after}}\right) \times 100\%$$

Using this model requires some assumptions, mostly that all units are of similar build and use. Further assumptions are that all houses use natural gas for space heating, this is true for most of them (Bourassa, 2017). Also, all houses have the same basic structural system and finish of the walls, with interior wooden paneling, 4” x 2” nominal studs as structural framing, air cavities in between studs and exterior plywood sheathing and wood shingles façade. There is no insulation before retrofitting. Appendix C shows the layers in tabulated form and the calculations for R-values to determine the effect on power consumption by adding insulation and installing better windows. It is expected that blown in cellulose is used (Bourassa, 2017) and that it completely fills the cavities in the wall. This insulation is chosen because it is made from recycled material and keeps the GWP of retrofits low.

A residential study shows that the average Californian household consumes 130.98 therms/year (KEMA, 2010). The emission factor for natural gas of 1.413 kg CO_2eq / household-year, is calculated as follows:

Table 9 - Calculation of emission factor for natural gas in carbon dioxide equivalents

Stationary Natural Gas Combustion		
Compound	**[g/mmBTU]**	**[kg CO_2eq/mmBtu]**
CO2	53.06	0.0531
CH4	1.00	0.0250
N2O	0.10	0.0298
Total		**0.10786**

Given 1 therm is equal to 0.1 mmBtu, we can convert this into the desired units as follows:

$$0.10786\ kg\ CO_2eq/mmBtu \times \frac{0.1\ mmBtu}{therm} \times 130.98\ therm/household\ year = 1.413\ kg\ CO_2eq/household\ year$$

6.1.3. Results and Findings

First, the avoided operational emissions associated with the reduced demand for natural gas heating were calculated. Using the relationship outlined in the previous section, the change in heat flux because of the insulation retrofit was found to be:

$$\left(1 - \frac{5.89}{8.79}\right) \times 100\% = -33\%$$

This would also represent a 33% decrease in natural gas consumption and thus an annual emissions reduction of 0.46 kg CO_2eq/household. If these savings are experienced in all twenty-six units across the block, over the course of fifteen years the total avoided operational emissions would be roughly **180 kg CO_2eq.**

Next, the embodied emissions associated with the production of both the walls and windows were considered. For the blow-in cellulose, we first needed to calculate the total insulation volume needed to cover the walls and attic of each of the twenty-six homes. To do this we referenced the Retrofit Estimate model from Bourassa (2017) which cites area dimensions of 66,698 ft^2 and 26,110 ft^2 for the walls and attic, respectively. Converting these values to the desired units and accounting for an open wall depth of 3.5" and attic insulation depth of 4", the total insulation volumes were found to be 550 m^3 and 250 m^3, for the walls and attic, respectively. It is worth noting here that no floor insulation was considered.

According to the lifecycle materials information provided for ISOCELL, the blow-in cellulose modeled here actually has a negative GWP value of 10 kg CO_2eq/m^3 because it is produced from fully recycled material (Bau EPD, 2014). Multiplying this value by the two previously stated volumes leaves us with total embodied emissions for the insulation retrofit of **-8,000 kg CO_2eq.**

For the windows, the embodied energy depends on the type of window. Aluminum-clad, timber-framed, double-paned windows have a relatively low production energy compared to PVC or aluminum windows, along with a lifetime of thirty-five years and minimal maintenance requirements. For a standard 1.2 m x 1.2 m window, the embodied energy is 1,460 MJ (Asif, Davidson, & Muneer, n.d.). Assuming production locally with the Oakland electricity mix (see calculations in Appendix B), gives emissions of:

$$1{,}460\ MJ/window \times \frac{1\ kWh}{3.6\ MJ} \times 0.26\ kg\ CO_2eq/kWh = 105\ kg\ CO_2eq/window$$

over the thirty-five-year lifetime, which reduces to 45 kg CO_2eq/window if we only consider a fifteen-year planning horizon.

With 26 households located in the southwest region of the country, where it is most common to have 10-15 windows (U.S. Energy Information Administration, 2017), we can estimate the worst-case scenario embodied emissions for window retrofits to be roughly:

Per unit: $45\ kg\ CO_2eq/window \times 15 \frac{windows}{household} \times 26\ households = \mathbf{17,600\ kg\ CO_2eq}$

Therefore, combining the avoided operational emissions and the embedded emissions from the blow-in cellulose insulation and the windows, the total life cycle emissions would be:

$$-180 - 8{,}000 + 17{,}600\ kgCO_2eq = \mathbf{9,420\ kgCO_2eq}$$

In order to convert this into the commonly used units of emissions per therm, we must consider the total energy consumption from natural gas:

$$130.98\ therms/houses\ year \times (0.67) \times 26\ houses \times 15\ years = \mathbf{32,225\ therms}$$

Thus, retrofitting wall insulation and replacing windows results in a total life cycle emissions of:

$$\frac{9{,}420\ kg\ CO_2eq}{32{,}225\ therms} = \mathbf{9.9 \times 10^{-4}\ kg\ CO_2eq/therm}$$

This means that retrofitting insulation and windows actually produce net positive emissions, and are not advisable considering the current calculations. It is clear that both installing new insulation and saved operational emissions give negative GWP. The embodied emissions of new windows are what offsets the result and turn the final GWP positive. If we therefore choose to not retrofit windows but only install insulation, the R-values will change to 5.89 Fft^2hr/Btu before and 8.64 Fft^2hr/Btu after retrofitting. This represents a change in heat flux of: 1-(5.89/8.64) x 100% = **32 %**

In this case, the avoided operational emissions would be 0.45 kg CO_2eq /household-year and a total of 175 kg CO_2eq for the whole planning horizon. The embodied emissions of windows can now be ignored and the total saved emissions for this section will be:

$$-[\ 175 + 8{,}000\ kg\ CO_2eq] = -8{,}175\ kg\ CO_2eq$$

Again, we need to convert this into an emissions per therm value. Doing so results in an updated value of **-0.24 kg CO_2eq/therm**. This makes it clear that an ideal retrofit would focus on the blow-in cellulose and ignore replacing the windows.

6.1.4. Sensitivity Analysis

Most likely, some retrofitting of insulation has already been done by the individual families in the Eco-Block. Estimating that 20% already have improved insulation and windows (Bourassa, 2017) would decrease the saved emissions by 20% because of decrease in material and heat flux, so that total saved emissions will be:

$$-0.24\ kg\ CO_2eq\ \times 0.80 =\ 0.19\ kg\ CO_2eq$$

The R-values used are estimated based on the typical of a house at the time of construction of the block. If the R-value before retrofitting is varied by 20% up and down compared to the value used in the calculations in section 6.1.3., it produces changes in heat flux ranging from 20 - 46%, which his leads to household operational avoided emissions with lower and upper bounds of –0.20 kg CO_2eq/therm and –0.30 kg CO_2eq/therm, respectively. If instead the R-value after retrofitting is varied by 20% up and down, a range of 17 - 44% heat flux saved and corresponding total saved emissions of -0.19 kg CO_2eq/therm to 0.29 kg CO_2eq/therm.

It is clear that the most significant value in the calculation of total saved emissions is from the embodied emissions of the cellulose insulation. The study used to calculate GWP of the insulation gives a range from –6.91 to -16.0 kg CO_2eq /m^3. Using this range gives corresponding total saved emissions in a range of -0.16 kg CO_2eq /therm to 0.37 kg CO_2eq/therm. If instead the volume of insulation is varied by 20%, this gives a range of total saved emissions equal to the original 0.24 kg CO_2eq /therm because of then number of significant figures.

From these calculations, we can establish an upper bound and lower bound total saved emissions as well as the expected, summarized in Table 10. The GWP of wall insulation is governing.

Table 10 **-** *Results of sensitivity analysis for retrofitting wall insulation and replacing windows*

Lower bound GWP	-0.16 kg CO_2eq /therm
Expected GWP	-0.24 kg CO_2eq /therm
Upper bound GWP	-0.37 kg CO_2eq /therm

6.1.5. Uncertainty Assessment and Management

There is also cellulose insulation sprayed into the attic, but calculations of the effect of this on the heat flux are not included here. The material used is however considered in the calculations on total saved emissions. Taking it into account in heat flux savings would contribute to an even greater reduction in GWP from natural gas usage.

The ISOCELL insulation is a primarily European company based in Germany. We chose to use their blow in cellulose environmental data because of the high data quality relative to other available resources. The actual GWP of insulation may vary slightly. If we choose to use ISOCELL blow-in cellulose, we will need to account for the transportation in our analysis.

It is unclear how and when the various houses are built, so there is potentially a significant error range, especially considering the Eco-Block project team does not have access to all units for an assessment of the construction method. This is somewhat accounted for through the sensitivity analysis in section **Error! Reference source not found.**6.1.4 but may have a larger impact than calculated.

To account for assumptions made and studies adapted to calculations in this section, a Data Quality Assessment is included in Table 11 to rate different aspects of the data used, where 1 is maximum quality and 5 is minimum quality.

Table 11 - Data Quality Assessment of Wall Insulation and Window Replacement

Item	Temporal Correlation	Geographical Correlation	Independence of Data Supplier	Acquisition Method	Further Technological Correlation
Embodied Emissions of Wall Insulation	1	3	2	3	2
Embodied Emissions of New Windows	4	3	3	3	2
Retrofit Induced Emission savings	1	2	2	3	2

6.2. High Efficiency LED

6.2.1. Introduction

In the retrofitting phase of the project, the indoor and outdoor lightning will be replaced with high efficiency LED lightning. Furthermore, light poles shall have the capability to turn lights on and off based on the time of sunset and sunrise, change light levels to respond to available moon light, and allow city control for emergency events. For the purpose of this study, it is assumed that all of the bulbs being replaced are incandescent lamps. The various advantages of the LED bulbs are presented in Table 12.

Table 12 - Performance parameters for the bulbs considered in this analysis (U.S. Department of Energy, 2012)

Characteristics	**Incandescent**	**CFL**	**LED lamp - 2012**	**LED lamp – 2017**
Power Consumption	60 watts	15 watts	12.5 watts	6.1 watts
Lumen output	900 lumens	825 lumens	812 lumens	824 lumens
Efficacy	15 lm/W	55 lm/W	65 lm/W	134 lm/W
Lamp Lifetime	1500 hours	8000 hours	25,000 hours	40,000 hours
Total Lifetime Light Output	1.35 Mlm-hr	6.6 Mlm-hr	20.3 Mlm-hr	33.0 Mlm-hr
Impacts Scalar	15.04	3.08	1.00	0.61

Of primary interest here are the reduced power consumption and improved lifetime of the LED lamps compared to the incandescent bulbs. Based on these properties, the lighting retrofit will reduce the electricity demand and the number of lamps required to meet lighting demand over the 15-year planning horizon. The following sections will quantify these energy savings and environmental benefits of switching to LED bulbs.

6.2.2. Energy Savings

To model the existing energy consumption associated with lighting on the block a few assumptions were key. First, based on the EIA's 2009 Residential Energy Consumption Survey it was assumed that average household consumes 7,000 kWh per year (EIA, 2009). The EIA also reports that on average roughly 10% of this electricity is used for lighting, which equates 700 kWh per household per year (EIA Independent Statistics and Analysis, 2017).

Using an annual lighting consumption of 700 kWh per household, a baseline was established with the incandescent power consumption of 60 W. To quantify the potential energy savings, a simple comparison was used with baseline on the left-hand side and the proposed scenario on the right as shown below.

$$\frac{60\ W}{700\ kWh} = \frac{12.5\ W}{x\ kWh}$$

By reducing the power consumption to 12.5 W, we estimate that the total lighting electricity load could be decreased to 145 kWh per year, which represents an annual energy saving of 555 kWh per household. Taking into consideration only the forty-four single family units on the Eco-Block, this would equate to a total annual energy savings of roughly 24,000 kWh across the block.

Following PG&E's initiative to replace 160,000 high-pressure-sodium-vapor (HPSV) street lights with high efficiency LEDs, the Eco-Block will also be upgrading its outdoor lighting (PG&E, 2017). Without detailed load data, it is difficult to accurately characterize the energy savings, but a few assumptions allow for a reasonable estimate.

Assumptions:

- Switching from 150W HPSV lamps to 60W LEDs
- Streetlights operating for 8 hours per night
- Replacing all 32 streetlights on the block

From here, it follows that the annual energy savings could be determined with the following simple calculation:

$$-90\ W/bulb \times 8\ hours/day \times 365\ days/year \times 32\ streetlights = 8{,}000\ kWh/year$$

6.2.3. Environmental Impact Assessment

There are two major impact categories to consider when evaluating the environmental impact of the Eco-Block's lighting retrofit. First and foremost, the energy savings outlined in the previous section will result in significant avoided operational emissions which were quantified using PG&E's most recently reported 2015 energy mix. Additionally, one must also consider the differences in the production and transport emissions of incandescent, high-pressure-sodium-vapor, and LED lamps.

In order to estimate avoided operational emissions, it is helpful to establish the three key components changing in the Eco-Block retrofit. These categories are outlined in Table 13.

Table 13 - Key alterations involved in Eco-Block lighting retrofit

Category	**Existing**	**Eco-Block**
Electricity Source	PG&E Energy Mix	Eco-Block Solar + Wind
Indoor Lighting	60W Incandescent	12.5W LED
Outdoor Lighting	150W HPSV	60W LED

As the previous section already outlined the energy savings associated with both the indoor and outdoor lighting upgrades, the only remaining task is to quantify the emissions (g CO_2eq/kWh) associated with PG&E's 2015 energy mix. The breakdown of energy sources was retrieved from PG&E's 2015 Power Content Label and the emissions factors were cited from Horvath & Stokes, 2017. Multiplying the final value by the total energy savings provides indoor and outdoor avoided operational emissions totals of 4,700 and 1,600 kg CO_2eq per year, respectively.

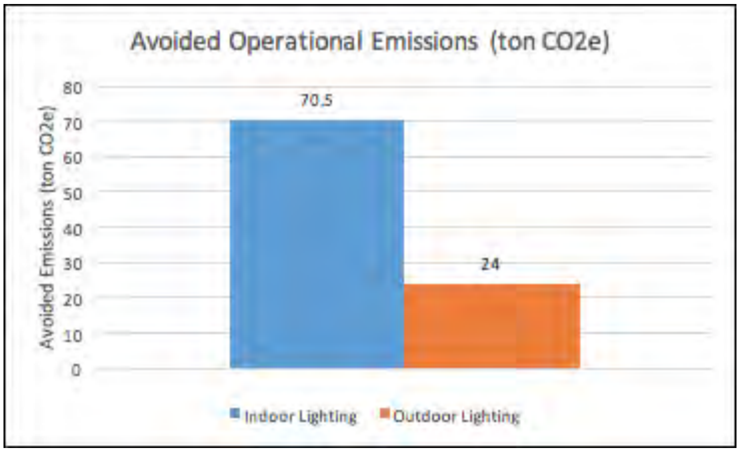


Figure 16 – Avoided operational emissions resulting from indoor and outdoor lighting efficiency upgrades

In order to provide a complete lifecycle assessment, the greenhouse gas emissions associated with the production, transport, and replacement of the indoor and outdoor lighting options must also be considered. For the indoor lights being replaced, Ramroth (2008) reports a lifecycle emissions factor for incandescent lamps of 3 kg CO_2eq per bulb. Accounting for the 20 necessary replacements this equates to a lifetime emissions of 60 kg CO_2eq per incandescent lamp. Assuming at least 3 bulbs will be replaced in each of the forty-four single family units, this equates to roughly 7,900 kg CO_2eq.

In terms of production and assembly, the LED bulbs are significantly more complex than the traditional incandescent lamps. For example, approximately 20% of an LED's life-cycle CO_2eq emissions are due to manufacturing, while this phase represents less than 1% of lifetime emissions for incandescent lamps (Quirk, 2009). To quantify these emissions, we retrieved lifetime emissions factors for LEDs from Scholand and Dillon (2012) that are represented in Table 14.

Table 14 **-** *Life-cycle impacts of the standard 12.5 W LED lamp*

LCA Stage	**Emissions [kg CO_2eq]**
Raw Materials	12.752
Manufacturing	3.450
Transport	0.052
Total	16.254

Taking the 40,000-hour lifetime reported by the EIA for the LED bulbs and assuming that each bulb will be operated for six hours per day, the LEDs would last for roughly 18 years. As this is beyond our 15-year planning horizon, it was concluded that the LED scenario would require no replacement of bulbs. Therefore, the lifetime emissions of the 12.5W LED bulb from production through its use are simply 16.254 kg CO_2eq. Although the bulbs used for street lighting will have a higher power rating, it is assumed that the differences in their embodied emissions are negligible, which allows us to estimate the total lifecycle emissions of 2,700 kg CO_2eq for the 132 indoor and 32 outdoor LED replacements combined.

Finally, to evaluate the manufacturing emissions associated with the existing streetlights, the Dale et al. (2011) study on the comparative lifecycle impacts of streetlight technology was referenced. Here they report that the materials' global warming potential impact (without considering use-phase) of the high-pressure sodium lamps are roughly twice that of the LED bulbs, which would result in a total estimated emissions of 32 kg CO_2eq per bulb and 1,000 kg CO_2eq for all 32 street lights.

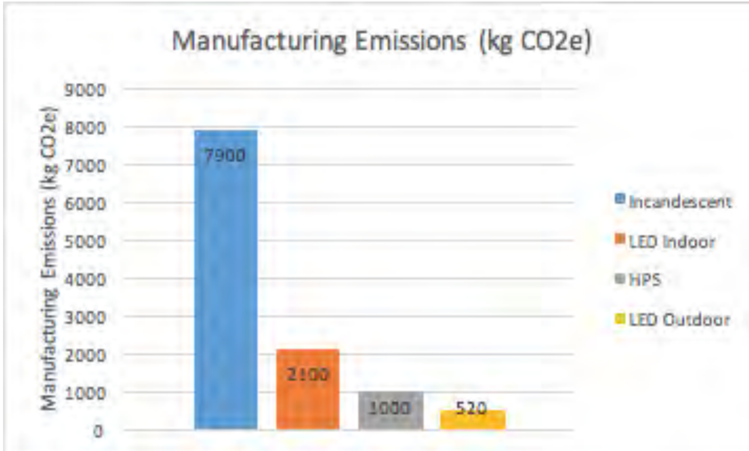


Figure 17 - Manufacturing emissions for each lighting technology both indoor and outdoor on a per bulb accounting for 132 indoor replacements and 32 outdoor

6.2.4. Sensitivity Analysis

A sensitivity analysis was performed to bound the reported values for the embodied emissions associated with the production and transport of the LED lamps used throughout the Eco-Block retrofit. Here, there is assumed to be significant certainty in the materials extraction and manufacturing information reported by Scholand and Dillon for the U.S. DOE's report and thus these values were assumed to have maximum variability of +/- 10%. On the other hand, the emissions associated with their operating assumption that each LED lamp will travel 11,000 kilometers by boat and truck could vary dramatically depending on the distance and type of transportation. Therefore, these values were bounded with variability of +/- 50%.

Given these bounded estimates and the 164 lights to be replaced (indoor plus streetlights) we could specify the total embodied emissions estimate of 2,700 kg CO_2eq with a lower and upper bound of 2,400 and 2,900 kg CO_2eq, respectively.

6.2.5. Uncertainty Assessment and Management

With the current understanding of the lighting situation inside each individual unit there exists significant uncertainty. Most of the ambiguity comes from our assumptions that each household currently has the same type and number of lamps to be replaced, and unfortunately without access to the units it is difficult to achieve a more precise approximation. Additionally, due to the upfront financial burden associated with LED lamps it is problematic to assume that all the tenants in the

44 single-family units on the Eco-Block will be willing to replace all of their existing lights. Therefore, the reported values should be taken as the best engineering estimates achievable with the information provided. As it has been shown that the largest reduction in emissions will come from reduced electricity demand, the best way to improve the certainty of this assessment would be to gather information on the quantity and type of existing bulbs in each of the units and ensure that all the residents would be able to replace these with high-efficiency LED lamps.

7. Transportation Systems

7.1. Introduction

The Transportation Sector accounts for 27% of the Greenhouse Gas Emissions in the United States as can be seen in Figure 18. This sector consists of moving goods and people from one location to another in either cars, trucks, airplanes, ships, or different modes of travel. The Light-Duty Vehicles (i.e. cars) used mostly by households make up 60% of the Transportation emissions in the U.S. This means that the Light Duty Vehicles make up for

$$0.6 \times 0.27 = 0.162 = 16.2\%$$

of the total emissions in the U.S. as can be seen from Figure 19. We hope to use any extra solar power capacity to fuel a shared electric vehicle system, in turn reducing the total GWP of the Eco-Block as a whole.

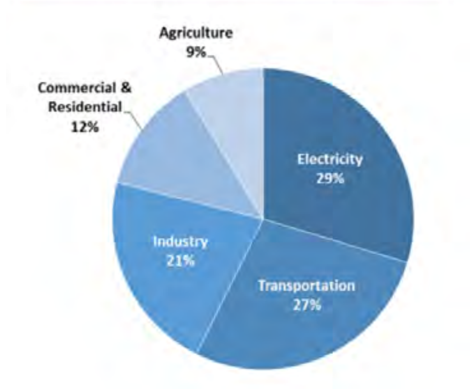


Figure 18 - 2015 Total U.S. greenhouse gas emissions by economic sector (EPA, Green House Gas Emissions, 2017)

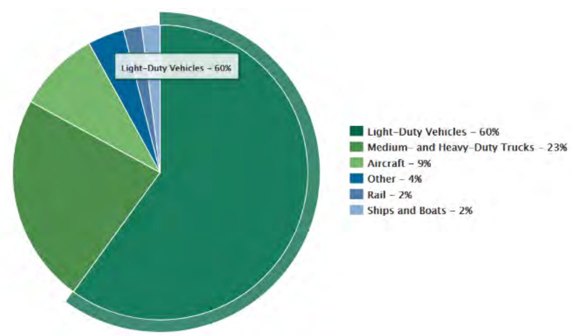


Figure 19 - 2015 U.S. Transportation greenhouse gas emissions by source, (EPA, Fast Facts Transportation Greenhouse Gas Emissions, 2017)

Reducing emissions in the transportation sector can be done by reducing the number of vehicles or choosing vehicles that have relatively low associated emissions. The former can have a significant impact especially when considering that 95% of a cars life is currently spent parked and unused (Morris, 2016). The latter depends on the type of car chosen (i.e. Gasoline or Electric Cars). We incorporate both methods in our proposed Eco-Block EV Car Sharing system. Our system will reduce the number of cars needed by the residents in addition to reducing the operational emissions for each ride due to solar or grid powered charging.

One of the objectives of the Eco-Block project is to reduce the greenhouse gas (GHG) emissions associated with transportation. The current suggested design is to adopt 10 Electric Vehicles (EVs) to be shared by the members of the block. The goal of this section is to carry out a lifecycle assessment on different car sharing scenarios to demonstrate the benefits and drawbacks of each option.

Five different scenarios were studied: a Toyota Camry 2017 (Gasoline Car), Nissan Leaf 2017 (Electric Vehicle) with level 1 charger, Nissan Leaf 2017 with level 2 charger, Nissan Leaf 2017 with level 3 charger, and a Nissan Leaf 2017 with solar charger.

7.2. Modeling Approach and Data

Our LCA considers two transportation systems over a planning horizon of 15 years; gasoline transportation system and electric transportation system as shown in Figure 20. The components of the LCA included the manufacturing and operation of the vehicles, without considering the end of life of vehicles. The life-cycle emission factors were then multiplied by the number of shared vehicles.

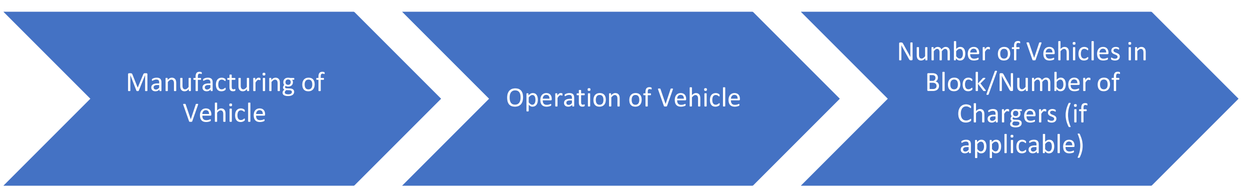


Figure 20 - Life cycle assessment components of the gasoline and electric vehicles

The manufacturing component of the LCA includes the assessment of car production for the electric and gasoline cars including raw materials and production processes.

The operation component of the LCA is different for gasoline and electric cars. For gasoline vehicles, the emissions resulting from gasoline production and consumption (i.e. Tail pipe emissions) were considered. For electric vehicles, the emissions resulting from electricity production and charging infrastructure were considered.

As for the number of cars, the desired performance and reliability of the transportation system will dictate the minimum number of cars required. The type of transportation system (gas vs electric) adopted might affect the number of cars needed depending on the non-operational time i.e. the time spent refueling or recharging.

The refueling of cars does not require significant time and was disregarded in the assessment. The recharging time of electric cars was considered and depends on the type of EV charger put in place. Three types of EV charges were examined, Level 1, Level 2, Level 3, and Solar EV chargers. Each type of charger will be explored in more depth in the following sections.

We carried out a case study on an EV, the Nissan Leaf 2017 and a gasoline vehicle, the Toyota Camry 2017. The case study considered the following 5 scenarios as shown in Table 15.

Table 15 **-** *Case study scenarios for Eco-Block transportation system*

Scenario	**Vehicle**	**Refuel/Recharge Type**
1	Toyota Camry 2017	Gasoline
2	Nissan Leaf 2017	Level 1 Charging Power
3	Nissan Leaf 2017	Level 2 Charging Power
4	Nissan Leaf 2017	Level 3 Charging Power
5	Nissan Leaf 2017	Solar Charging Power

7.2.1. Assumptions

Miles Traveled

The current design asks for 10 cars to serve 26 houses. Assume 3 people are sharing a car. The average daily miles traveled by one person is around 35 miles as displayed in Figure 21, i.e. the average between Men and Women daily person miles of travel in 2009 (Santos, McGuckin, Nakamoto, Gray, & Liss, 2009). Since the car is shared by three people,

$$Total\ daily\ miles\ traveled = 35 \times 3 = 105\ miles/day$$

The lifetime of the car is set to 15 years, therefore:

$$Total\ Lifetime\ miles\ traveled = 105\ miles/day\ \times 365\ days/year\ \times 15\ years = 574{,}875\ miles/vehicle$$

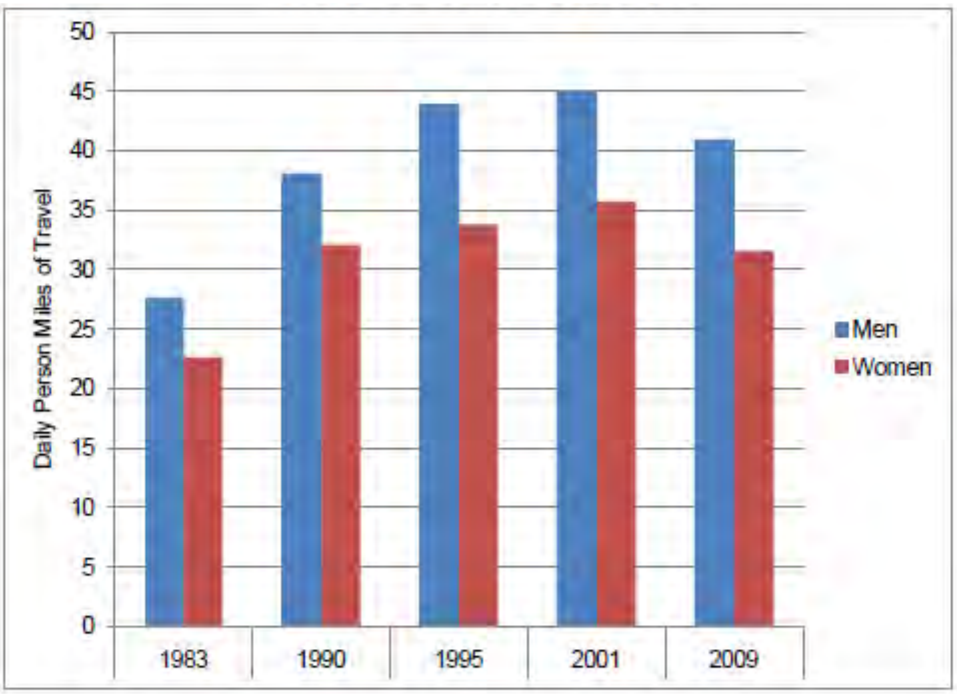


Figure 21 - Average daily person miles of travel per person by gender 1983, 1990, 1995 NPTS, and 2001 and 2009 NHTS (Santos, McGuckin, Nakamoto, Gray, & Liss, 2009)

7.3. Case Study

7.3.1. Scenario 1: Toyota Camry 2017 Gasoline

The LCA components include the manufacturing and operation of Toyota Camry and the number of Toyota Camrys required by the Eco-Block.

7.3.1.1. Manufacturing

The emissions associated with manufacturing the car is 10,210 kg CO_2eq. This includes the materials, parts manufacture, assembly, and transportation (Maimone, 2011).

7.3.1.2. Operation

The operation of Toyota Camry 2017 includes the Greenhouse Gas emissions associated with upstream fuel production from well to tank (i.e. Exploration and Development, Production, Surface Processing, and Transport) and the GHG emissions associated with tail pipe emissions over the product life of 15 years. The emissions were calculated based on g CO_2eq/mile, then multiplied by the lifetime miles driven.

The upstream GHG emissions for fuel production from well to tank in California is 26.3 g CO_2eq/MJ based on the Petroleum Administration for Defense District (PADD) using Figure SI-5 “Map of U.S. PADD” and Figure SI-15 “Life Cycle Well to Tank Emissions by Region-Gasoline” (Cooney, et al., 2016).

The GHG emissions are given in g CO_2eq/MJ gasoline. This needs to be multiplied by the energy content of gasoline (131 MJ/gallons) to find emissions per gallon of gasoline (MJ to gallons of gasoline, 2017), then divided by 27 miles (Toyota Camry, 2017). This means that the GHG emissions for fuel production from Well to Tank is about 128 g CO_2eq/mile.

The tailpipe carbon dioxide emitted by a gasoline powered Toyota Camry is 363 grams of CO_2eq/mile. (Energy Efficiency and Renewable Energy, 2017). By combining the GHG emissions from fuel production with the tailpipe emissions, we find that the total emissions per mile associated with the operation of the Toyota Camry are 491 g CO_2eq/mile. The lifetime distance traveled by the Toyota Camry was calculated to be 574,875 miles. Therefore, the total emissions associated with the life of the car are

$$Emissions = 491\ g\ CO_2eq/mile\ \times 574{,}875\ miles = 282{,}264\ kg\ CO_2eq.$$

7.3.1.3. Number of Cars and Chargers Required

Since the refueling time for the Toyota Camry is negligible (i.e. less than 10 minutes) and does not affect the vehicle's operation time, then the number of cars required is the minimum number of shared cars required by the Eco-Block. The minimum number of shared cars required by the Eco-Block is 10 according to the current design system. Table 16 shows a summary of the LCA for the Toyota Camry 2017, the total emissions for the life cycle of the Toyota Camry is 2,922,600 kg CO_2eq.

Table 16 - Summary of LCA of Toyota Camry (2017)

Vehicle Type	**Manufacturing [kg CO_2eq]**	**Operation [kg CO_2eq]**	**Number of Cars**	**Total Emissions [kg CO_2eq]**
Toyota Camry (2017)	10,200	282,260	10	2,922,600

7.3.2. Scenarios 2, 3, and 4: Nissan Leaf 2017 and Grid Powered EV Chargers

The LCA components include the manufacturing and operation of the Nissan Leaf 2017 and the number of Nissan Leafs required by the Eco-Block. The manufacturing component is similar for scenarios 2 to 5. The operation component of the Nissan Leaf will address the charging infrastructure and electricity consumed. The number of cars and number of chargers will depend on the infrastructure used to charge the car.

7.3.2.1. Manufacturing

The CO_2eq emissions associated with the car manufacturing is about 10,000 kg CO_2eq. This includes the battery production and vehicle production of a medium to large EV, i.e. between 24.4 kWh and 42.1 kWh battery (Ager & Ellingsen, 2016).

7.3.2.2. Operation

The operation assessment of Nissan Leaf 2017 includes the emissions associated with charging infrastructure and electricity consumed.

Charging Infrastructure – Charger Power Levels

The battery chargers are classified into three power levels: Level 1, Level 2 and Level 3. These levels reflect the power, charging time, location, cost, equipment, and effect on the grid (Yilmaz & Krein, 2012). The role of the battery charger is to draw power from the electrical grid, convert the power to DC current power and provide it to the DC battery of the EV. There are two types of battery chargers, the on-board battery charger and off-board battery charge. The on-board battery charger is located inside the EV while the off-board battery charger is at a fixed location outside the EV.

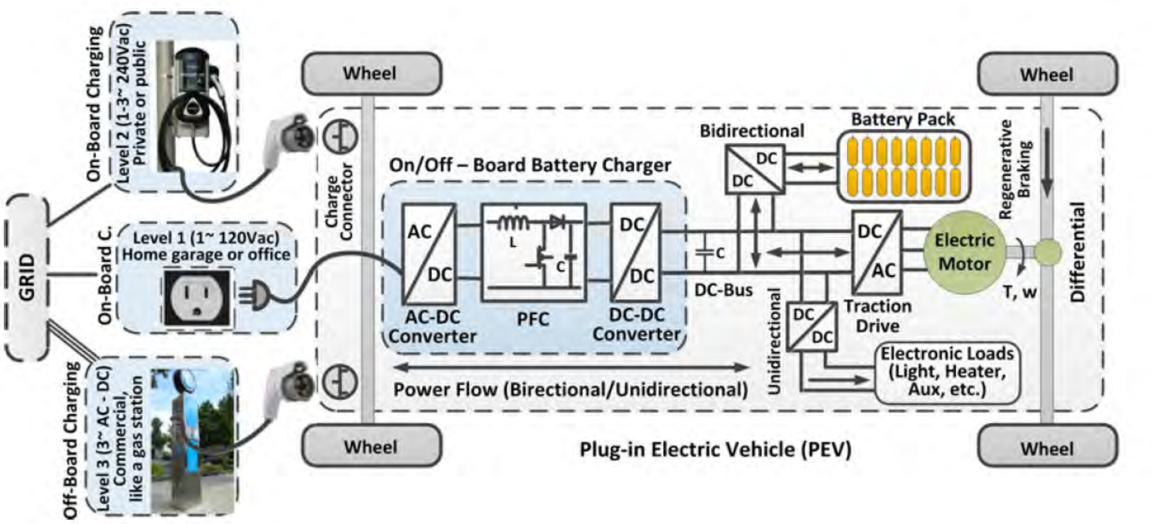


Figure 22 - On/Off-board charging systems and power levels for EVs (Yilmaz & Krein, 2012)

<u>*Level 1 Charging*</u>

Level 1 Charging is the slowest charging method. In the U.S., it offers regular AC charging of a voltage of 120 V/15 A single-phase grounded outlet (i.e. any regular outlet at home) to charge the EV via its on-board charger as seen in Figure 22. Other than the on-board battery charger no additional infrastructure is required (Yilmaz & Krein, 2012). The GHG emissions associated with installation and operation of Level 1 charging were assumed to be accounted for in the car production and operation phases (i.e. on-board battery charger).

Level 2 Charging

Level 2 charging is the main charging method that is used by public and private facilities. Level 2 requires the installation of electric vehicle supply equipment (EVSE). In the U.S., this equipment connects to the grid and offers AC charging ranging from 208 V to 240 V and up to 80 A to charge the EV via its on-board charger as can be seen in Figure 22. (Yilmaz & Krein, 2012). The GHG emissions associated with installation and operation of Level 2 charging is 10 kg CO_2eq/vehicle/year (Traut, 2013). We set the lifetime of the chargers to be 15 years and find that the resulting GHG emissions are 150 kg CO_2eq/vehicle.

Level 3 Charging

Level 3 charging is the fastest charging method. Level 3 requires the installation of electric vehicle supply equipment (EVSE). This equipment includes an off-board charger which provides DC power directly to the EV battery as can be seen from Figure 22 . Level 3 battery charger requires a three-phase circuit and operates at 480 V (Yilmaz & Krein, 2012). The GHG emissions associated with Level 3 charging is 12 kg CO_2eq/vehicle-year (Traut, 2013). We set the lifetime of the chargers to be 15 years and find that the resulting GHG emissions are 180 kg CO_2eq/vehicle. Figure 23 summarizes the different aspects of charging power levels. As can be seen from Figure 23, not all vehicles can be charged using Level 3 battery charging systems (i.e. PHEVs) (Yilmaz & Krein, 2012).

Power Level Types	Charger Location	Typical Use	Energy Supply Interface	Expected Power Level	Charging Time	Vehicle Technology
Level 1 (Opportunity) 120 Vac (US) 230 Vac (EU)	On-board 1-phase	Charging at home or office	Convenience outlet	1.4kW (12A) 1.9kW (20A)	4–11 hours 11–36 hours	PHEVs (5-15kWh) EVs (16-50kWh)
Level 2 (Primary) 240 Vac (US) 400 Vac (EU)	On-board 1- or 3-phase	Charging at private or public outlets	Dedicated EVSE	4kW (17A) 8kW (32 A) 19.2kW (80A)	1–4 hours 2–6 hours 2–3 hours	PHEVs (5-15 kWh) EVs (16-30kWh) EVs (3-50kWh)
Level 3 (Fast) (208-600 Vac or Vdc)	Off-board 3-phase	Commercial, analogous to a filling station	Dedicated EVSE	50kW 100kW	0.4–1 hour 0.2–0.5 hour	EVs (20-50kWh)

Figure 23 - Charging Power Levels (Yilmaz & Krein, 2012)

Charging

The charging component consists of the emissions associated with the amount of electricity consumed over the life-time of the car (i.e. 15 years). The amount of electricity varies for each type of charger depending on the grid to battery efficiency of the charger. The charging efficiency of grid to battery is 88% for Level 1, 83% for Level 2 and 78% for Level 3 (Traut, 2013).

The electricity consumed per charger type is expressed as

$$Electricity\ consumed = energy\ required\ by\ car / charger\ efficiency$$

The electricity required by the car is based on the efficiency of Nissan Leaf 2017. The efficiency of Nissan Leaf 2017 (30 kWh battery) for a highway and city mix is 30 kWh/100 mile = 0.3 kWh/mile (Electric Car Range Efficiency, 2017). Adjusting for the charger power level efficiencies we can conclude the following in Table 17:

Table 17 - Nissan Leaf Efficiency based on Charger Power Level Used

Charge Power Level	**Charger Power Level Efficiency [kWh battery/kWh grid]**	**Input kWh to achieve 0.3 kWh/mile fuel efficiency [kWh grid/mile]**
Level 1	88%	0.34
Level 2	83%	0.36
Level 3	78%	0.385

The emissions generated from electricity production is 0.26 kg CO_2eq/kWh (Refer to Appendix B).

If we multiply the PG&E electricity emission factor of 26 kg CO_2eq/kWh by the EV's efficiency (kWh/mile), we can determine the carbon footprint (g CO_2eq/mile), as shown in Table 18:

$$Carbon\ footprint\ [g\ CO_2eq/mile] =$$
$$Total\ emission\ per\ kWh\ [g\ CO_2eq/kWh] \times Car's\ efficiency\ [kWh/mile]$$

Table 18 - Carbon footprint (gCO_2eq/mile) of driving Nissan Leaf (2017) accounting for vehicle's electricity use

Charging Power Level	kWh based Emission Factor [g CO_2eq/kWh]	EV Efficiency [kWh/mile]	Mile based Emission Factor [g CO_2eq/mile]	Operational Emissions from 574,875 miles driven per car [kg CO_2eq]
Level 1	260	0.34	88.4	50,820
Level 2	260	0.36	93.6	53,810
Level 3	260	0.385	100.1	57,540

7.3.2.3. Number of Cars and Chargers Required

Every level of charger is associated with a different amount of time needed to fully charge the vehicle. The longer it takes to charge the vehicle, the less time it is available for use. Therefore, the number of vehicles and chargers needed, will vary based on the charger level. For our analysis, we assume each Leaf drives 105 miles/day (rounded from the actual 107 miles for simplicity) -- one full charge worth of travel (Nissan Leaf, 2017).

The charging time for the Nissan Leaf 2017 to achieve a range of 107 miles is 21 hours for Level 1, 6 hours for Level 2, and 0.5 hours for Level 3. (Nissan Leaf, 2017).

Level 1 charging requires 21 hours to charge the Nissan Leaf to full capacity. As such at least one car per house is required. The total miles traveled per 25 cars is assumed to be the same as for the 10 car scenario. As such the operation assessment for level 1 charged cars will remain the same.

The level 2 and level 3 charging for the 10 cars will suffice since the charging time for Level 2 is 6 hours and the charging for Level 3 is 0.5 hours. The car is bound to be inactive for at least 6 hours during the 24 hours of a day and thus can be charged in that time.

The number of chargers needed is a function of the amount and type of utilization the shared vehicles will experience. According to Figure 24, the typical number of trips from 11pm to 4am is very low, close to zero at some points. Therefore, we assume that the EVs will be able to charge for 5 hours during this chunk of time. The final hour of charge is assumed to happen throughout the day at the Eco-Block charger or at a commercial/workplace charging station. Since the level 2 charger requires 6 hours to charge the Nissan Leaf then one charger shall be available per car. As such the block requires 10 chargers.

Similarly, for the level 3 charger scenario, the charger can charge the Nissan Leaf in 30 minutes. Since the cars are available for 5 hours, then all the cars can be charged by one charger. Thus, one level 3 charger is required for the 10 cars although someone must move the cars in order to charge the other car.

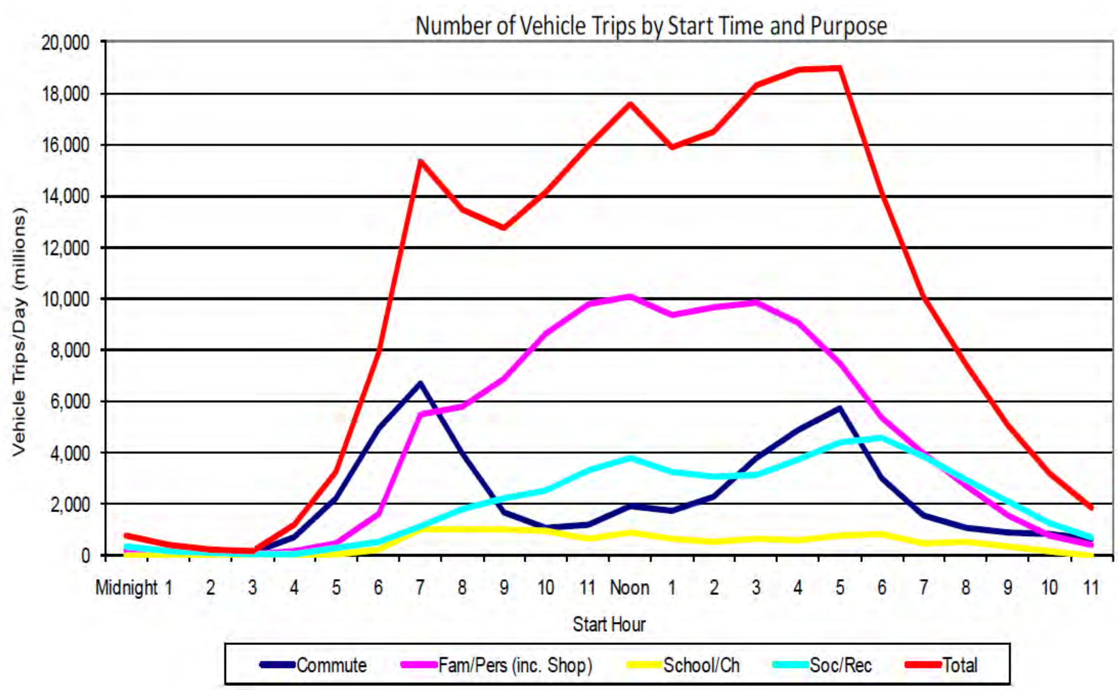


Figure 24 **-** *Distribution of vehicle trips by trip purpose and start time of trip 2009 NHTS (Santos, McGuckin, Nakamoto, Gray, & Liss, 2009)*

Table 19 shows a summary of the manufacturing emissions for the total number of vehicles for the Eco-Block. Please note that although only 10 cars are needed at one time for Level 2 and 3, we assumed that each vehicle needs to be replaced at least once at the end of its life (200,000 ~250,000 miles). Thus, the embodied emissions of the EVs for level 1 and 2 chargers must be double the blocks demand i.e. 20 EVs over the 15 year lifetime.

Table 19 - Life cycle manufacturing emissions of Nissan Leaf 2017

Scenarios	Number of Cars	Emissions per Car [kg CO_2eq/vehicle]	Total Manufacturing Emissions [kg CO_2eq/vehicle]
Level 1	25	10,000	250,000
Level 2	20	20,000	200,000
Level 3	20	20,000	200,000

Table 20 shows a summary of the operation emissions per scenario showing the charging infrastructure and electricity consumption emissions for the total number of cars of the Eco-Block.

Table 20 - Life Cycle Operations Emissions of Nissan Leaf 2017

	Charging Infrastructure Component				**Electricity Consumption**		
Scenarios	Number of Chargers	Number of Vehicles in the EV car sharing system at one time	Embodied Emissions due to infrastructure [kg CO_2eq/vehicle]	Embodied Emissions due to infrastructure [kgCO_2eq]	Operational Emissions due to electricity consumption [kg CO_2eq/car]	Operational Emissions of total miles driven of all cars 2017 [kg CO_2eq]	**Total Operations Emissions [kg CO_2eq]**
Level 1	N/A	25	N/A	N/A	50,820	508,200	508,200
Level 2	10	10	150	1,500	53,810	538,100	539,600
Level 3	1	10	N/A	180	57,540	575,400	578,200

7.3.3. Scenario 5: Nissan Leaf 2017 and Solar EV Charger

7.3.3.1. Manufacturing

There is about 10,000 kg CO2eq of emissions associated with the manufacturing of each EV. This includes the battery production and vehicle production of a medium to large EV, i.e. between 24.4 kWh and 42.1 kWh battery (Ager & Ellingsen, 2016).

7.3.3.2. Operation

The operation assessment of Nissan Leaf 2017 includes the emissions associated with charging infrastructure and electricity consumed.

Charging Infrastructure

The charging infrastructure for the Solar EV charger involves the solar panels and the charger itself. The emissions associated with the solar panels will be considered as part of the electricity consumption in the charging phase. The emissions associated with the solar EV Charger are similar to the Level 2 EV charger (Lombardi, 2011) as considered in section 7.3.2.2. and is equivalent to 150 kg CO_2eq/vehicle.

Charging

The emissions associated with charging are accounted for in the electricity section and will not be included for EVs not to be counted twice in the assessment.

7.3.3.3. Number of Cars and EV Chargers

As stated earlier, the solar EV charger is similar to the Level 2 EV charger in terms of charging efficiency and charging time. As such, 10 solar EV chargers should be sufficient to service 10 EVs at once (20 over the 15 year planning horizon). Therefore, the total emissions associated with ten solar EV chargers are

$$Emissions = (20\ EVs * 10{,}000 + 10\ EV\ chargers * 150) \approx \boldsymbol{201{,}500\ kg\ CO_2eq}$$

7.4. Results and Findings

Table 21 shows the summary of the life cycle assessment of the five transportation scenarios. It shows that the highest total emissions among all five scenarios were produced by the gasoline Toyota Camry 2017.

For the electric vehicles, the highest emissions were for the Level 1 charging. This is because of the long charging hours for Level 1 which led to increasing the number of cars and in turn immensely increasing the associated manufacturing emissions. The second highest emissions for electric cars were for Level 3 charging. The emissions associated with Level 3 are higher because the efficiency of the grid to battery electricity transfer is significantly lower than the other options. The third highest emissions were associated with Level 2 chargers. The lowest emissions were associated with solar chargers which are significantly lower because they use solar power as opposed to the PG&E fuel mix.

The Life Cycle Analysis of the five scenarios shows that the transportation system of Nissan Leaf 2017 with a Solar EV charger will produce the lowest emissions.

Table 21 **-** *Life cycle assessment of the five transportations system scenarios*

Scenario	**Vehicle**	**Refuel/Recharge Type**	**Number of Cars over 15 years**	**Number of Chargers**	**Life Cycle Emissions [kg CO_2eq]**	**Saved Life Cycle Emissions [kg CO_2eq]**
1	Toyota Camry 2017	Gasoline	10	N/A	3,024,000	0
2	Nissan Leaf 2017	Level 1 Charging Power	25	N/A	758,000	2,266,000
3	Nissan Leaf 2017	Level 2 Charging Power	20	10	753,000	2,271,000
4	Nissan Leaf 2017	Level 3 Charging Power	20	1	676,000	2,246,000
5	Nissan Leaf 2017	Solar Charger	20	10	202,000	2,822,000

7.5. Sensitivity Analysis

A sensitivity analysis was done on the winning scenario, which is the Nissan Leaf 2017 with the solar charger. The data used in calculating the emissions associated with this scenario are the car manufacturing emissions, the charger emissions, and number of chargers and cars. The operations emissions were not considered in this case because the emissions associated with solar power were considered in the electrical system. The emissions associated with this scenario are calculated by

$$Total\ emissions = Number\ of\ cars\ \times Car\ manufacturing\ emissions + Number\ of\ chargers\ \times Charger\ emissions$$

The number of cars and chargers are the same since one charger is required per one car. Then the above equation could be simplified as follows:

$$Total\ emissions = Number\ of\ cars\ and\ chargers \times (Car\ manufacturing\ emissions + Charger\ emissions)$$

- Number of Cars and Chargers = 10
- Car Manufacturing Emissions = 10,000 kg CO_2eq/car
- Charger Emissions = 150 kg CO_2eq/charger

As can be seen from Table 22, the emissions associated with the Solar EV charger scenario is sensitive to the number of cars and chargers and to the emissions associated with car manufacturing. The reason can be attributed to the fact that the car manufacturing emissions make up 98% of the emissions of the scenario, making the emissions of the scenario directly proportional to the number of cars and chargers.

Table 22 - Sensitivity analysis of Nissan Leaf 2017 with solar EV charger scenario

Number of Cars and Chargers at one time	**Car Manufacturing (this number is doubled in the "Total Emissions Calculation" to account for the EV replacement [kg CO_2eq]**	**Charging Infrastructure [kg CO_2eq]**	**Total Emissions [kg CO_2eq]**
10	10,000	150	201,500
10	11,000	150	221,500
10	10,000	165	201,650
11	10,000	150	221,650

7.6. Uncertainty Assessment and Management

An uncertainty assessment was carried out for the Scenario 5, the 2017 Nissan Leaf with solar charger. The data used in calculating the emissions associated with this scenario are the car manufacturing emissions, the charger emissions, and number of chargers and cars. This data was retrieved from different sources. Since no assumptions were made in the scenarios, the quality of the data was assessed in the form of a pedigree matrix as shown in Table 23.

As shown in Table 23, the data used for the embodied emissions of EV charger was within the last 5 years, the data supplier is verified information from an enterprise, the acquisition method includes calculated data partly based on assumptions, and finally the data collected for level 2 charging was also used for the solar charging scenario.

As shown in Table 23, the data used for the embodied emissions of the Nissan Leaf was within the collected within last 3 years, it was retrieved from a verified enterprise, the acquisition method includes calculated data partly based on assumptions, and finally the data collected was for electric vehicles is general.

Table 23 - Data quality assessment for Nissan Leaf 2017 with solar EV charger

	Data Quality Assessment for Nissan Leaf 2017 with Solar EV Charger				
Item	**Temporal Correlation**	**Geographical Correlation**	**Independence of Data Supplier**	**Acquisition Method**	**Further Technological Correlation**
Embodied Emissions of Solar EV Charger	2	N/A	2	3	3
Embodied Emissions of Nissan Leaf 2017	1	N/A	2	3	2

8. Alternatives

In addition to the distributed generation and storage resources proposed for the Eco-Block, we chose to explore a few alternative options that may help achieve the goal of minimizing the block's environmental footprint. First, we investigated the impact of replacing the proposed flywheel storage system with a group of Tesla Powerwalls. Additionally, we considered the possibility of implementing roof-top mounted vertical axis wind turbines to supplement the electricity generated by the solar array. Both components were subject to a lifecycle assessment and the results of each study will be outlined in greater detail in the sections below.

8.1. Powerwall

8.1.1. Introduction

The Powerwall is a battery designed and manufactured by Tesla for residential use. It is not currently planned as part of the electrical fixtures of the Eco-Block, but is researched here as a possible alternative or complement to the to the flywheel storage system. One or more connected batteries can absorb excess energy generated during peak production hours to store and release it to the block when the sun goes down and demand peaks as residents return home from work.

If the Powerwall is not charged to full capacity by the photovoltaics, another use is charging the battery using grid electricity during off peak hours. This can be cost effective if done properly as off-peak electricity is generally cheaper than electricity used during peak hours (Pacific Gas and Electric Company, 2017). This is however not applicable to the Eco-Block, as we assume Powerwall will be charged from the block's PV installation and therefore not be in contact with the main grid.

Thirdly, Powerwall can serve as a power outage backup (Tesla, 2017a), providing electricity if the grid is not available.

8.1.2. Modelling approach and Data

The Powerwall is a lithium ion battery with a stated weight of 125 kg and capacity of 13.5 kWh (Tesla, 2017a). The Eco-Block team requires an energy storage capacity of 800 kWh, so 60 Powerwalls should be installed to provide this. The only impact category shown in the results is global warming potential (GWP), in the interest of length of the report.

Powerwalls come with a 10-year warranty (Tesla, 2017a), indicating that a lifetime of 10 years is a minimum expectation. Other components in this paper assume a planning horizon of 15 years, so this will also apply to the Powerwall, although that might be optimistic. This lifetime uncertainty is further explored in the sensitivity analysis.

As the Powerwall is quite a new product, it is difficult to find research investigating the environmental impact of this exact product. However, it consists of a lithium ion battery with a nickel, manganese, cobalt oxide cathode, called a NMC battery (Fehrenbacher, 2015). As it is produced by a battery electric vehicle (EV) manufacturer, it is reasonable to assume this battery is similar to a BEV battery regarding its carbon footprint of production and end of life. Common NMC batteries use equal parts of nickel, manganese and cobalt, but this is not specified for the Powerwall cell (Fehrenbacher, 2015). A study investigating the environmental impact of producing a EV NMC battery (Ellingsen, et al., 2013) with about twice the weight and capacity (253 kg, 26.6 kWh) was used for comparison. Table 24 gives the main constraints of the assessment.

Table 24 - System boundaries of lithium ion battery study (Ellingsen, et al., 2013)

Included	**Excluded**
Cell manufacture: node; cathode; separator; electrolyte; and cell container	Other EV components than the battery
Packaging: module packaging; battery retention; and battery tray	Construction of capital equipment, overhead, etc.
Battery management system (BMS): battery module boards (BMBs), the Integrated Battery Interface System (IBIS), fasteners, a high-voltage (HV) system, and a low-voltage system	End-of-life
Cooling system	Transportation and installation of battery
Battery assembly	
Transport of battery cells and module packaging from East Asia to Norway	

8.1.3. Results and Findings

Embodied emissions of producing a single Powerwall can be calculated several ways. The article gives the result in impact categories with various functional units and three values where the lower-bound value is considered to "better reflect large-scale production volumes" (Ellingsen, et al., 2013) such as the Tesla Gigafactory in Nevada where Powerwall is produced (Tesla, 2017c). The lower-bound value of GWP of the production of a battery is 18 kg CO_2eq/kg or 172 kgCO_2/kWh (Ellingsen, et al., 2013). For the Powerwall, that gives a GWP of

$$125\ kg \times 18 \frac{kg\ CO_2eq}{kg} = 2{,}250\ kg\ CO_2eq$$

or

$$13.5\ kWh \times 172 \frac{kg\ CO_2eq}{kWh} = 2{,}322\ kg\ CO_2eq.$$

Choosing conservatively means using the larger number hereafter. As 60 Powerwalls are needed in this project, there will be emissions of

$$60 \times 2{,}322\ kg\ CO_2eq = 139{,}320\ kg\ CO_2eq$$

associated with production of the battery capacity for the Eco-Block.

Operation of the Powerwall will only consider charging from the PV installations. With a 90% round-trip efficiency (Tesla, 2017a), thus 10% of the energy stored will be dissipated. However, Powerwalls will not be active all day, but rather only be charged and discharged 25 % of the time. The remaining 75 % of the time, is assumed that the electricity production will be consumed instantly at a 100 % efficiency without passing through Powerwalls. That means the weighted efficiency of the Eco-Block electricity consumption with a Powerwall will be

$$90\% \times 0.25 + 100\% \times 0.75 = 97.5\%$$

The electricity passing through Powerwalls is renewable energy where the embodied emissions are accounted for in the LCA of the PV system. The only loss is therefore dissipation of energy, which only slightly decreases the overall system efficiency. Maintenance is not considered as it is stated that it is not required (Tesla, 2017b) and other aspects in the use phase are not considered. End of life is also not in the scope of this report. If we then assume that all the electricity produced by the PV system, 12.06 GWh calculated in section 5.1, will pass through or charge the Powerwalls, the total electricity output from these batteries will be

$$10.06 \times 10^6 kWh \times 0.975 = 9{,}808{,}500\ kWh$$

Per kWh passing through, the total embodied emission of Powerwalls for Eco-Block will therefore be

$$\frac{139{,}320\ kg\ CO_2eq}{9{,}808{,}500\ kWh} = \mathbf{0.014\ kg\ CO_2eq/kWh}$$

8.1.4. Sensitivity Analysis

The study used in calculations in 8.1.3. utilized an electricity mix of 6% coal; 33% nuclear; 15% gas; 4.4% oil; 1.4% hydro; 0.15% wind; 0.12% solar photovoltaic; and 0.044% waste incineration based on production in East Asia (Ellingsen, et al., 2013). Assuming all production of parts and assembly is done at the Tesla Gigafactory in Nevada, emissions would change based on the power mix of the different location. Using the power mix for Nevada shown in Table 25 and the emission factors and calculation method as shown for California in Appendix B gives the total of 582.32 g CO_2eq/kWh, while the number based on the (Ellingsen, et al., 2013) study would be 640.15 g CO_2eq/kWh. That means the production GWP can be calculated as the slightly better value

$$0.014\ kg\ CO_2eq/kWh \times \frac{582.32}{640.15} = 0.013\ kg\ CO_2eq/kWh.$$

Table 25 - Power mix of Nevada (U.S. Energy Information Administration, 2016), (Nuclear Energy Institute, 2017)

Location	Coal [%]	Oil [%]	Natural Gas [%]	Nuclear [%]	Hydro [%]	Biomass [%]	Wind [%]	Solar [%]	Geothermal [%]
Nevada	7.6	0.0	71.5	0.0	4.4	0.1	0.9	6.5	9.8

The study gave resulting values in lower-bound value (LBV), asymptotic value (ASV) and average value (AVV). Out of these, AVV was the most pessimistic estimate (Ellingsen, et al., 2013). It can therefore represent an upper bound GWP value to produce Powerwall with

$$\frac{13.5\ kWh \times 487\ kg\ CO_2eq/kWh \times 60}{9{,}808{,}500\ kWh} = 0.040\ kg\ CO_2eq/kWh$$

If it is assumed that the 10-year warranty covers the expected lifetime of the batteries, replacement after 10 years is therefore necessary with a planning horizon of 15 years. This would mean the GWP would double to 0.028 kg CO_2eq/kWh, as all Powerwalls are replaced. That is still less than the pessimistic estimate based on Ellingsen, et.al.'s study from 2013.

Varying these parameters in the sensitivity analysis give upper, lower and expected GWP as shown in Table 26.

Table 26 - Results of sensitivity analysis for the GWP of Powerwall

Lower bound GWP	0.013 kg CO_2eq/kWh
Expected GWP	0.014 kg CO_2eq/kWh
Upper bound GWP	0.040 kg CO_2eq/kWh

8.1.5. Uncertainty Assessment and Management

There are many assumptions and approximations in these calculations, as well as aspects not considered. For example, installation of the Powerwalls on site is not in the emission calculations. The main environmental impact here is probably transportation of Powerwalls from the manufacturer to the Eco-Block, which is about 230 miles on road (Google, 2017) and causes direct emissions from the fuel as well as the embodies emissions of the vehicle and infrastructure around it. In addition, there are embodied emissions of the extra products and retrofits needed to install the batteries and the impact from transportation and tools of the professional completing this task.

Maintenance is not covered either, which includes traveling for the operator and tools. Taking all these processes into account would likely increase the total GWP associated with the batteries.

It is not clear exactly how similar the Powerwall is to an EV battery. Efforts were made to find a peer reviewed study more similar to the type of battery, but there exists a myriad of factors that differ and cause a very different result in the production of Powerwall.

To account for assumptions made and studies adapted to calculations in this section, a Data Quality Assessment is included in Table 27 to rate different aspects of the data used, where 1 is maximum quality and 5 is minimum quality.

Table 27 - Data Quality Assessment on Powerwall Calculations

Item	**Temporal Correlation**	**Geographical Correlation**	**Independence of Data Supplier**	**Acquisition Method**	**Further Technological Correlation**
Construction of Powerwall	1	2	4	4	1
Embodied Emissions of Powerwall	4	4	2	3	4
Operational Emissions of Powerwall	1	2	4	4	1

8.2. Vertical Axis Wind Turbines (VAWT)

8.2.1. Introduction

In addition to the solar PV panels proposed in the original project outline, this analysis will also evaluate the potential for implementing small, vertical axis wind turbines (VAWT) to increase the block's renewable generation capacity. Some of the advertised benefits of VAWTs include their ability to utilize wind in all directions to maximize efficiency, even load distribution to minimize the vibration in the roof mount, and aerodynamic helical blade design to minimize noise during generation.

8.2.2. Modelling approach and Data

As VAWT deployment has not been widespread up to this point, the resources on their performance and lifecycle emissions are limited. For the purpose of this report, a brief literature review was performed to identify previous lifecycle assessment studies performed on similar turbines. Two reports have examined scenarios similar to the turbine intended for use in the Eco-Block.

First, Uddin and Kumar (2014) examined the environmental impact of vertical axis wind turbines deployed in three locations across Thailand chosen based on their varied wind resource profiles. Unfortunately, all three locations were rural and experienced wind speeds much higher than those expected throughout the Eco-Block. Since the emissions are reported on a per kilowatt-hour basis this would provide a significant underestimate of the emissions associated with this project.

Similarly, Tremeac and Meunier (2009) calculated the life cycle emissions associated with a building-integrated 250W Windside WS-0.3C VAWT produced in Finland. This study provided detailed production and transportation data that will be outlined in the following sections, and adapted to fit our application.

8.2.3. Results and Findings

Production

As wind turbines are inherently void of emissions during operation, all of the lifecycle emissions will occur during production and transport. The main components of the system include two blades made of aluminum and fiberglass and the attached generator which contains mostly steel, aluminum, and copper. The emissions associated with production are estimated based on Finland's average energy mix at the time of the study (30% nuclear, 24% coal, 18% hydropower, and 14% gas mainly). Additionally, average transport distance of 100 km is assumed. Based on these assumptions, the SimaPro software was used to estimate lifecycle emissions values that can be found in Table 28.

Table 28 - Environmental impacts of 250W VAWT

Phase	**Emissions [kg CO_2eq]**
Construction	160
Transport	20
Total	180
Total (kWh^{-1})	0.11

As urban wind speeds tend to be relatively low and highly variable, the turbines are assumed to have 5% capacity factor. This means that they produce 5% of their rated output over the course of a year. Therefore, over the course of the 15-year planning horizon one VAWT will produce roughly 1,600 kWh as shown below.

$$250W \times 8760\frac{hours}{year} \times 15\, years \times 0.05 = 1{,}600\, kWh$$

Dividing the total emissions by the energy output provides the targeted value for emissions per kilowatt-hour, which was found to be **0.11 kg CO_2eq/kWh** for the Windside VAWT.

8.2.4. Sensitivity Analysis

In order to quantify the impact variability in the operating assumptions may have on the embodied emissions, a sensitivity analysis was performed. Here the two primary categories of uncertainty are related to the construction and transport of the vertical axis wind turbines. The construction emissions were calculated based on Finland's average energy mix, and the transportation emissions were based on distribution by boat and truck from the factory in Finland to the facility in South France. It is clear that the embodied emissions of the VAWTs used on the Eco-Block cannot be perfectly represented by these numbers, so each of the emissions categories were assigned +/- 50% variability. Assuming the eight VAWTs would generate 1,600 kWh per year over the 15-year planning horizon we were able to bound the embodied emissions of 1,400 kg CO_2eq with lower and upper bounds of 700 and 2,000 kg CO_2eq, respectively.

8.2.5. Uncertainty Assessment and Management

A few key components involved with the implementation of vertical axis wind turbines on the Eco-Block require further consideration before a decision could be made. First, it is unclear at this point which of the units have roofs suitable for mounting a VAWT, which means that there is uncertainty in the number of turbines that could be integrated into the block's grid. Additionally, variability in urban wind resources could result in significant divergence from the five percent capacity factor assumed for the purpose of this study. This would affect the total expected generation and the viability of the VAWTs as a reliable generation source for the Eco-Block. Finally, without proper load data it is hard to determine whether or not it will be necessary to include wind in the block's generation profile. Considering the total estimated generation will be several orders of magnitude smaller than the solar panels, we do not foresee the turbines becoming an essential part of the Eco-Block.

9. Summary of Alternatives

In order to evaluate the feasibility of the proposed alternatives for generation and storage a few different criteria were used. For the vertical axis wind turbines, we wanted to see whether or not they would represent a significant contribution to the electricity generated on the block. In addition, with the Powerwall, our goal was to make a comparison of the lifecycle emissions to those associated with the flywheel system from Amber Kinetics.

Implementing a Powerwall system like to the one modeled in this report would represent a lifecycle emissions savings of roughly **110,000 kg CO_2eq** compared to the proposed flywheel bank over the fifteen-year planning horizon. While there are certainly other criteria by which a battery's performance can be evaluated, our analysis suggests that the Powerwall would significantly reduce the Eco-Block's overall environmental footprint.

With an estimated generation of 1,600 kWh per VAWT over the course of fifteen years, no reasonable number of turbines can be installed on the block that would represent a significant contribution to the electricity generated by the solar array (12 GWh). For instance, if turbines were placed on each of the existing streetlights the flywheels would generate roughly 0.4% of the energy produced by the solar panels, and with less than thirty buildings, this does not appear to be a feasible or worthwhile solution. Therefore, we would not recommend implementing VAWTs into the block's generation profile.

10. Interpretation and Discussion of Results

In this section, we will assess the lifecycle GWP of the block before and after the retrofits. We will refer to the scenario before retrofits as the "base case", and after as the "Eco-Block." We take into account the GHG emissions associated with the electricity system retrofits, building efficiency retrofits, and the potential added transportation system. We will also discuss the pros and cons of the energy generation and storage alternatives explored in the report.

In our assessment, we consider three potential fates for the PV electricity: home use, EV charging for a 10-vehicle car sharing fleet, and return to the grid. To compare the Eco-Block and the base case side by side we assume the following: the base case is assumed to have zero embodied emissions (no added systems) and operational emissions are assumed to be solely from home electricity consumption and the use of gasoline-powered vehicles. Conversely, the Eco-Block is assumed to have no operational emissions (100% solar powered) however, it has embodied emissions associated with the solar panels, inverter, flywheels, EVs, and EV chargers. Figure 25 shows the GWP of the Eco-Block's energy system (electricity and transportation system) compared to the GWP of the base case over the 15-year planning horizon.

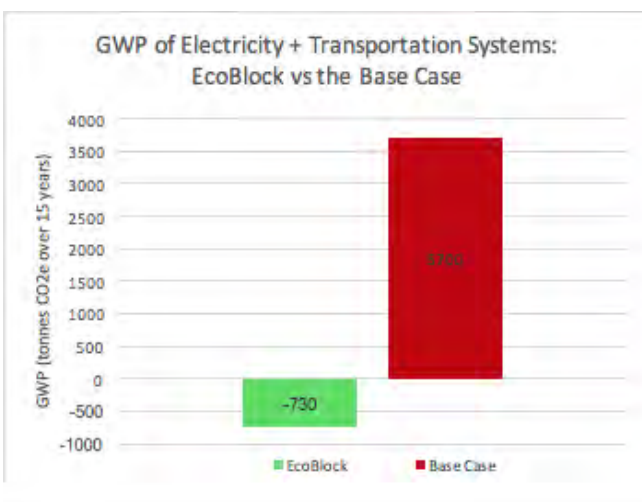


Figure 25 - *GWP of Electricity + Transportation*

In Figure 25 the GWP of the Eco-Block is calculated by subtracting the avoided operational emissions associated with the electricity that is returned to the grid, from the embodied emissions associated with the newly added electricity infrastructure. The GWP of the base case is calculated by adding the operational emissions of the current gasoline powered vehicle use of the block, to the emissions associated with the base case's use of PG&E electricity in their homes. The lifecycle GWP of the combined electricity and transportation system (embodied - avoided operational) is approximately –0.34 kg CO_2eq/kWh of PV generated electricity. The scenario without an EV car sharing system gives us –0.18 kg CO_2eq/kWh of PV generated electricity.

To help inform the decision of whether or not an EV car sharing fleet is worth it from an environmental perspective, we have included our assessment comparing the GHG impact of the Eco-Block with and without an EV car sharing system. Figure 26 shows the difference in GWP of the Eco-Block's energy system with and without the EV car sharing system.

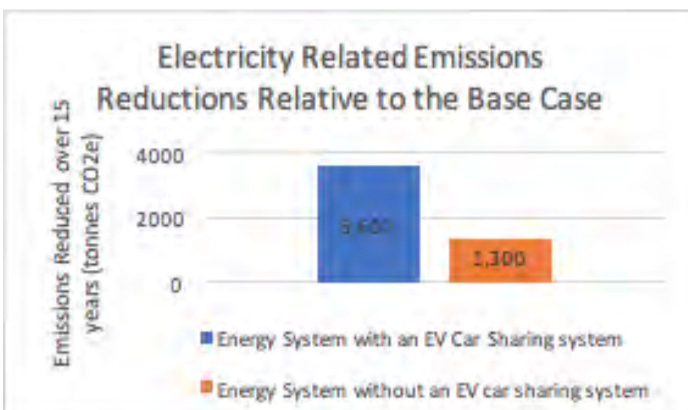


Figure 26 - *Electricity Related Emissions Reductions*

The "emissions reduced" quantity in Figure 26 is calculated by subtracting the avoided operational emissions (gasoline and PG&E fuel mix emissions prevented by switching to solar powered homes and EVs) from the embodied emissions of the added electrical systems (solar panels, inverter, flywheels, EV chargers, and EVs). These "emissions reduced" values include home electricity use, EV car sharing electricity consumption, and electricity returned to the grid.

The GWP of the Eco-Block is heavily dependent on the amount of photovoltaic electricity we generate. After performing a sensitivity analysis, our estimates show that the Eco-Block's home electricity consumption exceeds the lower bound of the PV electricity generation, meaning that there is a possibility that we will not generate enough electricity to power every home. Furthermore, we do not take into account seasonal differences or irregular diurnal load events – our analysis uses an annual average of a modeled building electricity load profile (Bourassa, 2017). Thus, although our estimates suggest that we will generate enough electricity to meet the home electricity needs as well as the EV charging load demand, further analysis must be done to better understand the dynamic between the Eco-Block's electricity generation, consumption, and the associated avoided operational emissions. Figure 27 shows the sensitivity analysis that visualizes the overlap between lower bound generation estimates and upper bound consumption.

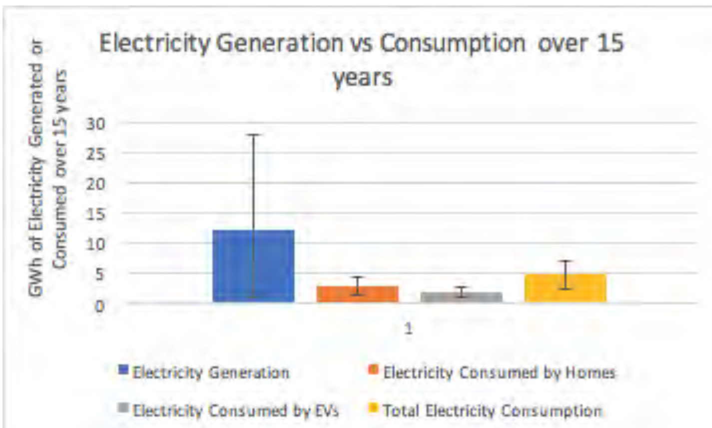


Figure 27 - Electricity generation vs. electricity consumption (see Appendix A for calculations)

The building efficiency retrofits consist of added wall insulation, replacement of single paned windows with double paned, low-E windows, and replacement of inefficient lighting with LEDs. We take into account the embodied emissions of the added insulation, new windows, and new lightbulbs. The operational emissions of the wall and window retrofits was quantified by the kg CO_2eq that was saved by improving thermal insulation which in turn reduced the amount of natural gas burned to heat the homes. The GWP of the lighting retrofits is calculated based on the embodied emissions of the LEDs and the avoided operational emissions (the difference between the amount of electricity consumed by LEDs vs. incandescent bulbs assuming they are powered by the PG&E electricity fuel mix). Figure 28 and Figure 29 highlight the difference in GWP before and after the building efficiency retrofits.

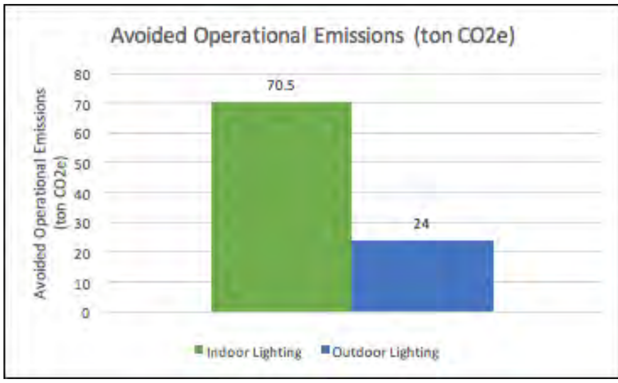


Figure 28 - *Operational emissions of efficiency Retrofits*

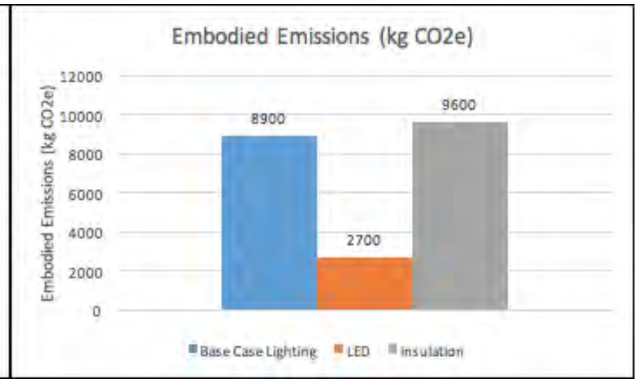


Figure 29 - *Embodied emissions of efficiency retrofits*

Our assessment of the thermal insulation retrofits signaled that replacement of the windows with double paned, low-E windows, had a negligible effect on the overall system, thus we advise the use of more accurate building efficiency modeling techniques to better understand if window replacements are beneficial to the lifecycle environmental impact of the block, given their high embodied emission content. Based on our findings, we chose to leave out window replacements in the final GWP calculations for building efficiency retrofits. In Figure 30, you see the net GWP (embodied – avoided operational emissions) of the lighting retrofits compared to the addition of blow-in cellulose wall insulation.

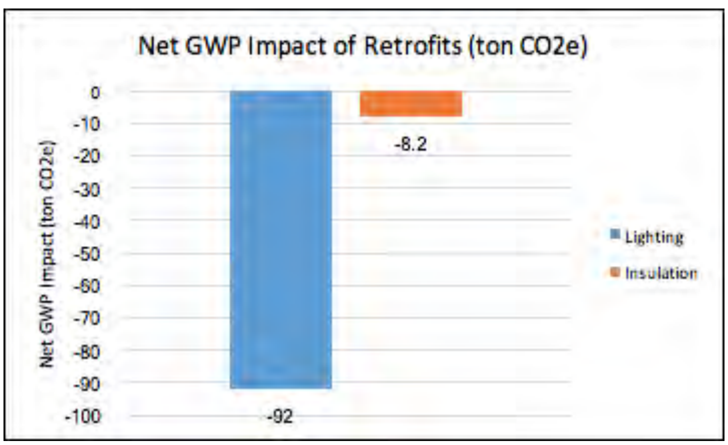


Figure 30 - *Net GWP impact of Building Efficiency Retrofits (lighting and wall insulation)*

In this report, we performed an LCA on comparative energy storage and electricity generation alternatives, namely the Tesla Powerwall as a potential energy storage option and vertical axis wind turbines as a source of additional electricity generation. Our assessment showed us that due to the low urban wind speeds, the VAWTs would produce a near negligible amount of electricity relative to the PV system. If we placed one VAWT on each of the 32 streetlights on the block, they would generate a maximum of 3,400 kWh of electricity per year, about 0.4% that of the solar panels.

The lifecycle GHG impact of lithium-ion battery storage vs flywheel energy storage resulted in an inconclusive finding-- the error range of our calculations makes the decision too close to call. The roundtrip efficiency of the two systems are very similar thus we assume that the impact of the use-phase is negligible relative to that of the embodied emissions. Figure 31 shows the comparison of the analogous storage systems.

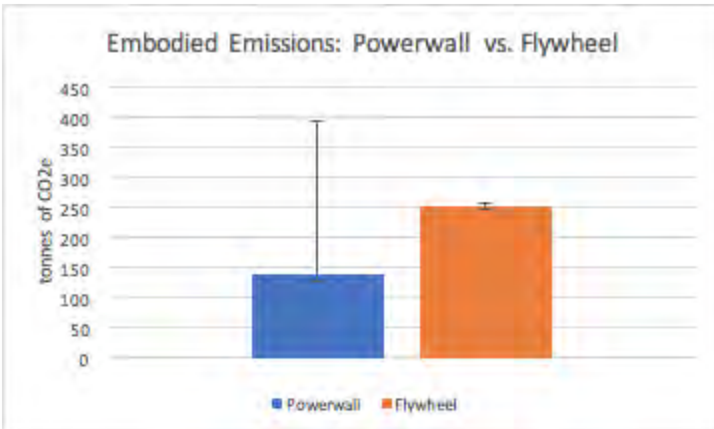


Figure 31- Embodied Emissions: Powerwall vs Flywheel

After comparing the contribution of building efficiency retrofits, electricity system retrofits with an EV car sharing system, and electricity system retrofits without an EV car sharing system, we found that the energy system with an EV car sharing system performed nearly 3 times better than the system without the EV car sharing system. The building efficiency retrofits provide a negligible benefit in comparison. Figure 32, shows the net benefit of switching to the Eco-Block and the performance of the different retrofit scenarios/components.

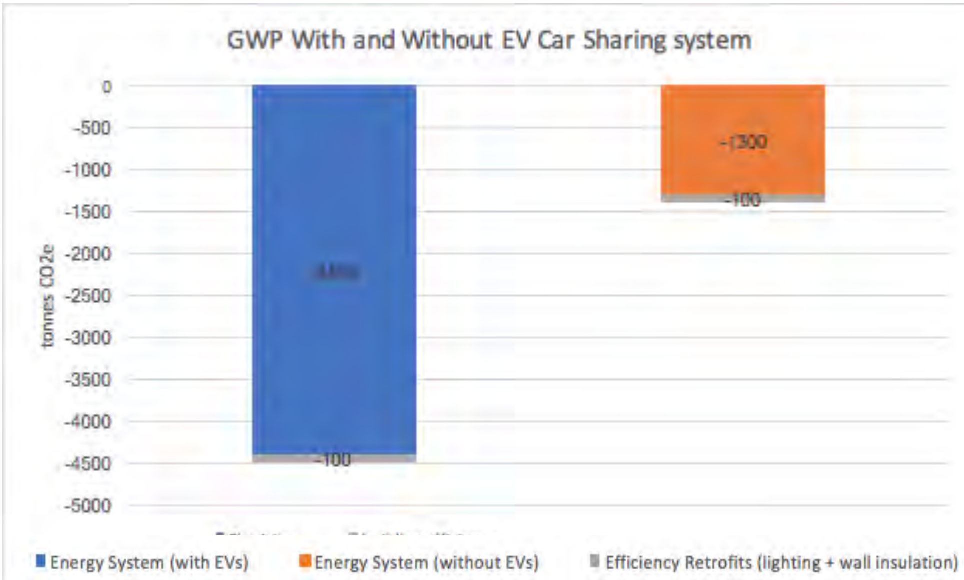


Figure 32 - Lifecycle GWP of the Eco-Block

The final GWP of the Eco-Block given our set parameters is –4,500 tons CO_2eq with an EV car sharing system and –1,400 tons CO_2eq without an EV car sharing system. It is important to note that the building efficiency retrofits, small as their impact may appear to be, have been assessed in this report over a very small timescale relative to their potential lifetime; the impact of improving thermal insulation and switching to LED lighting will most probably effect the energy savings of the block over a far greater time horizon than the 15-year period we allotted them in this study. Similarly, our modeling techniques for building efficiency energy savings involved making simplifying assumptions that should not take the place of a hiring a building efficiency expert.

11. Conclusion and Recommendations

The purpose of this section is to provide a concise overview of the key takeaways from each analysis and make recommendations where possible. This will include the Eco-Block's microgrid, insulation and lighting retrofits, transportation system, as well as the proposed alternatives for generation and storage. Our results are as follows:

GWP with an EV car sharing system = -4500 tons CO_2eq

GWP without an EV car sharing system = -1400 tons CO_2eq

Our analysis of the Eco-Block's proposed microgrid included the solar photovoltaic array, the solar inverter, and the flywheel storage system. It was estimated that the solar PV system would generate 12 GWh over the fifteen-year planning horizon. The embodied emissions of the PV system, inverter, and flywheels came out to 970,000 kg CO_2eq. This provides a perfect example of a trend noticed throughout the study in which the operational emissions avoided by improved technology far outweighed the embodied emissions associated with installing new equipment.

The building efficiency retrofit portion of this study focused on the embodied emissions and energy savings associated with adding wall insulation, replacing windows with double paned low-E windows, and replacing existing lights (indoor and outdoor) with high-efficiency LED bulbs. The most significant component of the building efficiency retrofits were the lighting upgrades. A conservative estimate of lighting replacements produced emissions savings in an order of magnitude larger than any of the emissions embodied in the production and transportation of the bulbs. Also, based on our evaluation of the insulation retrofits, the net environmental impact is negative when the windows' embodied emissions are included, therefore, we recommend only retrofitting the interior insolation and leaving the existing windows in place.

The study also assessed the embodied and operational emissions of different transportation systems. The transportation systems considered five different scenarios. The base scenario considered a regular gasoline vehicle (i.e. Toyota Camry), the four other scenarios considered an electric vehicle (i.e. Nissan Leaf) with four different charging methods (i.e. Level 1, Level 2, Level 3, and Solar Chargers). The assessment showed that the electrical vehicle, regardless of the charging method, produces fewer emissions than the gasoline car. As for the charging methods, they were all comparable except for the solar option, which was significantly lower. The reason being that the emissions associated with the vehicle's operation were near zero for the solar charger whereas the other charging options used electricity from PG&E and therefore had emissions associated with the PG&E fuel mix emission factor. As such, the recommended transportation system is the electrical vehicles with solar chargers.

After further investigating the energy storage and electricity generation alternatives, we concluded that the VAWT provide negligible gain and the Powerwall vs Flywheel dilemma remains unsolved. Our assessment made it clear that the VAWT would not provide enough electricity to warrant implementation. Where the solar array will produce 12 GWh over fifteen years, a conservative estimate suggests that each turbine will only produce about 1,600 kWh. Thus, even if every house on the block were to install a VAWT their total production would not even add up to one percent of the solar photovoltaic system. Furthermore, the similarity in GWP of the flywheel and Powerwall, along with the underlying uncertainty makes the decision too close to call, thus we recommend further analysis into the comparison of the two before a decision is made.

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Appendix A: Electricity Consumption VS. Photovoltaic Electricity Generation

Analysis of solar panel electricity generation vs block load consumption (negative values mean there is more consumption than generation). Here we held home electricity consumption constant.

Lower Bound		
annual kWh consumed	198476.05	kwh/yr
15 year kwH consumption	2977140.75	kwh
15 yr panel generation	1067000	kWh
annual electricity generation	**71133.3333**	kWh/yr
annual difference: gen vs consume	-127342.72	kWh/yr
daily difference: gen vs consume	-348.88416	kwh

Upper Bound		
annual kWh consumed	198476.05	kwh/yr
15 year kwH consumption	2977140.75	kwh
15 yr panel generation	28000000	kWh
annual electricity generation	**1866666.67**	kWh/yr
annual difference: gen vs consume	1668190.62	kWh/yr
daily difference: gen vs consume	4570.38525	kwh

Our Estimate		
annual kWh consumed	198476.05	kwh/yr
15 year kwH consumption	2977140.75	kwh
15 yr panel generation	12.0567	kwh/15 yrs
annual electricity gen	803780	kWh/yr
annual difference: gen vs consume	605303.95	kWh/yr
daily difference: gen vs consume	1658.36699	kwh

Figure 33 - Analysis of solar panel electricity generation vs block load consumption

Appendix B: Emissions from Electricity Production by PG&E in Oakland, CA

The emissions generated from electricity production can be calculated as follows:

$$PG\&E\ Emission\ Facor\ [g\ CO_2eq/kWh] =$$
$$\sum Each\ power\ source\ used\ by\ PG\&E\ [\%] \times$$
$$Life\ cycle\ emission\ factor\ for\ electricity\ generation\ for\ each\ power\ source\ [g\ CO_2eq/kWh]$$

Table 29 shows the electricity power mix of the utility (i.e. for Oakland, CA). A portion of the electricity was unspecified, this portion was not included in the assessment.

Table 29 **-** *Power mix of PG&E in Oakland, CA (Utility Annual Power Content Labels for 2015)*

Location	Coal [%]	Oil [%]	Natural Gas [%]	Nuclear [%]	Hydro [%]	Biomass [%]	Wind [%]	Solar [%]	Geothermal [%]
Oakland, CA[1]	-	0.0	25.0	23.0	6.0	4.0	8.0	11.0	5.0

Table 30 shows the Life Cycle Emission factor for Electricity Generation in the State of California.

Table 30 **-** *Life cycle emission factors for electricity generation. (Horvath & Stokes, 2017)*

	Coal [%]	Oil [%]	Natural Gas [%]	Nuclear [%]	Hydro [%]	Biomass [%]	Wind [%]	Solar [%]	Geothermal [%]
Emission factor [g CO_2eq/kWh]	1059	957	696	17	55	56	31	64	28

Table 31 shows the Life Cycle Emissions in g CO_2eq/kWh for each power source in Oakland, CA. This was obtained by multiplying Table 29 with Table 30.

Table 31 **-** *Life cycle emission factors for electricity power mix in Oakland, CA*

Location	Coal	Oil	Natural Gas	Nuclear	Hydro	Biomass	Wind	Solar	Geothermal	**Total**
	[g CO_2eq/kWh]									

Oakland, CA[1]	**-**	0.23	239.25	3.91	3.30	2.24	2.48	7.04	1.40	**260**

Accounting for transmission loss of 6.58% (CPUC, 2017), our emission factor from using power from PG&E is: 0.26 kg CO2eq/kWh * 1.0658 = 0.277 kg CO2eq/kWh

Appendix C: Calculation of R-values for Walls and Windows Retrofittings

Table 32 - Calculation of R-value for walls and windows before retrofitting (Martin, 2016)

Before retrofitting			
Layer	**Thickness [in]**	**R in studs [F ft^2 hr / Btu]**	**R in cavities [F ft^2 hr / Btu]**
Wall-outside air		0.25	0.25
Wood shingles		0.97	0.97
Plywood sheathing	0.500	0.63	0.63
Studs	3.500	4.38	1.00
Interior paneling	0.375	0.47	0.47
Inside air film		0.68	0.68
Percent for 16" o.c. + additional studs		75 %	25 %
Total wall component R-values		7.38	4.00
Total wall assembly R-value		6.54	
Window (Haberern, n.d.)		1.10	
Window to wall ratio		0.12	
Total wall + window R-value before		**5.89**	

Table 33 - Calculation of R-value for walls and windows after retrofitting insulation and windows (Martin, 2016)

After retrofitting			
Layer	**Thickness [in]**	**R in studs [F ft^2 hr / Btu]**	**R in cavities [F ft^2 hr / Btu]**
Wall-outside air		0.25	0.25
Wood shingles		0.97	0.97
Plywood sheathing	0.500	0.63	0.63
Cellulose insulation, blown	3.500		13.48
Studs	3.500	4.38	
Interior paneling	0.375	0.47	0.47
Inside air film		0.68	0.68
Percent for 16" o.c. + additional studs		75 %	25 %
Total wall component R-values		7.38	16.48
Total wall assembly R-value		9.65	
Window		2.38	
Window to wall ratio		0.12	
Total wall + window R-value after		**8.79**	

Appendix D: Pedigree Matrix Criteria Used for Data Quality Assessment

Based on Junnila, S. and Horvath, A. (2003) "Life-cycle Environmental Effects of an Office Building." Journal of Infrastructure Systems, ASCE, 9(4), pp. 157-166.

Table 34 - Data quality assessment matrix indicators explained

Item	Indicator Score				
	1	2	3	4	5
Temporal correlation	Less than three years of difference to year of study	Less than five years of difference	Less than 10 years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Independence of data supplier	Verified data, information from public or other independent source	Verified information from enterprise with interest in the study	Independent source, but based on nonverified information from industry	Nonverified information from industry	Nonverified information from the enterprise interested in the study
Acquisition method	Measured data	Calculated data based on measurements	Calculated data partially based on assumptions	Qualified estimate (by industrial expert)	Nonqualified estimate
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study, but from different enterprises	Data from processes and materials under study, but from different technology	Data on related processes or materials, but same technology	Data on related processes or materials, but different technology

APPENDIX G: ECOBLOCK: GRID IMPACTS, SCALING, AND RESILIENCE

EcoBlock: Grid Impacts, Scaling, and Resilience

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Introduction

Widespread deployment of EcoBlocks has the potential to transform today's electricity system into one that is more resilient, flexible, efficient and sustainable. In this vision, the system will consist of self-sufficient, renewable-powered, block-scale entities that can deliberately adjust their net power exchange and can optimize performance, maintain stability, support each other, or disconnect entirely from the grid as needed. This vision requires not only effective design of the EcoBlocks themselves to realize these capabilities, but also substantial changes in the operation of the grid itself. Ideally, the transition would be a win-win for EcoBlocks and the grid, and grid operators and planners would be proactive participants in the redesign. However, depending on the design and management of the EcoBlocks, the changes could also be detrimental to the grid and other participants, causing utilities and regulators to resist EcoBlock deployment. Therefore, for this model to succeed, it is necessary to anticipate the range of possible interactions between EcoBlocks and the grid as their number and penetration level scales up. The system architecture must be designed with the final vision in mind to ensure the means of managing EcoBlocks are fully scalable. At the same time, compatibility with today's planning and operational conventions is necessary to facilitate the entry of the first EcoBlocks into the power system.

This report is intended as an independent analysis of the potential relationships, both constructive and adverse, between EcoBlocks and the grid. We thoroughly survey the possible impacts of EcoBlocks and the distributed energy resources (DERs) embedded in them, initially making no assumptions about how the resources are controlled. Then, we evaluate possible strategies for managing both the resources within EcoBlocks and the EcoBlocks themselves, with specific focus on supporting positive impacts on the power system as the EcoBlock penetration level scales.

Of the many potential capabilities of EcoBlocks, we expect adaptive islanding to be particularly transformative. The ability of individual blocks to disconnect from the grid and self-supply their loads during an emergency, then seamlessly re-connect when the problem is solved, is a huge advance in power system resilience. While this is a major shift from how the grid operates today, it is in utilities' best interest to support efforts to improve resilience. Grid resilience is vital for safety and security, public health, and the economy, and is only increasing in importance as the occurrence of extreme weather events increases due to climate change. We therefore give particular attention to the themes of adaptive islanding, resilience and self-sufficiency throughout this report.

Section 1 will outline the diversity of potential impacts, positive and negative, that EcoBlocks could have in the context of today's grid. Section 2 discusses the range of design choices for EcoBlock hardware and operations, as well as the framework for their interactions with the main grid, to shift the balance toward positive impact. Section 3 focuses on the thresholds of penetration level at which specific changes in impact and grid operations may occur. Section 4 summarizes the changes in the form of paradigm shifts in power system functions. Section 5 is a quantitative analysis of resilience under the adaptive islanding paradigm, probabilistically estimating self-sufficiency of islanded EcoBlocks under a range of scenarios. Finally, section 6 presents suggestions for future work.

Contents

1 Overview of potential grid impacts

The potential impacts of EcoBlocks on the electric grid are wide-ranging and depend on the EcoBlocks' physical characteristics, how they operate, and what knowledge and control grid operators have of their behavior. Analyzing the potential impacts of distributed energy resources—including photovoltaics (PV), inverters, electric vehicles (EVs), energy storage devices, and demand response (DR)—is already a significant area of research. Since EcoBlocks are a combination of all of these resources, much of the literature in this area could be relevant for EcoBlocks. The range of potential impacts on loading, resilience, flexibility, situational awareness, and planning are discussed in the following sections and summarized in Tables 1-5. For each of these categories, there are numerous ways in which DERs, and therefore EcoBlocks, can have positive effects or negative ones. Importantly, if the EcoBlock aggregates these resources into a single unit with a single point of connection to the grid, it offers the additional possibility of controlling their behavior in a holistic way to shift the balance toward the positive.

1.1 Loading

Today, there is concern that uncontrolled DERs will negatively impact the loading on distribution systems. For example, if large numbers of electric vehicles are allowed to charge simultaneously or during high load conditions, the increased peak current can exceed the thermal ampacity ratings of lines or transformers [1]. Other significant new electric loads could have a similar effect, for example if gas-powered heaters and water heaters are replaced in large numbers with inefficient electric counterparts. Similarly, during periods of low load and high PV generation, reverse power flow exceeding thermal limits can occur [2]. Upgraded protection devices may be required if the peak current due to new generation or loads exceeds the rating of the existing device. It is also possible for losses to increase as a result of increased real power flow or improper control of inverter power factor, for example if inverters absorb reactive power to regulate the voltage during reverse power flow conditions [3], [4]. Increased peak load and reverse power flow due to EVs and PV also increase the likelihood of undervoltage and overvoltage conditions, respectively, particularly on secondary circuits and long, high-impedance feeders that are most susceptible to voltage problems [1], [2], [5]. If not remedied, voltages out of the permissible range could damage sensitive equipment, including appliances belonging to neighboring customers. Additional or upgraded voltage regulation equipment would therefore be required. Furthermore, when variability in PV generation and electric vehicle charging load cause voltage to fluctuate, voltage regulation equipment such as tap changers may operate more frequently and require maintenance or replacement sooner [5], [6]. EcoBlocks with inadequate coordination among their generation and load resources and/or inadequate energy storage could potentially cause these same problems.

On the other hand, appropriate control of DERs can not only mitigate these negative impacts but even improve conditions relative to the baseline (pre-DER) scenario. These positive impacts arise from the combination of local generation and energy efficiency retrofits leading to low *average* load, plus scheduling of storage and DR to minimize *peaks* in load. First, reduced power flow in lines and transformers would reduce losses, decreasing generation requirements and cost. Optimizing inverter power factor can minimize reactive power flow, further reducing losses [3]. Generally, as electricity demand and distributed generation increase, it is expected that some equipment will become overloaded during times of peak load or generation and require upgrades. However, if EcoBlocks are managed to reduce peak load, the investment in these upgrades could be deferred, allowing a greater renewable energy penetration to be achieved at lower cost to the utility. Optimal scheduling of distributed energy storage has been shown to be effective at reducing peak load on distribution circuits [7], [8]. With high enough penetration of EcoBlocks performing peak load shaving, congestion at the transmission level could also be reduced. Additionally, if the power flow on distribution lines can be lowered, the voltage drop is also lowered. As a result, the voltage at the feeder head can often be reduced while still maintaining voltages within the allowable range (within 5% of the nominal value in the United States, according to the ANSI standard C84.1). This technique, known as conservation voltage reduction, has been proven effective at reducing energy demand on many US circuits

Table 1: Potential benefits and caveats of EcoBlocks related to loading.

Benefits	**Caveats**
• Reduced losses due to reduced real power flow • Reduced losses due to reactive power control • Reduced peak load • Deferred equipment upgrades due to reduced loading • Reduced transmission congestion • Reduced voltage drop on distribution circuits • Increased potential for conservation voltage reduction • Reduced wear on legacy voltage regulation equipment • Three-phase balancing	• Potential to cause or worsen loading and voltage problems if EcoBlocks are ineffectively controlled • Benefits highly dependent on EcoBlock assets and controls, and feeder characteristics; loss reduction and voltage improvements may be negligible • Reduced load factor • Potential need for equipment upgrades (e.g. for protection coordination); these may outweigh other upgrade deferral benefits

[9]. Reduced variation in load over time would also reduce variation in voltage. This in turn could reduce wear on voltage regulation equipment such as tap changers or capacitor banks, delaying the need for maintenance or replacement of the equipment. Finally, EcoBlocks could play a proactive role in three-phase balancing, which is not a major concern for utilities at present but is expected to become a bigger issue with the increasing amount of PV and EVs on single-phase connections. The impact of EcoBlock topology on three-phase balancing capability will be discussed further in Section 2.1.

EcoBlocks could in theory provide these benefits with minimal interaction with the grid operator, particularly if most of the customers on a circuit are EcoBlocks, each working independently to flatten their net load profiles at their respective points of common coupling. However, when there are other significant players on a circuit—for example, large or numerous customers not in EcoBlocks, or a large variable generation resource—nearby EcoBlocks could also be recruited to compensate for these and reduce the power flow upstream. EcoBlocks with excess generation could also provide power to their neighbors, relaxing the constraints on net load for individual EcoBlocks while still flattening the load profile of the aggregate.

A few caveats with these potential benefits should be noted. First, the benefit of reducing losses and voltage variation is highly dependent on the particular system being considered. Losses and voltage problems are most common on long, rural distribution feeders and improvements through DER could have substantial value, but it is not obvious how the EcoBlock concept will apply to areas with low load density. However, in an urban distribution system where voltage drops and losses already tend to be small, the improvement due to EcoBlocks could be negligible.

Second, EcoBlocks may reduce load factor (i.e. the ratio of average to peak demand) as seen by the grid. Even if they reduce loading in the typical case, they may still occasionally rely on the grid for providing peak load if their local energy resources are insufficient. This would require the grid operator to continue maintaining infrastructure sized for peak load, but with reduced revenue due to the reduction in kWh consumed. This challenge, and potential solutions such as alternative tariff structures for high EcoBlock penetration areas, will be discussed further throughout this report. Finally, the topology of the EcoBlock plays an important role. For example, if the EcoBlock interfaces with the main grid at a single point of common coupling (PCC), then minimizing net load translates directly to minimizing power flowing through that point. The situation would be quite different if the loads connect to the main grid at a different point from the energy sources (PV and storage)—for example if all the loads are AC and interface with the grid through existing service transformers—especially if EVs are included. In this case, the service transformers would need to support all the power flowing from the sources to the loads, and could therefore be at risk of overload even if the *net* load of the EcoBlock is small.

In sum, the potential impacts of EcoBlock adoption on loading and the related issues of voltage, losses and equipment upgrades may vary widely, depending on the capacity of the resources within the EcoBlocks, how they connect to the main grid, and what objectives are used in their control.

1.2 Resilience

The National Infrastructure Advisory Council defines resilience as "the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event" [10]. One major component of grid resilience is the ability to continue serving customers even if parts of the infrastructure fail. The traditional way to achieve this type of resilience is through redundancy, particularly at the transmission level. However, redundant infrastructure requires significant capital investment, and may still be insufficient in the case of major catastrophes. While systems are often designed with N–1 or N–2 redundancy—meaning they can survive a loss of 1 or 2 components—2012's Hurricane Sandy, for example, was an N–90 contingency [11]. At the distribution level, where 90% of outages originate [12], circuits are typically radial, meaning a single failure will often cause an outage for all the customers downstream.

EcoBlocks, positioned at the distribution level and having the capability to operate as islands, have the potential to revolutionize grid resilience. As long as they have the necessary hardware and controls to disconnect and re-connect to the main grid, and sufficient generation and storage to meet demand while islanded, they can continue to serve loads regardless of what has occurred upstream on the main grid. If the investment required to make EcoBlocks self-sufficient is less than that required for an equivalent level of traditional infrastructure redundancy, then EcoBlocks are a favorable business proposition for utility planners. Adaptive islanding would also be, of course, advantageous for residential customers. In the event of major disasters, where the main grid is unavailable for a long time, benefits include improving public safety by keeping lights on, keeping food fresh in refrigerators, and keeping phones and other vital electronics charged. Many critical loads such as hospitals and data centers already have backup power systems, typically in the form of diesel generators. EcoBlock technology would be an upgrade for these customers as well, since solar PV systems do not cause local pollution and do not rely on fuel supply chains.

In addition to serving the customers within the EcoBlock, the presence of a few energized areas can also benefit other people in the region during a wide-area outage. For example, neighbors without power could go to EcoBlocks to charge critical electronics and vehicles that they may need in an emergency. In this way, EcoBlocks could help society cope with disasters even at low penetration levels.

Another way that the adaptive islanding behavior of EcoBlocks may contribute to grid resilience is through avoidance of cascading failures. Cascading failures occur when the protective mechanisms to disconnect grid components during excursions in voltage or frequency inadvertently worsen the grid condition and cause other components to disconnect or fail. For example, inverters tripping offline in response to low voltage can further depress the voltage and thus exacerbate the condition. If EcoBlocks can detect these events, or respond to a command from the grid operator, and automatically disconnect from the grid, they can reduce the loading on the system and potentially stop the cascading failure from continuing. EcoBlocks controlled for disturbance rejection could even prevent a cascading failure scenario from starting at all.

EcoBlocks could also facilitate recovery from outage events, which is currently a difficult process that requires careful balancing of generation and load units that are re-energized step by step. If too much load is added all at once, the generators may not be able to support it and the system will collapse again. EcoBlocks, on the other hand, could be controlled to maintain zero net power exchange while the physical re-connection is in progress, then begin to inject or consume power gradually after ensuring the system is stable.

The adaptive islanding capability of EcoBlocks thus represents a true paradigm shift in grid resilience, which would improve as the number of EcoBlocks scales up. The rollout of EcoBlocks would be desirable both for customers, especially those with critical loads, and for grid operators whose bottom line is to keep

Table 2: Potential benefits and caveats of EcoBlocks related to resilience.

Benefits	Caveats
• Ability to continue serving loads despite outage of main grid • Cleaner and more sustainable power source than diesel backup generators • Ability to help non-EcoBlock neighbors by providing pockets of service during wide-area outages • Prevention of cascading failures • Smoother and more reliable recovery from outage events	• High reliability and large energy resources required for long-term islanding • Loss of protection coordination due to reverse power flow • Potential to increase cascading failure risk by disconnecting at wrong time • Potential to accelerate grid defection • Potentially worse reliability for non-EcoBlock customers, due to reduced utility budget for infrastructure maintenance

the lights on. However, this vision is not without its challenges. First of all, new resources that include their own control systems and generation have the potential to disrupt existing procedures for protection and reliability. Just as disconnecting at the right time could mitigate disturbances, disconnecting at the wrong time could exacerbate disturbances and increase the risk of cascading failures. Also, reverse power flow on distribution networks designed for unidirectional flow can lead to a loss of protection coordination. The operating strategy of the EcoBlock must therefore be well-designed and synergistic with that of the main grid so that these problems are avoided.

The usefulness of the EcoBlock as a backup power system is limited by the self-sufficiency and reliability of the EcoBlock infrastructure itself. If faults occur frequently on the EcoBlock itself, while the adaptive islanding paradigm could prevent them from impacting other customers, it would not help the reliability of service within the EcoBlock. Also, to function in islanded mode for long periods of time (for example, in response to an extreme weather event that destroys grid infrastructure) the EcoBlock must have enough generation, storage, and demand response capacity to be self-sufficient in the long term.

Another challenge with the scaling of EcoBlocks is that as fewer loads and even fewer critical loads remain on the main grid, there would also likely be less motivation and less revenue for grid operators to maintain reliable infrastructure. This could lead to an increase in service interruptions for non-EcoBlock customers. If the cost to customers of upgrading to EcoBlock infrastructure is significant, low-income customers would likely participate later or not at all, and would therefore suffer a disproportionate number of interruptions. It will be necessary to plan in detail which aspects of infrastructure maintenance are the responsibility of the grid operator and which are the responsibility of the EcoBlocks, as well as to design a tariff system that gives each party enough revenue to perform its responsibilities.

The grid defection problem is not limited to EcoBlocks; similar concerns exist for individual customers with local generation and storage. However, as will be shown in Section 5, block-level aggregation is more reliable than individual home self-consumption. Therefore, the option to participate in EcoBlocks may accelerate grid defection. On the other hand, if the EcoBlock design is presented to utilities along with a viable market solution to the grid defection problem, it may be highly appealing.

1.3 Flexibility

In addition to the ability to adapt and recover after a disturbance, grid resilience also requires flexibility—the ability to balance supply and demand dynamically at various timescales. Flexibility services are characterized by the magnitude and direction of the power adjustment (increase or decrease), the starting time and duration of the adjustment, and the location of the resource [13]. Today, multiple markets for flexibility exist at different time scales, from frequency regulation (which relies on automated control with a new setpoint every few seconds) to hour-ahead balancing markets to day-ahead energy markets [14].

Table 3: Potential benefits and caveats of EcoBlocks related to flexibility.

Benefits	**Caveats**
• Increased operating reserves • Increased resource for voltage support, through reactive power control • Increased interruptible load resource • Increased range of locations where flexibility resources are available	• Potential to cause local problems while providing higher-level services • Burden of optimally dispatching and communicating with large number of blocks

Since EcoBlocks include a diversity of resources that can increase or decrease net power, and some with flexible time of operation (such as energy storage), they have the potential to perform a range of services while connected to the grid. For example, energy storage can be treated as operating reserves and dispatched quickly to meet demand. If vehicle-to-grid power is possible, electric vehicle batteries can also act as a form of reserves. Inverters can be recruited to provide voltage support through reactive power compensation. PV generation can be curtailed if it is causing unfavorable conditions. In addition, since EcoBlocks can island and reduce consumption, they can act as flexible or interruptible loads in order to help the grid operator manage situations such as supply shortages and voltage constraints. Increased penetration of EcoBlocks would be expected to improve flexibility (assuming they all choose to offer flexibility services), since it would not only increase the overall capacity of the flexibility resource, but also the number of locations where the resources are available. One concern with DERs participating in flexibility markets is that in the process of performing one service they may cause other problems. For example, distributed resources performing services for the transmission level such as frequency regulation could cause voltage problems locally. Widespread deployment of EcoBlocks could mitigate this issue by allowing grid operators to select the optimal EcoBlocks to dispatch, although the success of this approach would depend greatly on the quality of distribution-level circuit models and the grid operator's knowledge of the EcoBlocks' characteristics. EcoBlocks will be a particularly useful resource if they can perform the services at a lower cost—for example, if the cost of interrupting EcoBlocks is lower than that of other interruptible loads—or if the existing resource is already fully exhausted.

To enable these services, the grid operator must not only know what capacity is available in the form of EcoBlocks, but also be able to influence EcoBlock operation, either through direct control or through price signals. The practicality of recruiting EcoBlocks for flexibility will be limited if the grid operator needs to negotiate with each EcoBlock as an individual resource, particularly as the number of EcoBlocks increases. Needing to compute the optimal dispatch of a very large number of EcoBlocks, each having relatively small capacity on its own, could also be a burden. Today, virtual power plants (VPPs) exist to facilitate recruitment of diverse resources, which may or may not be geographic neighbors, for flexibility services [15]. An aggregation of EcoBlocks could offer similar services as the VPP, plus the additional option of islanding one or more of the blocks. In this model, the grid operator would communicate with an aggregator representing a group of EcoBlocks and request a service (such as providing a particular amount of power or interrupting a particular amount of load, at a certain time). The aggregator would then decide how to distribute the commands among its EcoBlocks to produce the desired outcome. Alternatively, a location-specific dynamic pricing scheme could be implemented to incentivize EcoBlocks to behave in desirable ways. Communication would be straightforward, if the grid operator simply broadcasts price signals without negotiation, but significant computation would still be required in order to determine the prices that would cause the desired behavior.

Table 4: Potential benefits and caveats of EcoBlocks related to situational awareness.

Benefits	**Caveats**
• Reduced uncertainty due to statistical aggregation of resources • Reduced uncertainty due to active compensation for generation and load fluctuations • Opportunity to install sensing infrastructure and improve visibility	• Increased uncertainty if generation is masked by load • Increased uncertainty if EcoBlocks island without proper notification • Potential to overwhelm grid operator with non-standard communications and large data size

1.4 Situational awareness

Situational awareness refers to knowledge of conditions in the grid including physically installed grid infrastructure, past and present states of the network (e.g. voltages, power flows, and switch status), and the health and security of the network and its components. This knowledge helps grid operators make decisions that are safe, efficient and economical. Historically, the focus has been on observability of transmission systems; monitoring distribution systems, with their smaller signals of interest and much greater numbers of nodes, has generally not been considered worth the investment. However, with the increasing penetration of DERs, particularly variable and unpredictable generation such as PV, visibility at the distribution tier is becoming increasingly important as well.

Variable and unpredictable generation can present a significant challenge for situational awareness. In particular, when PV generation is behind a net meter, the grid operator is only able to see the net load; the total amount of load is masked by the generation. As a result, net load may fluctuate significantly when clouds pass over, but it is challenging to predict the magnitude of these changes. The grid operator is also unaware of the cold load pickup requirement should an outage occur. It is possible that EcoBlocks could increase these forms of uncertainty, thereby increasing exposure to contingencies. This would occur if the EcoBlocks allow the net load at their PCC to fluctuate freely (i.e. if the storage does not smooth the net load curve adequately) and if the grid operator lacks information on their generation and consumption. Uncertainty would be further increased if the EcoBlocks disconnect and re-connect from the main grid at their convenience without communicating with the grid operator. In this case, the grid would be exposed to sudden increases or decreases in net load as EcoBlocks connect and disconnect, without awareness of the total number of EcoBlocks connected at each moment in time.

On the other hand, uncertainty could also be reduced due to the aggregation of the generation, load, and storage resources within EcoBlocks. Although the generation and load may fluctuate on their own, storage or demand response with sufficiently fast response time could compensate for these fluctuations and maintain the net load within a reasonable range. In this case, EcoBlocks would greatly reduce uncertainty compared to PV systems without integrated storage. Furthermore, variability of PV generation tends to decrease with spatial distribution of the PV systems, because passing clouds impact only some of the panels at a time [16], [17]. As a result, for a given PV penetration on a circuit, variability would be reduced if the PV panels are distributed across many homes in many EcoBlocks rather than concentrated in one large array. These reductions in variability are not only beneficial in terms of uncertainty, but would also reduce voltage volatility and related issues such as excessive operation of tap changers.

The design and retrofit process for the EcoBlocks also presents an opportunity to install monitoring and communication infrastructure to improve situational awareness. For example, a device such as a micro-phasor measurement unit (μPMU) [18] could be installed at the PCC of each EcoBlock to measure AC current and voltage phasors. Additional sensors on the EcoBlock's DC system could monitor behavior of components inside the EcoBlock, such as PV generation and charging rates of the storage and EVs. This data could be transmitted to the grid operator to disaggregate the net load observed at the PCC and aid in the prediction of future conditions. The potential challenge of the EcoBlock connecting and disconnecting at will could also be remedied with communication. For example, the EcoBlock could simply notify the grid operator when it connects or disconnects, or it could request confirmation from the grid operator beforehand. If the switch to disconnect the EcoBlock from the grid is on the AC side of the inverter, a μPMU could independently validate the switch status by measuring the voltage angle difference between the EcoBlock and the main grid. With all this information, EcoBlocks could not only avoid worsening situational awareness, but in fact increase visibility at the distribution level from what it is today. The ability to observe previously undetected problems on the grid, coupled with controllable resources located at the same site as the sensors, has great potential to improve power quality, reliability and efficiency.

It should be noted that since grid operators are already exposed to large amounts of data and frequent alerts, more information is not always better for situational awareness. With a large number of EcoBlocks in a system, visualizing information from every one of them could prove overwhelming for the grid operator, complicating their decision making or obscuring more urgent problems. Therefore, some sort of aggregation would be essential to condense the data from a large number of EcoBlocks into a smaller number of messages that are useful and actionable for the grid operator. What exactly these messages should be, and how to distill them from the data, is an active area of research [19]. This wealth of information could also support automated operations, including control of the EcoBlocks themselves, in situations not requiring human involvement. For automated operations and human operators alike, the use of non-standard communication schemes for EcoBlocks could complicate interactions and compromise situational awareness. Therefore, the communication protocols and data formats should be standardized across all EcoBlocks so that the new data sources can easily be integrated into a unified monitoring framework.

1.5 Planning

Today, utilities are responsible for calculating the PV hosting capacity of their feeders for compliance with power quality and network constraints. This process requires an accurate model for each feeder in question, since the impact of PV depends on the characteristics of the circuit, and a large number of simulations to represent the range of possible installation locations and sizes. If the hosting capacity on a circuit is low or unknown, impact studies for proposed PV installations are required even at low penetration. The utility may also choose to mitigate the expected PV impacts by upgrading conductors or transformers, or installing new voltage regulation equipment [20]. Both of these options increase costs and disincentivize PV adoption. On the other hand, suppose the designer of an EcoBlock guarantees the EcoBlock will have certain behavior—e.g. limits on power and its rate of change—regardless of the actual amount of PV present. Then, not only can the permissible PV penetration levels increase, but the burden of calculating them can be shifted away from the utility. Additionally, as discussed in section 1.1, equipment upgrades can be deferred if EcoBlocks reduce peak load and voltage range compared to an uncontrolled DER scenario. Of course, it is essential for these calculations to be dependably correct: if they are not, the planning burden for the utility would not decrease, or could even increase, if they must both check the EcoBlock designer's work and redo some of the calculations.

Although EcoBlocks may have positive impacts on planning for normal operation scenarios, they may require additional upgrades to ensure proper protection coordination. Several protection issues can occur when there is significant PV penetration on a circuit. For example, excessive reverse power flow could trip protection devices in non-fault conditions, or additional fault current due to PV could exceed the interruption rating of existing protection devices. If the substation current is very low due to large amounts of generation downstream, a fault might not cause the substation breaker to trip. Atypical power flow conditions could also cause the wrong protection devices to operate: for example, if EcoBlocks on one feeder are providing power to another feeder, and a fault occurs on the second feeder, the protection on the first feeder might operate first, which is not the correct response. These problems would become more likely with higher penetration of EcoBlocks, requiring the utility to perform protection studies and potentially upgrade devices. It is worth evaluating whether the EcoBlock designer can participate in the design of new protection schemes, for example by incorporating certain protection devices into the EcoBlock to

Table 5: Potential benefits and caveats of EcoBlocks related to planning.

Benefits	Caveats
• Increased permissible PV penetration levels • Improved ease of PV hosting capacity determination and other planning studies if EcoBlocks participate • Equipment upgrade deferral • Potentially improved power quality and reliability in the neighborhood, e.g. through harmonic cancellation and voltage support	• Increased planning burden for utility if EcoBlock calculations are unreliable • Need for protection studies and possibly upgrades • Potentially worse power quality and reliability in the neighborhood due to grid defection or inadequate EcoBlock management

ensure that it does not cause certain protection coordination issues. This way, the burden for the utility of designing (and installing) protection schemes for circuits with EcoBlocks could be reduced. Again, of course, accuracy and reliability of the EcoBlock designer's contribution to protection design are vital to ensure that EcoBlocks do not worsen or cause dangerous situations.

Unless a circuit consists exclusively of EcoBlocks, the potential positive or negative impacts on power quality and reliability for non-EcoBlock customers must be considered. The planning process must therefore also include establishing guidelines and accountability for these impacts. EcoBlocks could improve power quality in their vicinity if their inverters are used for harmonic cancellation and their DERs provide voltage support (such as actively reducing voltage volatility and canceling flicker). On the other hand, they could worsen voltage volatility and harmonics. EV charging in particular can cause significant harmonic distortion, which can accelerate transformer aging and damage sensitive electronic loads [21]. As discussed previously, EcoBlocks could also mitigate disturbances or exacerbate them, including preventing or contributing to cascading outages, depending on how they are controlled. The non-EcoBlock customers on the circuit are exposed to these same risks, but without the safety net of local backup power and islanding capability that the EcoBlocks have. To avoid these issues, particularly as the penetration of EcoBlocks increases, EcoBlocks should be held to a high standard in terms of power quality and reliability impacts. For example, they could promise to keep their harmonics injection within certain limits, offer control of their resources for voltage support, and design their islanding schemes to minimize the risk of exacerbating disturbances. If the EcoBlocks themselves are not responsible for maintaining an acceptable level of power quality and reliability, then the utility must take up the responsibility. Since this would require additional investment on the part of the utility, and charging the near-zero-net-energy EcoBlocks by the kWh would produce insufficient revenue at high penetration levels, a new tariff structure would be required to keep rates from increasing for non-EcoBlock customers.

1.6 Summary

Since EcoBlocks are at heart a collection of PV generators, energy storage, electric vehicles and other loads, they could potentially cause all the problems associated with uncoordinated operation of these components. But with appropriate design and control of the resources within the EcoBlocks, plus communication with the grid operator, it should be possible not only to avoid these negative impacts but to add positively to grid performance and resilience. In an ideal scenario, EcoBlocks would present a smooth net load profile to the grid, minimizing losses and voltage problems and reducing uncertainty; revolutionize resilience and flexibility through adaptive islanding; improve situational awareness through the addition of new sensors and communication channels; assist in planning and delay infrastructure upgrade needs. It is crucial to understand the "control knobs" in the design of the EcoBlock that will avoid the negative outcomes and facilitate the positive ones. These design choices center around the specific assets in the EcoBlocks, their operating strategies, and how they interact with the grid operator. The next section will elaborate on these choices and how they can enable the positive scenario, particularly as the number of EcoBlocks scales up.

2 EcoBlock design for positive impact

From the potential impacts discussed above, a set of functional requirements for EcoBlocks and the system surrounding them can be outlined:

- While connected to the main grid, the EcoBlock should be able to control the net power it exchanges with the grid. At a minimum, this requires control of energy storage charging and discharging. The ability to modify the consumption or timing of some loads and to curtail generation would further expand the range of net power available to the EcoBlock. This control capability will allow optimization of the EcoBlock net power, for example to flatten the net-load curve or to minimize costs, or at least ensure no constraints are violated. Ability to tune reactive power, e.g. through the inverter power factor, would offer an additional control knob for further optimization.

- Some communication is needed to indicate what the EcoBlock's net power should be. This could take the form of a direct command sent by the grid operator or an aggregator, a price signal, or even peer-to-peer communication with neighboring EcoBlocks. Any entity making decisions requires information (data or models, preferably both) for the resources it controls as well as other relevant network and load characteristics.

- While connected to the grid, the EcoBlock should not adversely affect power quality for its neighbors, for example by injecting excessive harmonics or causing voltage flicker.

- While disconnected from the main grid, the EcoBlock should be self-sufficient. If the islanded portion consists of DC power distribution only, this translates to balancing power supply and demand, while if AC is included, both real and reactive power must be balanced. Therefore, the total rated power of controllable resources (energy storage real power, inverter reactive power, and any interruptible loads) must be sufficient to ensure demand is met without additional input from the grid. The energy capacity of storage resources must also be sufficient to meet demand, at least for a certain pre-determined amount of time.

- To ensure stability while islanded, there must be resources in the EcoBlock with sufficiently fast response time to adjust their output dynamically as load and generation change. Like for longer-term self-sufficiency in the point above, stability here includes real power balancing plus reactive power balancing if AC devices are present. These resources must be controlled to maintain voltage (and frequency, in the AC case) within allowable bounds.

- The components in the EcoBlock should have sufficient reliability and/or redundancy so that if there is a failure on the main grid, the EcoBlock is highly likely to remain operational.

- The islandable portion of the EcoBlock should be able to connect and disconnect from the main grid through a single point of common coupling. If only the DC system can island, the inverter is the natural choice for this point, while if the AC system can island, AC switchgear is required. Ideally, seamless resynchronization would be performed in the AC cases by monitoring the frequency and voltage phasor difference across the switch, then controlling resources within the EcoBlock to match the phasors before closing the switch.

- Any faults occurring in the EcoBlock must be immediately isolated from energy sources within the EcoBlock (PV, flywheel, and any EVs having vehicle-to-grid capability), as well as from the main grid. If a fault occurs on the main grid upstream of the EcoBlock, the EcoBlock must island to avoid energizing the fault. However, if a disturbance occurs that is not a fault, for example a voltage sag due to a momentary load increase on the grid, EcoBlocks can help to remedy the issue by supplying power and should therefore *not* island.

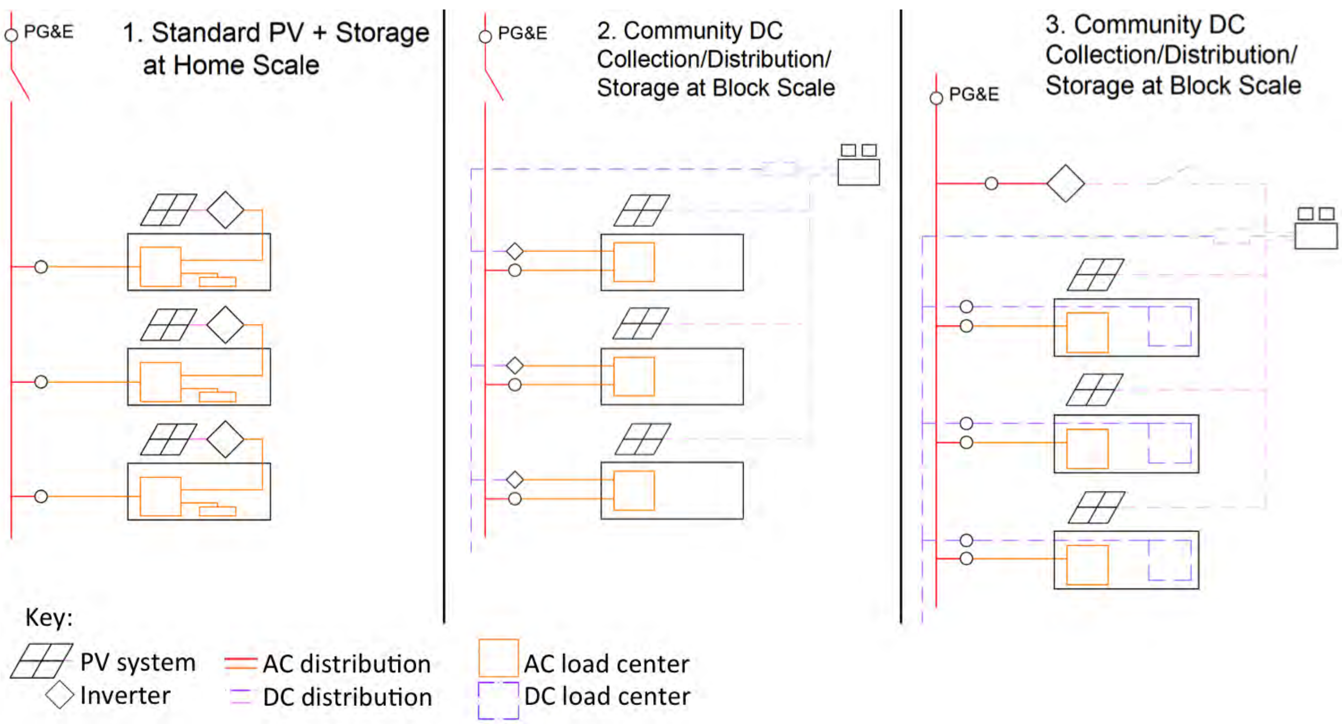

Figure 1: Power distribution scenarios under consideration for the EcoBlock. Scenarios are: (1) standard PV and storage at home scale; (2) community DC collection, distribution, and storage at block scale; and (3) community DC collection, distribution, and storage at block scale with home DC loads. Credit: Integral Group, Inc.

There are several factors in and around the EcoBlocks that will collectively determine their impact. These factors are: installed assets and their capabilities; operating strategies of the EcoBlock itself; the grid operator's prior knowledge of the EcoBlock operating strategy; the grid operator's ability to influence the operating strategy or exercise direct control; and the tariff structure. This section will outline design choices for these factors that could meet the requirements for positive grid impact.

2.1 Installed assets

As illustrated in Figure 1, three power distribution scenarios are considered:

- **Scenario 1: Standard PV and Storage at Home Scale.** Each home has its own PV and energy storage installation. Residents' AC loads are powered by these devices (through inverters located at each home) and by the utility grid. The entire system can be islanded from the grid and the homes have the ability to share power with each other.

- **Scenario 2: Community DC Collection, Distribution, and Storage at Block Scale.** The rooftop PV systems connect to a shared DC bus and charge a shared energy storage system. Residents' AC loads are powered from the DC bus (through inverters located at each home) and by the utility grid. The entire system can be islanded from the grid.

- **Scenario 3: Community DC Collection, Distribution, and Storage at Block Scale with Home DC Loads.** The rooftop PV systems connect to a shared DC bus and charge a shared energy storage system. Both DC and AC power are distributed to homes, which have a combination of AC and DC loads. A central inverter allows for power exchange between the DC bus and the utility grid. Only the DC bus stays energized when the system islands.

The hardware requirements for the EcoBlock to perform the desired functions include some requirements that are common to all three scenarios and some that depend on the scenario. These requirements are listed in Table 6. While additional hardware will be required depending on DC voltage levels, EV charging needs, demand response capabilities and other design choices, this discussion is limited to the requirements for desired grid impacts and general resilience.

Table 6: EcoBlock hardware and important characteristics. For characteristics specific to a particular power distribution scenario, the scenario number is given in parentheses.

Asset	**Important Characteristics**
PV systems	Located on all feasible rooftops. Size for net-zero energy with expected energy efficiency retrofits and full EV deployment.
Energy storage	Located at each house (1) or central (2,3). Size based on duration of islanding that is desired (see section 5).
Inverter	One per home (1,2) or per EcoBlock (3). Size based on each customer's generation (1), each customer's load (2), or total EcoBlock generation + storage power rating (3). Bidirectional (3). Should allow control of power factor.
DC charge controller	One per home (1) or per EcoBlock (2,3). Sufficiently fast response time to maintain system stability while islanded.
Energy manager	Master device that optimizes power injections and extractions of controllable components in EcoBlock (see section 2.2). Could be combined with charge controller (2,3), or could be separate entity that sends commands to charge controller.
Cables within EcoBlock	Underground, for resilience against weather events and vegetation. Should be sized to support anticipated EV charging loads.
Service transformers	If the PCC is upstream of the transformers, they should serve only EcoBlock customers so that only EcoBlock customers participate in islanding.
Switchgear	Either AC (1,2) or DC (3). If AC, must be able to communicate with resources in the EcoBlock to match phasors for resynchronization after islanding (1,2).
AC sensor (μPMU)	At PCC. If on EcoBlock side of switch, can be used to match phasor to rest of feeder for resynchronization (1,2).
Other meters	Measure power flows and voltages within EcoBlock, including PV generation, storage charge/discharge rate, and power exchanged with grid. Some of these may already be integrated into other components such as inverter or charge controller. Will be AC or DC in different places depending on the scenario. Should also include meters for utility billing purposes.
Real-time communication channel with grid operator	Send data to grid operator and receive signals for desired EcoBlock behavior (see section 2.3).
Protection devices at individual homes	Interrupt fault currents and isolate faults at homes from rest of EcoBlock. AC (1) or both AC and DC (2,3).
Protection devices for entire EcoBlock	Interrupt fault currents and isolate faults on EcoBlock from generators, storage and rest of grid. AC (1) or both AC and DC (2,3).

The choice of AC or DC power distribution, or both, has many important implications for the management of individual EcoBlocks as well as their relation to the wider grid ecosystem. Protection is more straightforward for AC systems than for DC, since current can be interrupted easily at the zero crossing that occurs twice per AC cycle. On the other hand, DC power islands are easier to manage than AC because they do not require frequency regulation or reactive power balancing, and because they do not need to be synchronized with the main grid before re-connecting. If large amounts of load remain connected to the grid when the EcoBlock islands, as would be the case in scenario 3 if most load remains on the AC system, then present-day restoration problems such as cold load pickup may continue to exist. Considering these tradeoffs, as well as the efficiency benefit of DC power for many loads, the best option in the long term may be to choose scenario 3 and incentivize as many loads as possible to migrate to the DC system—relying on continued innovation and commercialization of DC protection devices.

The choice of AC vs. DC is also expected to affect the rates and impacts of EcoBlock scaling. Since AC equipment and loads are more developed technologies than their DC counterparts, the retrofit process would be relatively straightforward and inexpensive, leaving more resources available to accelerate scaling at the early stages. Deployment of DC EcoBlocks would likely take longer to reach the same penetration level due to the increased effort and cost required to retrofit each EcoBlock. However, once large-scale deployment has been achieved, the benefits of DC would become more evident. The reduction in power flows due to higher-efficiency DC appliances, negligible at low penetration, would scale roughly proportionally to the number of EcoBlocks. In addition to facilitating re-connection to the main grid after islanding, the choice of DC could also enable entirely new strategies for managing regions saturated with EcoBlocks. For example, EcoBlocks could connect to each other via a DC link, again avoiding the requirements of synchronization, balancing reactive power and frequency. While we show in Section 5 that connecting two already self-sufficient blocks together does not further improve self-sufficiency significantly, this approach *could* be beneficial in other scenarios, for example if it is more economical to have a large energy storage system shared by several blocks than to design each block for complete self-sufficiency.

This same strategy could even be extended beyond the few-block scale. DC is advantageous for power transmission over long distances due to the lack of reactive power (which reduces losses), reduced capacitive losses in underground and underwater cables, and the lack of phase angle stability concerns. One can envision a scenario where entire power systems—transmission, distribution, and EcoBlocks—are converted to DC simultaneously, improving efficiency and stability across the board and avoiding the need for AC-DC conversion. However, this vision would require a complete overhaul of utility infrastructure and operations, and is unlikely to occur in the near future. Therefore, it is essential for EcoBlocks to be able to participate in the AC grid of today even if their main internal power distribution system is DC.

One way in which EcoBlocks could assist the present-day AC grid is through phase balancing, which is expected to become a more important concern in the near future, as PV systems and EVs may be connected in unequal numbers to the three phases. We expect most EcoBlocks in urban areas to have access to three-phase connections. The balanced three-phase central inverter in scenario 3 would ensure that the installed PV generation does not worsen phase imbalance. The greater the fraction of loads—particularly EV chargers—that are on the DC side, the more balanced the EcoBlock would be. In scenario 1, where there is no DC system, the EV chargers could be connected to each AC phase in equal numbers to improve balancing. In all cases, the EcoBlock construction process would provide an opportunity to determine the homes' phase connectivity and change it if needed. Demand response (and storage, in scenario 1) at individual homes could also be leveraged for dynamic phase balancing, although it would not be fair to count on these resources alone to correct systemic imbalances. If only a single phase is available for the EcoBlock, as in more rural areas, the design could be modified to use a single-phase inverter. The impact of single-phase EcoBlocks on phase balancing requires further evaluation, but in general, deployment of EcoBlocks at the same rate on all phases is likely to be an appropriate strategy.

A final characteristic of scenario 3 worth mentioning is that its design with a central energy storage system and inverter takes greatest advantage of economies of scale. However, these components also represent single points of failure and may limit the reliability of the system. The motivation for deploying EcoBlocks is greatly reduced if they are less reliable than the main grid or have greater maintenance requirements. It may therefore be worth considering investing in redundant infrastructure such as a second inverter. Since it consists of several smaller flywheels in parallel, the flywheel system has some redundancy built in already; the system for managing the flywheels should support an operation mode with one or more flywheels out of service.

2.2 EcoBlock operating strategies

The operating strategy of the EcoBlock should include the following functions:

1. Dynamic power balancing (and reactive power balancing, if applicable) to maintain stability, particularly while islanded

2. Longer-term energy balancing to maintain a reasonable reserve of stored energy

3. Further optimization of power flows, for example to minimize cost, losses, peak load, or power exchanged with the main grid

4. Connection and disconnection from the main grid at appropriate times and without causing major disturbances to either the grid or the EcoBlock

There are a number of possible strategies that could be used to control the hardware listed in the previous section in order to meet these objectives. In centralized control, a single controller computes a target set of conditions (for example, the power flows in or out of each resource) that satisfy some criteria (for example, minimizing losses while maintaining voltage within certain bounds). The central controller then sends signals to each resource, causing the resources to behave in the desired way. This approach is most effective when the central controller has an accurate model of the system, the controllable resources and their constraints, so that optimal behavior can be achieved with minimum iteration. Central control is well-suited for the long-term energy balancing and optimization functions of the EcoBlock (functions 2 and 3) because it provides a single optimal snapshot of the system that every resource agrees upon. It is also appropriate for resynchronization of AC islands (function 4), since the resources in the EcoBlock must be collectively controlled to match the voltage phasors on both sides of the PCC before closing the switch.

However, central control requires communication with every resource and the optimization may be computationally intensive, particularly for systems with many resources and constraints. In topology scenario 1, for example, optimizing the charge and discharge of the energy storage systems located at every home to balance house-level and block-level objectives may be challenging. When a very fast response time is needed, such as for function 1, a decentralized control strategy is preferable. In this case, a resource able to perform decentralized control would immediately adjust its power according to a local control curve: for example, increasing power output if it observes that voltage has gotten too low. If the resources only have local information, though, optimizing their collective behavior for the other three functions is not possible. Therefore, the ideal approach is likely a combination of local control for stability plus some sort of centralized control for optimality [22], [23].

For the centralized layer, there are multiple options for the type of signal the central energy manager sends to its resources. The energy manager may simply command each resource to produce or consume the particular amount of power that is optimal at each point in time. Or, it may send a signal that implies a certain behavior is preferable. For example, in a dynamic pricing scheme, the energy manager would broadcast a price based on present energy availability, and each entity in the EcoBlock would decide how much power to buy or sell. In the ARDA DC microgrid design [22], the energy manager regulates the DC voltage as a control signal. Increasing the voltage signifies that energy is abundant and consumption is encouraged, while decreasing the voltage signifies the opposite. Devices in the system have their own internal algorithms to automate their responses to the voltage signal. The voltage- and price-signaling approaches give each resource more freedom to determine its individual behavior, compared to the command-and-control approach. However, for the energy manager to achieve a particular deterministic outcome with these approaches—for example when performing resynchronization—it either needs accurate models of each resource's behavior, or must iterate after observing the responses to the original signal. There should be an additional mechanism in place to prevent individual actors from doing something detrimental to the group (for example, consuming an unfair share of power in islanded mode when the EcoBlock is at risk of running out of energy.)

2.3 EcoBlock-grid interaction

The potential strategies for managing groups of EcoBlocks on the grid mirror the options for managing the resources in a single EcoBlock. Architectures may be central or distributed, or some hybrid of the two, and control strategies may be direct or indirect. A fundamental question to answer in the design of the EcoBlock-grid interaction is to what degree the grid operator should be able to influence EcoBlock behavior. On one extreme, the grid operator could view the EcoBlocks as fully controllable resources and command them to have a particular net power at each point in time. This approach would ensure the grid operator's objectives are met, but at the expense of optimality for the EcoBlocks. It might not even be possible for EcoBlocks to provide the requested net power at times, depending on their internal generation, load, and storage state of charge. On the other extreme, the EcoBlocks could be allowed to behave however they choose, similar to traditional energy customers today. This would place great responsibility on the utility to ensure grid infrastructure—including utility-scale generation—is sized appropriately to support the range of EcoBlock behaviors. Unless strict limitations are placed on EcoBlock behavior, this approach would only be acceptable for the utility up to a certain hosting capacity for EcoBlocks, above which infrastructure upgrades would be required.

The ideal approach is surely somewhere between these two extremes. The EcoBlocks should make at least a few guarantees to be good citizens on the grid; these include rules for islanding and re-connecting at appropriate times only, and limits on power to avoid constraint violations. Once these rules are set, several options remain for balancing the benefits to EcoBlocks and the grid [8]. One possibility is for each EcoBlock to offer the amount of power it prefers to inject or consume from the grid, or multiple possible amounts with different associated prices. Then, similar to today's energy markets, the grid operator would optimize cost across the offers and communicate the dispatch to the EcoBlocks. Since this option requires bidirectional communication with all EcoBlocks and optimization on the part of the grid operator, it is not well suited to short timescales, and scalability to large numbers of EcoBlocks is limited.

Alternatively, EcoBlocks could offer to provide flexibility services at times when it is beneficial for them. During those times, the grid operator would be able to exercise direct control over them, at least within the range of power injection specified in the offer. EcoBlocks not contracted to provide flexibility at those times would be allowed to operate freely. This approach could also provide a solution to the challenge of maintaining sufficient revenue for the utility when most customers are consuming near net-zero energy. Instead of paying or receiving a rate for each kilowatt-hour they consume or produce, each customer would pay a fixed amount to the utility for the grid infrastructure they rely upon. Then, those that offer flexibility services would receive compensation based on the level of flexibility they offer (regardless of the net energy they end up providing to the grid). The exact amounts for the infrastructure charges and flexibility tariffs would have to be optimized to ensure that the utility can afford to maintain its infrastructure and that there is enough flexibility at all times. It may be challenging for the EcoBlocks to be financially viable with this infrastructure fee model, compared to today's net metering model where customers with self-generation are effectively subsidized. Scaling up the penetration of EcoBlocks would increase the number of variables in the optimization but, importantly, also increase the amount of flexibility available to make this approach possible.

A hierarchical control and communication architecture could facilitate grid-EcoBlock interactions in the high-penetration scenario. Distribution feeders typically serve about 1000 customers each, which would translate to about 30 EcoBlocks per feeder in the 100% EcoBlock penetration limit (assuming roughly 30 customers per EcoBlock). Monitoring every EcoBlock would be unmanageable for distribution operators, who currently monitor only about 5 or 6 signals per feeder. Therefore, aggregating the EcoBlocks into groups of 5 or 6 would be preferred for maintaining a constant level of complexity in distribution operations. The grid operator (and automated distribution management systems) would communicate with this intermediate aggregation level, which would in turn communicate with the individual EcoBlocks in its jurisdiction. Each aggregator should represent a set of EcoBlocks that are geographical and electrical neighbors so that there is a clear point differentiating the aggregator's jurisdiction (downstream) from the grid operator's (upstream).

Recent advances in distribution synchrophasor technology enable a new paradigm in distributed control, in which resources are controlled to track a target voltage phasor rather than a particular power injection [19]. In this model a supervisory controller (grid operator) periodically performs an optimization to determine target phasors for various nodes in the network, then communicates those targets to local controllers, which in turn leverage their local resources to meet the targets. In the EcoBlock case, the local controllers could be the EcoBlock energy managers themselves (in which case the phasor targets would be set at the PCC of each EcoBlock), or there could be an intermediate level of aggregators between the supervisory controller and EcoBlocks, depending on the complexity of the system. There are several potential advantages to this approach. Phasor-based control is uniquely suited to adaptive islanding because tracking a target voltage phasor is precisely what must happen during resynchronization—specifically, matching the phasors on both sides of the switch to be closed. Framing the control objective as a voltage phasor inherently avoids voltage constraint violations and other voltage problems. This approach also promises stability: if something unexpected occurs, for example an EcoBlock disconnects suddenly, the voltage phasors in that region will deviate from their targets and the local controller will immediately know to take action.

Finally, rather than controlling the physical variables of voltage and power, a dynamic pricing scheme could be implemented to incentivize EcoBlock behavior. Here, the grid operator would compute the optimal energy price to offer each EcoBlock at each point in time and broadcast that information; each EcoBlock would then perform a local optimization to determine how much power it should inject or extract from the grid given that price. Compared to options that require negotiation, dynamic pricing should be faster. On the other hand, it is likely to be slower than direct control because at every time step the grid operator must convert from physical variables to prices, then the EcoBlock must convert from price back to its own physical variables. Dynamic pricing may circumvent one of the challenges with direct control: the possibility that the target set by the grid operator is undesirable or even impossible for the EcoBlock. With dynamic pricing, the EcoBlock would always have the option of paying more for a certain amount of power if the benefit is sufficient. However, there is the challenge of how exactly the grid operator should decide the prices. If too many EcoBlocks are offered the same price, there is a risk that they will all behave the same way, reducing diversity and potentially causing new problems. For example, if prices are increased due to a shortage of generation, a large number of EcoBlocks may choose to inject power or reduce demand, turning the supply shortage into an excess. To avoid this, the price would need a high granularity with respect to location. However, excessively high locational granularity could lead to equity issues, for example if one block is consistently charged higher rates than its neighbor because it is at the end of a long feeder with voltage problems.

While challenging, designing the framework for EcoBlock-grid interaction is essential to enable an efficient, resilient and cost-effective scenario with high EcoBlock penetration. We add a few final comments on additional constraints and possibilities.

- The accuracy of the grid operator's (or aggregator's) optimization is highly dependent on the accuracy and completeness of the information they have. This information should include models of the grid infrastructure, or at least the parts of it in their control domain, including connectivity, impedances, and the control schemes of any automated regulation equipment present. It should also include ampacity limits of the conductors and other equipment; voltage constraints; and limits on real and reactive power, rate of change of power, and energy of the controllable DERs. Measurements of physical variables on the network are also important, to provide real-time feedback and to support offline analysis.

- If EcoBlocks are given the freedom to decide their net power, there must be some backup plan (such as automated control, or an option for the grid operator to exercise control) to be used in case of emergency.

- To facilitate interactions between EcoBlocks and the grid, in both planning and operations stages, a third party company (perhaps a spinoff of existing utility companies) could manage the EcoBlocks.

Similar to PV designers and financiers today, this company could work to ensure that plans and real-time operating strategies are favorable for both EcoBlocks and the grid.

3 EcoBlock scaling

As we have discussed throughout the previous sections, scaling the penetration of EcoBlocks from 0 to 100% represents a paradigm shift along multiple axes of power system operation, spanning both normal and abnormal conditions. Fundamentally, the transition to full deployment of EcoBlocks is from a centralized architecture to a decentralized one. Today, the grid and its utility-scale generators are by far the dominant source of power for customers, and in most places still the only source of power. In the high-penetration limit, they will become secondary, relied upon to supplement the EcoBlocks' individual sources only when it is necessary or economical. At the same time, the responsibilities of the EcoBlocks must increase, as they become more and more capable of impacting conditions on the grid.

With the large number of possible impacts, and presumably different deployment strategies in different regions, EcoBlock scaling will likely be a continuous transformation. However, there are a few specific penetration thresholds at which qualitative changes in EcoBlock impacts and capabilities begin to take place. A few of these changes are discussed here, along with the approximate number of EcoBlocks per distribution feeder at which they may first occur. Impacts on the distribution level are expected to occur first: with a lower overall power flow compared to the transmission system, the power injection of each EcoBlock is more significant. Also, impacts such as reverse power flow may require new equipment and operating strategies on distribution circuits designed for unidirectional power flow, while on transmission systems, bidirectional power flow is already expected.

It is important to distinguish between the penetration level at which EcoBlocks become *capable* of producing a certain impact and the level at which they are *likely* to have that impact. This discussion focuses on thresholds of capability because grid operators need to understand and prepare for the range of possible operating conditions, both normal and abnormal. Furthermore, at what penetration level an impact becomes likely to occur depends on the specific operating strategies, which have yet to be fully decided. Awareness of these capability thresholds should help the EcoBlock designer create a plan that appropriately synchronizes the construction of EcoBlocks themselves with the deployment of systems for EcoBlock management.

3.1 Distribution power flow thresholds

The first threshold where EcoBlocks may begin to have impact is when their aggregate load surpasses the pre-existing level of load variability on a distribution feeder. At this point, their behavior becomes statistically observable. To establish this noise floor, the standard deviation of current at the feeder head has been quantified for a few feeders in previous studies with μPMUs. For example, for a particular 12 kV line-to-line residential feeder in the southern United States, the standard deviation of current taken in 10-minute windows is typically between 2 and 6 A per phase (depending on the day and time), or about 0.5-2% of the mean.[1] For a small 12 kV primarily commercial feeder in the western United States, the typical variation is between 1 and 3 A per phase, or 1-3% of the mean, while for a larger feeder in the same region, it is 4-7 A or 2-3%. Under a 1% noise level, for example, a change in power as low as 27 kW per phase on the southern feeder, and 8 and 19 kW per phase respectively on the two western feeders, could be observable. The significance of this result is that if the average load of an EcoBlock is about 40 kW (as expected for the Oakland EcoBlock after the energy efficiency retrofits—not including generation), then even a single EcoBlock transitioning from zero net load (or islanded state) to average load could be

[1] This result was obtained by computing the mean and standard deviation of the current magnitude data stream from a μPMU with 100-millisecond resolution, at 10-minute intervals, for three nonconsecutive weeks spanning different seasons. The middle 80% of the 10-minute chunks were considered the "typical" range of current variation. Major events were excluded from the analysis.

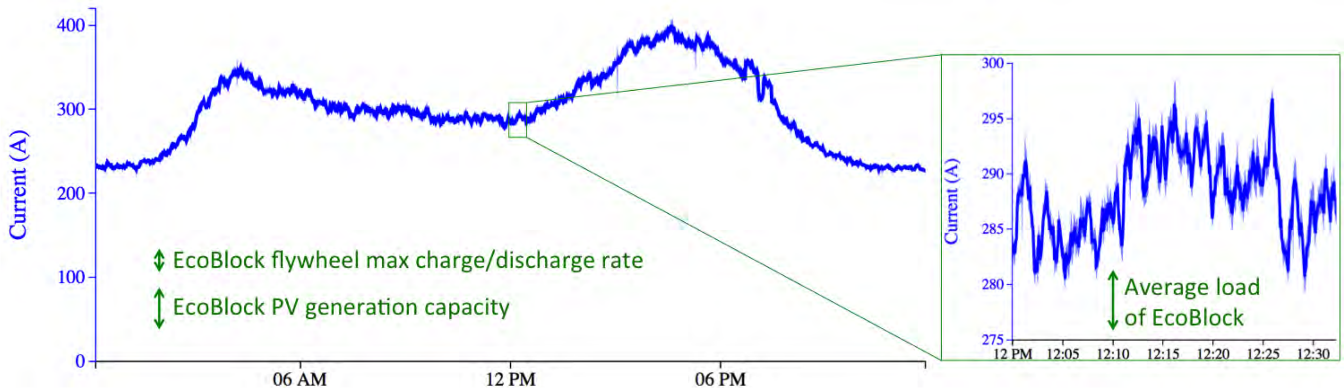

Figure 2: Example of μPMU current magnitude measurements on one phase of a typical 12kV residential distribution feeder for a spring day, to indicate magnitude and variability. Inset: half an hour of data at a higher zoom level, showing minute-to-minute variation. Magnitudes of the Oakland EcoBlock's PV generation capacity, flywheel charge/discharge rate, and estimated average load are shown on the same scales, for comparison with feeder load current and variability.

observable, depending on whether it has a single-phase or three-phase connection. However, the 10-minute time window was intentionally chosen to capture the effects of individual loads while neglecting the effect of time of day. The change in load from off-peak to peak times of day on these feeders is about an order of magnitude greater than the standard deviation in the 10-minute windows. Therefore, while a major shift in power at a single EcoBlock may be observable compared to the noise, it falls well within the normal daily range of load and is unlikely to impact operations. Figure 2 provides a visual indication of how some possible "signals" due to EcoBlock behavior would compare to the "noise" of existing feeder load variability. The figure shows an example current magnitude trace for one of the feeders, measured by a μPMU, to demonstrate the typical magnitudes and variability over the course of a day and from minute to minute. The current levels corresponding to certain EcoBlock characteristics (PV generation capacity, maximum flywheel charge/discharge rate, and average load) are compared on the same scales.

The second threshold is where there are enough EcoBlocks that their collective behavior could trigger a control action, either taken by a distribution operator or automatically. For example, a sufficiently large change in current would trigger an automatic tap change operation under a line-drop compensation scheme. This threshold is highly dependent on the feeder impedance characteristics, which determine how sensitive the voltage is to changes in load, and on the specifics of the line-drop compensation scheme. In one example, a change in current of 70 A per phase (on an 11kV line-to-line feeder) triggers a tap change operation [8]. This magnitude of current change is equivalent to, for example, the 200-kW flywheels in two EcoBlocks transitioning from zero to full charge or discharge rate. This is the threshold where the operating strategy of the EcoBlock begins to influence grid operations directly. If the EcoBlock operating strategy allows the power injection to fluctuate frequently over a large range, then at this penetration level it may have adverse effects such as accelerated wear on voltage regulation equipment. On the other hand, if the EcoBlocks manage their power injection, and infrastructure for grid interactions is already in place, EcoBlocks can avoid these adverse effects and may begin to counteract the impacts of other variable generators or loads on the grid.

Third, when the maximum power injection from EcoBlocks surpasses the minimum load on a feeder, reverse power flow becomes possible. The maximum possible power injection at midday is equal to the sum of the PV generation capacity and the energy storage maximum discharge rate; at night it is just the energy storage maximum discharge rate. The threshold at which EcoBlocks are likely to enable reverse power flow therefore depends not only on the minimum load itself but also at what time of day it occurs. For the prototype Oakland EcoBlock, we assume the maximum PV generation is 360 kW, the maximum discharge rate of the flywheel system is 200 kW, and the minimum load in the EcoBlock is small by comparison, and compare to the daytime load of the three reference feeders analyzed above. For the residential feeder, the minimum daytime load is approximately 2 MW per phase. If 4 EcoBlocks per phase were deployed on this feeder, and both their PV generation and flywheel discharge rate were at maximum, they could cause reverse power flow. Similarly for the commercial feeders, under the same conditions, just one EcoBlock per phase on the smaller feeder and 3 on the larger feeder could cause reverse power flow. Today, reverse power flow is often considered a problem (for protection coordination and voltage regulation), but it can also be viewed from a much more positive standpoint. When EcoBlocks have the potential to cause reverse power flow, it signifies that they are capable of supporting the other loads on the feeder if it is necessary or economic, and they are crossing the threshold into being able to support other parts of the grid as well.

3.2 Topological thresholds

While the impacts above relate to the number of EcoBlocks on a feeder and are relatively independent of topology, there are a few additional impacts that do depend on topology and where the EcoBlocks are located in a system. Different strategies for EcoBlock deployment may make sense depending on what the priorities are in the particular system. For example, customers at the end of a feeder have the greatest impact on voltage because power flowing between them and the substation travels along the entire length of the feeder, causing the greatest voltage drop. Therefore, for feeders with pre-existing voltage problems, the ideal EcoBlock deployment strategy may be to prioritize locations at the end of the feeder, and manage the EcoBlock net power in order to regulate voltage. This strategy would mitigate the voltage problems as quickly as possible.

Often, feeders or sections thereof can be completely isolated from the rest of the grid by switches or breakers. A section entirely made up of EcoBlocks could potentially be operated as an island in the event of a problem on the main grid. Allowing EcoBlocks to share power could help overcome generation-load mismatches on individual blocks, improving resilience compared to the case where each block operates independently. This would be especially advantageous in long-term grid outage scenarios and if generation and load are highly variable on some of the EcoBlocks. While a section containing non-EcoBlock customers could also be islanded in this way, the self-sufficiency of the island would be reduced if they do not contribute generation, and managing both EcoBlock and non-EcoBlock customers in the same island might be challenging. Therefore, in areas that are at high risk of outages—for example, if they interface with the main grid through a small number of low-reliability connections—the ideal deployment strategy may be to fully populate islandable sections with EcoBlocks one at a time, before moving on to lower-risk areas.

Although sensing infrastructure can of course be deployed independently of EcoBlocks, system observability could be an additional benefit of high-penetration EcoBlock deployment. Assuming that each EcoBlock is accompanied by a monitoring device such as a μPMU at its point of common coupling, there will be a threshold at which the penetration of monitoring devices affords full observability of the system. Full observability requires a large fraction of the nodes in a system to be monitored; the exact fraction of nodes needed is dependent on the system topology. Optimal PMU placement algorithms have been developed to enable observability of distribution systems with the minimum number of sensors [24].

3.3 Beyond the distribution level

A threshold for utility financial operations will occur when there are enough near-net-zero energy EcoBlocks (or other "prosumers" with significant DERs) in a system that traditional energy rate structures are no longer feasible to cover grid infrastructure maintenance costs. At this point, utilities should already have a new business model in place to avoid the so-called "death spiral". Similarly, as the reliance on traditional power plants is reduced, there will be a point for each plant where the capacity factor and revenue are low enough compared to the maintenance costs that it is no longer economical to keep the plant in operation. Generators with the lowest costs and greatest flexibility are likely to remain in operation the longest.

The penetration levels at which these thresholds occur depend on the physical assets and structure of the network, as well as the existing market and rate structures, and are outside the scope of this report.

3.4 Significance of the block scale

The discussion above focuses on the impacts of scaling the penetration level of EcoBlocks given that the city-block size has already been selected. The block scale is certainly an appropriate choice from the construction and internal management perspectives, as it offers a convenient physical location for shared resources, including electric infrastructure (e.g. energy storage systems, inverters, electric vehicle chargers), water reclamation systems, and even food systems (gardens, composting). However, it is also important to consider explicitly other ways the grid could be partitioned, besides the block scale, and compare their benefits and downsides to those of EcoBlocks.

On the smallest end of the scale, each individual home could act as a microgrid, with control over its own energy resources and islanding capability. However, the high variability of power consumption in an individual home means that a comparatively larger amount of energy storage is required to achieve the same level of self-sufficiency while islanded, relative to a scenario where the homes are allowed to share power [25]. The scalability of this model is also limited, as managing a large number of home energy systems to achieve distribution-level benefits such as voltage regulation would be computationally and communication intensive.

Beyond the customer meter, the smallest electrical unit of aggregation that can be readily connected or disconnected is a lateral or section of a distribution feeder. But these separation points are mainly intended for protection, not active switching, and may not be equipped with remote sensing and control; they also may not have loads balanced across three phases. Therefore, the smallest operationally relevant unit for separation from the grid would typically be an entire distribution feeder, which can be easily disconnected at the substation. A key problem with the feeder scale is that a feeder encompasses a much larger number of customers (hundreds or even thousands), making it more difficult to coordinate generation and voluntary load curtailment (not to mention liability for power quality issues).

Block-scale microgrids, by contrast, are small enough for internal administration, while also having a point of common coupling that provides a safe and convenient transfer mechanism to disconnect and re-connect their aggregated loads and generation to the main grid. While a block consists of far fewer customers than a feeder, it is nevertheless sufficient to provide the benefits of statistically aggregating variable loads and generation, as will be demonstrated in Section 5. Furthermore, particularly in suburban and lower-density urban regions, distribution feeders often include overhead lines that are susceptible to weather- and vegetation-related damage. If these lines are damaged, a collection of independent EcoBlocks (especially with underground internal power distribution) could continue to be energized while a single feeder-level power island could not. In these ways, EcoBlocks would introduce operational flexibility to distribution systems at an intermediate scale, between individual home and entire feeder.

One notable challenge with the block scale arises from the frequent disconnect between the electrical and spatial layouts of distribution systems. In particular, customers on the same city block may be connected to different feeders, and service transformers may supply customers on more than one block. Changing the connectivity, reconfiguring or replacing utility equipment may therefore be necessary to create block-scale electrical units that connect to the grid at a single point of common coupling. It may be helpful to include these modifications in the EcoBlock development plan and budget so that supporting EcoBlock construction is not cost prohibitive for the utility.

4 Summary of paradigm shifts

In the preceding sections, we detailed the potential impacts of EcoBlocks on the grid, discussed the conditions under which they are likely to occur, and evaluated design choices from the standpoint of balancing benefits to EcoBlock participants and the grid. Here, as a form of summary, we review the three major paradigm shifts in the nature of the power system that we expect to occur at high penetration levels of EcoBlocks.

4.1 Power flows

The architecture of today's power grid is designed to transfer power from large generation facilities to consumers in different locations. As a result, conductors and other grid infrastructure consistently carry large power flows. At the distribution level in particular, protection and voltage regulation are designed assuming unidirectional power flow, a requirement limiting the permissible DG penetration. Since most customers consume more energy than they produce, pricing electricity by the kWh generates revenue for the grid operators to maintain the infrastructure.

With high penetration of EcoBlocks, on the other hand, distributed generation will be ubiquitous and co-located with loads. Customers' consumption and production will differ on short time scales, but will be comparable in the long term, leading to near-zero net kWh consumption. While the grid infrastructure will be used less frequently and with reduced loading, it will likely still be relied upon at times to provide power from distant, low-cost bulk energy sources, and to facilitate power sharing between EcoBlocks. Maintenance needs will therefore be reduced but not disappear entirely. Protection and voltage regulation may need to be updated in many places to support bidirectional power flows. Pricing by the kWh will likely no longer be sufficient to finance the maintenance, necessitating a new market structure.

4.2 Flexibility

Today, resources that are flexible, such as energy storage and interruptible loads, represent a relatively small portion of the total power being exchanged on the grid. Due to their special capabilities, these resources may be recruited to solve problems such as supply-demand imbalance (due to the large amount of inflexible demand), thermal and voltage constraint violations, and emergencies.

In the new paradigm, by contrast, most of the participants in the grid will be flexible. There should no longer be concern about the supply adequacy of flexible resources, since the remaining inflexible demand will be small by comparison. The presence of a much greater number of resources to choose from will likely enable cost reductions, as well as new optimization objectives such as dispatching the resources geographically closest to the site of the problem. At the same time, a new challenge will emerge around optimizing the dispatch of the greatly increased number of resources and communicating with them in a timely manner.

4.3 Resilience

Today, when grid infrastructure goes out of service (for example, when power lines are damaged in a storm), customers in the area experience outages—particularly those downstream of a failed component. Since generation and load are geographically separate, multiple repairs and a long time may be required before service can be restored after a major event. Even where local generators such as rooftop solar installations are present, they are not allowed to energize the system under these conditions. The restoration process itself is risky and complex, since not all generators have black-start capability, and even a brief supply-demand imbalance during restoration can cause the system to collapse again. Therefore, generators and loads must be brought online gradually and in an appropriate order.

In the future, the deployment of EcoBlocks is expected both to reduce the severity of outages and to facilitate service restoration. With co-located generation, storage and loads, and the ability to disconnect from the main grid, EcoBlocks can power themselves if components in the main grid fail. Since the EcoBlocks by definition exchange zero net power with the grid while islanded, the risk and complexity of system restoration will be greatly reduced compared to the present-day scenario. The rules and processes for islanding, power balancing while islanded, and re-connection to the main grid must be well-designed and robust to ensure this adaptive islanding model is reliable and predictable.

5 Resilience analysis

In 2015, the average PG&E customer experienced about 150 minutes of power outages, and 36,000 customers experienced outages longer than one day due to weather events [26]. Outages frequently result from weather or vegetation damaging overhead conductors, and are worsened when the conductors are in remote locations where locating the fault is difficult. With the increasing occurrence of extreme weather events due to climate change—consider hurricanes Sandy, Harvey, Irma, and Maria, for example—improving grid resilience is a growing priority [27]. The adaptive islanding capabilities of EcoBlocks have great potential to improve resilience: since they can disconnect and self-supply, loss of a component in the transmission or distribution system will not necessarily cause an outage for EcoBlock customers. This is in contrast to today's concepts of virtual power plants and DER aggregators, which may have similar benefits to EcoBlocks in terms of peak shaving and loss minimization, but do not allow islanding because the DERs and loads are not necessarily geographic or electrical neighbors. Since adaptive islanding for resilience is directly in line with utilities' goal of keeping the lights on as much as possible, it is perhaps the strongest argument in favor of EcoBlock development. However, it is not guaranteed that all demand in an EcoBlock will be met during an islanding event, since generation, load, and the timing of the event are variable. Therefore, this section attempts to quantify probabilistically the self-sufficiency of EcoBlocks—defined as the fraction of load demand served—and its dependence on EcoBlock design parameters.

5.1 Simulation Procedures and Data

One relevant design parameter is topology, particularly the three topology scenarios considered in Figure 1. In Scenario 3, only the loads connected to the DC system can be served in the islanded state, while in the other two, all loads can be served in the islanded state. This analysis focuses primarily on the case where all loads are present in the island, since that represents an upper bound on demand, but also compares cases representing Scenario 3 where all or only half of the candidate loads are migrated to DC. A second design parameter we evaluate is aggregation level. As an alternative to block-level aggregation, each household could maintain its own generation and storage and operate independently. Due to the variation in individual generation and demand, aggregating multiple homes into a microgrid has been shown to increase the fraction of total demand that can be met [25], [28]. This analysis assesses the value of statistical aggregation in the EcoBlock context, and further evaluates whether connecting multiple EcoBlocks into a larger island offers additional benefits. We further consider factors influencing self-sufficiency during a particular islanding event: conditions at the start of islanding (time of day and storage state of charge); duration of islanding; and generation and load, which depend on weather, time of year and other factors.

Since customer meter data for the pilot EcoBlock location was not available at the time of writing, this analysis was instead performed using residential load and PV generation data from Pecan Street, Inc, located in Austin, Texas [29]. A set of thirty homes with PV was selected from the Pecan Street data set to create a simulated EcoBlock. These homes were selected randomly from the subset of homes that had load and PV generation data for the entire year of 2014, and that had multiple disaggregated load time series corresponding to individual appliances and circuits within the home. This disaggregated load data is necessary to estimate the self-sufficiency of a DC system in which only certain loads participate. The Pecan Street dataset also includes households that have and have not participated in demand response programs. Since we expect the behavior of many, but not all, EcoBlock residents to be similar to those in demand response programs, we introduced a bias in the selection of the homes for the simulated EcoBlock so that 24 of them (80%) participated in the programs. A few key differences between the Pecan Street data and the expected load and generation at the Oakland EcoBlock site should be noted:

- Austin has higher summer temperatures and therefore greater air conditioning usage compared to Oakland.

- Since the Pecan Street PV installations were not designed for self-sufficient microgrid operation, the ratio of load to PV generation differs from the Oakland EcoBlock plans, and energy storage is not present.
- Since the homes differ in size and in number and type of appliances, the peak and average load values in Pecan Street differ from those in Oakland. In particular, the Pecan Street homes in this analysis are single-family homes, while the Oakland EcoBlock includes several multi-family residences.
- While a relatively smaller effect, we note for completeness that Austin is at about 30 degrees north latitude, whereas Oakland is at about 38 degrees. As a result, days are about 40 minutes longer in the summer and 40 minutes shorter in the winter in Oakland compared to Austin, likely making the seasonal differences in generation more extreme.

Despite these differences, there are several reasons justifying the use of Pecan Street data for this analysis. First, while the summer temperatures and air conditioning use in Austin differ from those of Oakland, they are more similar to conditions in parts of Southern California and the Central Valley. Therefore, analysis conducted for Austin would be more directly applicable to these regions, which are also of interest for future EcoBlock deployment. Second, the Pecan Street data offers unparalleled insight into the energy consumption of individual end-use loads as well as the statistical distributions of household load and generation over the course of multiple years. For resilience analysis, which by nature deals with system behavior under unlikely circumstances, data reflecting the variability of individual loads and PV generation is of utmost importance. The analysis framework demonstrated here with Pecan Street data could easily be applied to other locations such as Oakland when sufficient customer meter data becomes available. Finally, the Pecan Street PV generation was scaled so that the ratio of annual generation to annual energy demand would equal that of the Oakland EcoBlock. Additionally, the storage capacity in the simulated EcoBlock was chosen to give the same ratio of storage capacity to annual energy demand as in the Oakland EcoBlock.

At the time of writing, the most recent estimates for the Oakland EcoBlock were: 357,500 kWh of load per year, assuming conversion of all gas appliances to electric plus energy efficiency retrofits; 509,500 kWh of solar generation per year (1.425 times the annual load); and 200 kW or 800 kWh of storage capacity (1/447 times the annual load). The generation and storage in the simulated EcoBlock were scaled to give the same ratios compared to annual load: annual demand was 384,100 kWh, annual generation 541,500 kWh (prior to scaling it was 220,700 kWh), and the storage was sized at 215 kW or 860 kWh. The other storage parameters used in the simulations were based on the Amber Kinetics flywheel currently on the market [30]: charge and discharge efficiencies of 94%, giving a round-trip efficiency of 88%, and a constant self-discharge rate of 65 W per 8 kW of capacity. Since the Oakland EcoBlock design is intended to power streetlights in addition to customer loads, streetlights were added to the block-level demand in this analysis as well. Streetlight power consumption was assumed to be 900 W, based on the 10 streetlights currently installed within the EcoBlock boundaries and an assumed consumption of 90 W per light, the mean of the LED streetlights for residential locations compared in [31]. Streetlights were assumed to be on whenever the generation dropped below 1% of peak (encompassing nighttime hours but not cloudy days), and off otherwise. A very simple demand response scheme was assumed: at each time step, the EcoBlock served as much of the load as possible given the energy available from generation and storage. Any remaining load was recorded as unserved. This is equivalent to assuming that all loads have some sort of demand response capability, allowing an arbitrary fraction of load to be shed at each time step. The ability to shed noncritical loads is essential in order to maximize the power delivered to critical loads: in the absence of demand response, if power demand exceeds supply, the entire microgrid will experience an outage [25], [28].

The flow of the self-sufficiency simulation for the simulated EcoBlock is described below and in Figure 3:

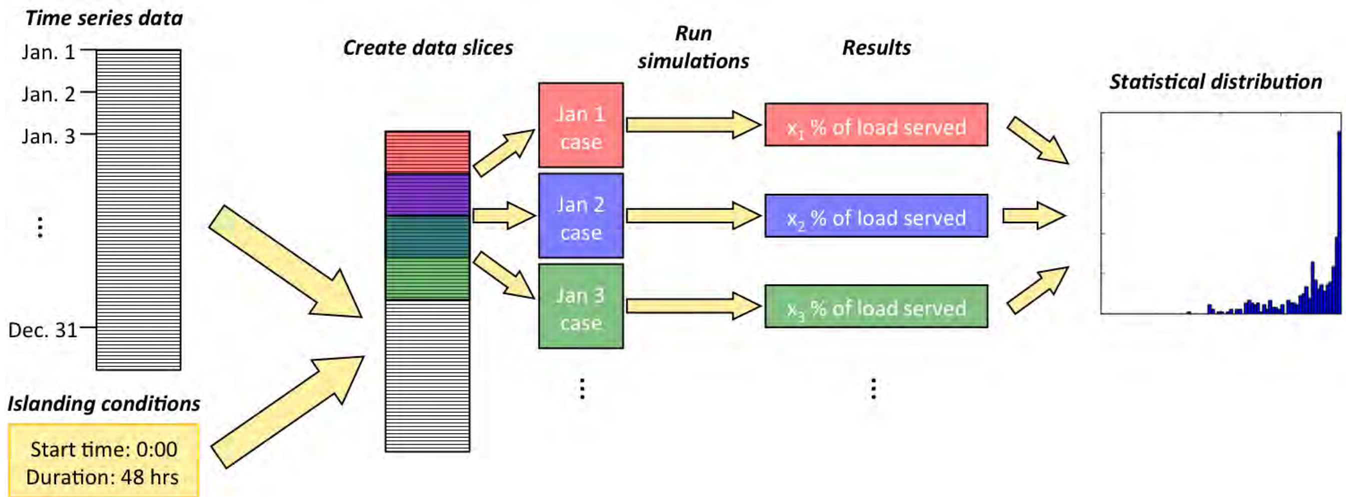

Figure 3: Self-sufficiency simulation process flow.

1. Data preparation
    1. Scale generation and storage to match Oakland EcoBlock ratios
    2. Select load: all loads, all DC-candidate loads, or half of DC-candidate loads
    3. Add streetlight load
    4. Outputs:
        1. Time series of generation E_G and load demand E_L, with time step dt (here, $dt = 1$ hour), for one year
        2. Storage parameters: capacity E_C, maximum charge/discharge rate P_{max}, charge and discharge efficiencies η_C and η_D, self-discharge rate P_{SD}
2. Self-sufficiency simulation
    1. Choose a start time t_{start}, duration T, and initial storage state of charge $E_{S,init}$
    2. Select all slices of generation and load data with that start time and duration (one slice for each day of the year)
    3. For each data slice:
        1. At each time step: compute energy delivered to loads $E_{L,served}$, energy stored E_S, and excess (spilled) generation $E_{G,excess}$; as a function of E_G, E_L, and $E_{S,init}$; within the storage rate and capacity constraints
        2. Calculate total demand, fraction of total demand served, and total excess generation
    4. Analyze the statistical distributions of total demand, fraction of total demand served, and total excess generation over the year

5.2 Results and discussion

Impacts of islanding start time and duration

We first focus on the case where the entire block islands as one—including all loads, both AC and DC—and consider a long-term unplanned islanding scenario. This type of scenario would most likely be the response to a fault on the main grid that would otherwise cause an outage, such as a weather event, component failure, or vegetation-related conductor damage. As a baseline case we assumed the energy storage was 50% charged at the start of islanding, and determined the effects of varying islanding start time and duration on self-sufficiency.

We determined the distributions of self-sufficiency, as a function of islanding duration, for start times of midnight, morning (8:00), and afternoon (16:00). The means of these distributions are plotted in Figure 4. For short islanding periods of just a few hours, the block only needs to rely on the initial energy stored

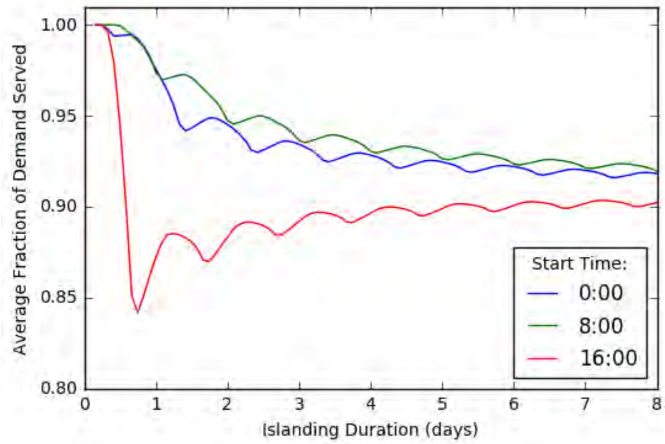

Figure 4: Dependence of the mean fraction of demand served during islanding on the start time and duration of islanding.

in the flywheel, and is therefore highly self-sufficient regardless of start time. For intermediate durations (half a day to about 2 days), the start time has a significant influence on self-sufficiency. In particular, the greatest amount of load has to be shed when islanding begins in the afternoon, because load is near peak at the same time that PV generation is ending for the day. When the islanding duration increases to several days, the effect of the starting conditions diminish, and the steady-state distributions of generation and demand take over. The ripples seen in Figure 4 result from the periodically changing fraction of the islanding event that includes daylight.

The distributions of self-sufficiency that result in these mean values are explored in more detail in Figure 5. Figures 5a-c show histograms of self-sufficiency for the three start times with durations of 1 day and 8 days. Figures 5d-f show scatter plots of self-sufficiency versus total demand for a few notable islanding scenarios, with results from the four seasons indicated in different colors. The histograms show that for most conditions, nearly 100% of load is served in the majority of islanding events, with a few low-self-sufficiency outlier events. As shown in Figures 5d-e, these outliers tend to occur in fall and winter. Although demand is modest during these times, overcast weather is most common, resulting in days of very low generation. Figure 6 shows generation and demand time series for two consecutive winter days, one overcast and one clear. Although demand is similar for the two days, the extreme difference in generation leads to very different self-sufficiency results. If the EcoBlock is islanded for the first day, only 35% of demand can be met, while if it is islanded on the second day, all demand can be met. For the 0:00 and 8:00 start times, Figures 4 and 5 show that the probability of low self-sufficiency increases for long durations of islanding. This results from the fact that the weather on one day affects the stored energy available on subsequent days. In particular, after a cloudy day, the stored energy is low, increasing the need for load shedding on the following day.

If islanding begins in the afternoon, while 100% self-sufficiency is still possible, significant load shedding is more likely regardless of the season, as shown in Figures 5c and f. At this time of day, generation is ending at the same time as load is nearing its peak. Since the storage is only half charged at this time, there is often not enough energy to last through the night. While winter peak load is lower than summer in this climate, generation is also lower and ends earlier in the day, leading to similar overall ranges of self-sufficiency throughout the year. A well-managed EcoBlock would try to have the storage fully charged by the afternoon to avoid this scenario. If that were the case, the self-sufficiency of the EcoBlock would be much greater, both on average and in the worst case, as shown in Table 7. Table 7 also shows that while a greater initial state of charge is advantageous for short-term islanding, the effect is reduced for long-term islanding. A complete analysis would incorporate a statistical distribution of the storage state of charge that depends on the time of day. Deriving this statistical distribution would require knowledge

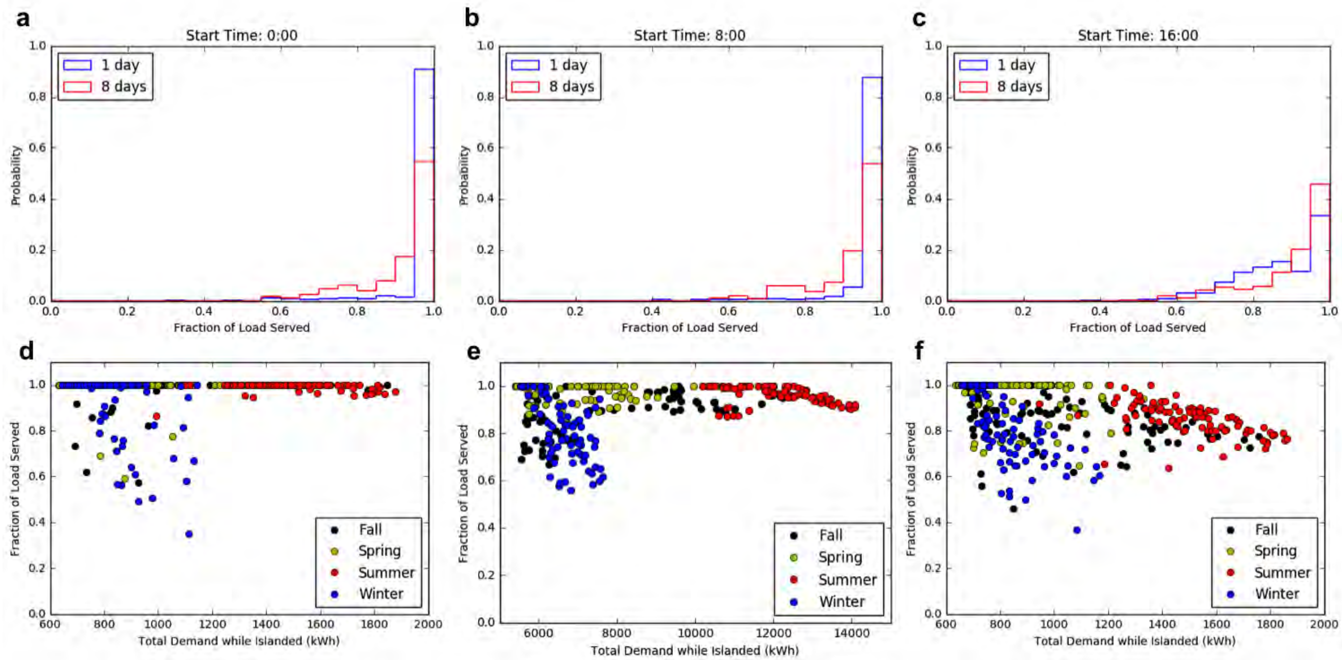

Figure 5: (a-c) Histograms of the fraction of demand served with islanding durations of 1 and 8 days, with start times of 0:00 (a), 8:00 (b), and 16:00 (c). (d-f) Scatter plots of the fraction of demand served versus total demand while islanded for each season of the year. Start times and durations are 0:00 and 1 day (d), 0:00 and 8 days (e), and 16:00 and 1 day (f).

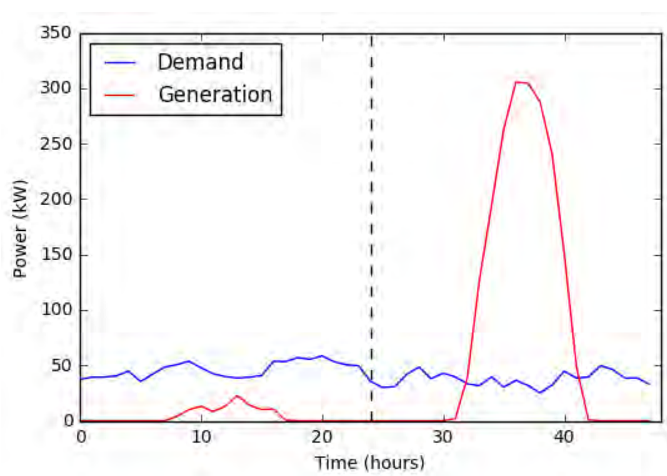

Figure 6: Generation and demand time series for two consecutive winter days, one overcast and one sunny.

Table 7: Mean and minimum self-sufficiency results for various islanding scenarios, comparing 50% and 100% state of charge for the energy storage at the start of islanding.

Duration	Start time	Self-sufficiency: 50% initial charge		Self-sufficiency: 100% initial charge	
		Mean	Min	Mean	Min
1 day	0:00	0.97	0.35	0.999	0.79
1 day	8:00	0.97	0.44	0.99	0.80
1 day	16:00	0.87	0.37	0.99	0.72
8 days	0:00	0.92	0.56	0.93	0.59
8 days	16:00	0.90	0.50	0.92	0.57

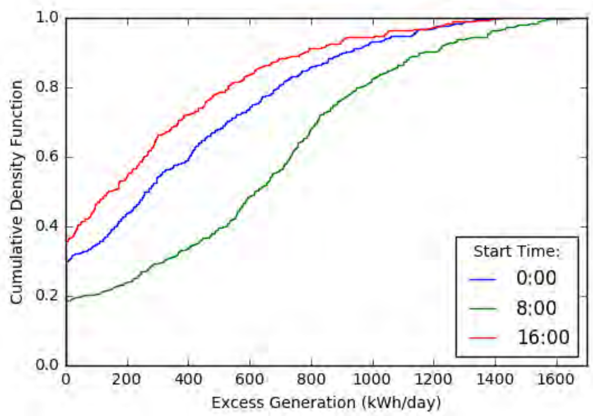

Figure 7: Cumulative density function of excess generation for islanding duration of 1 day and start times of 0:00, 8:00, and 16:00.

of the EcoBlock operating strategy while connected to the grid.

In addition to the fraction of demand met, we quantify the excess generation, which is the generation that cannot be stored in the flywheel because the flywheel is already fully charged. About half of the homes in the simulated EcoBlock already have electric vehicles; the excess generation can be considered an estimate of the energy that is available to charge additional EVs without needing to shed any additional loads or install additional power sources. For the excess generation to be useful for this purpose, it is of course necessary for EVs to be present and needing charge at the times the generation is available. Figure 7 shows cumulative density functions of excess generation with an islanding duration of 1 day. For the best case, the 8:00 start time, about half of the days have over 600 kWh/day of excess generation, and 75% of days have at least 220 kWh/day. Considering the 30 kWh battery of the Nissan Leaf [32], for example, this means that seven Nissan Leafs could be fully charged, while islanded, 75% of the time. It should be noted, though, that a significant fraction of the days do not have excess generation (seen in the figure as a y-intercept greater than zero). The EV charging capability could be investigated further given more information on customers' EV usage and constraints. Constraints include the number of miles driven by each EV customer and the frequency that they drive, times of day that the EVs are plugged in to charge, and how critical it is for each EV to be charged. With this information, it would be possible to determine a distribution of the critical EV load that could be served and the amount of other, noncritical load that would need to be shed in the process.

Impacts of topology and aggregation level

Up to this point it has been assumed that all loads will be present on the islanded EcoBlock. However, in topology scenario 3, only loads connected to the DC system would be powered during islanding. The

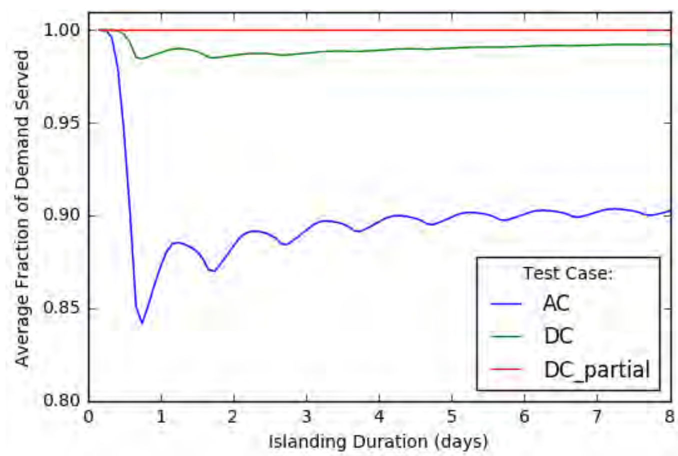

Figure 8: Mean fraction of demand served during islanding vs. islanding duration, for a start time of 16:00, if the island includes all loads ("AC"), all DC-candidate loads ("DC"), or half of DC-candidate loads ("DC partial").

main candidate loads to migrate to the DC system are expected to be lighting, electronics, and thermal loads (heating, refrigeration, air conditioning). These loads are likely to be more efficient when powered by DC, since they are inherently DC (in the case of LED lighting and electronics) or in the case of thermal loads, could be replaced by high-efficiency DC heat pump devices. These loads are also generally the most important to keep powered during emergencies. The shared electric vehicle charging stations may also be connected to the DC network. Therefore, we simulated the DC scenario by adding up the disaggregated load data for each home corresponding to EVs, lighting, plug loads, heating and water heating, air conditioning, and refrigeration. Since we expect that not all residents would upgrade to DC appliances immediately, we also modeled a scenario where only half of the homes' DC-candidate loads (randomly selected) are actually migrated to the DC system. Differences in power consumption between the actual loads and their DC counterparts were neglected. Figure 8 shows that, as expected, including only a subset of loads in the island greatly increases the fraction of that load that can be powered. In fact, self-sufficiency is 100% in the scenario where only half of DC-candidate loads are on the island. The significance of this result is that if fewer loads are able to connect to the islandable circuit in the first place, fewer of them need to have demand response capabilities to ensure self-sufficiency.

We next evaluated the benefits of sharing power and storage resources at the block scale. This was accomplished by comparing the amount of load served at each of the 30 homes, assuming they operate as independent islands, against that of the aggregated EcoBlock. The generation at each home was scaled by the same multiplier so that the *total* generation of the block would be the same as the block-level aggregation case, while preserving the differences in generation-load ratio between homes. This accounts for the fact that homes have differing amounts of viable roof space for PV. The storage sizing at each home followed the same rule as the entire block: 1 kWh of storage for every 447 kWh of annual energy demand. Self-sufficiency in the independent home case was then calculated by dividing the total load served at all of the homes by the total demand. As shown in Figure 9, aggregating the resources offers a significant advantage compared to independent home self-consumption. This is a similar overall trend to that observed in [25], [28], but with greater overall self-sufficiency due to the larger sizes of generation and storage relative to load.

A major reason for this result is that for individual homes, variation in net load is very high; even turning on or off a single appliance can change a home's load significantly. That same appliance is insignificant on the scale of a 30-home block. While generation tends to be highly correlated across homes in the same neighborhood, load spikes at individual homes are not as well synchronized. As a result, block-scale aggregation reduces variability of net load, thereby reducing the likelihood of running up against

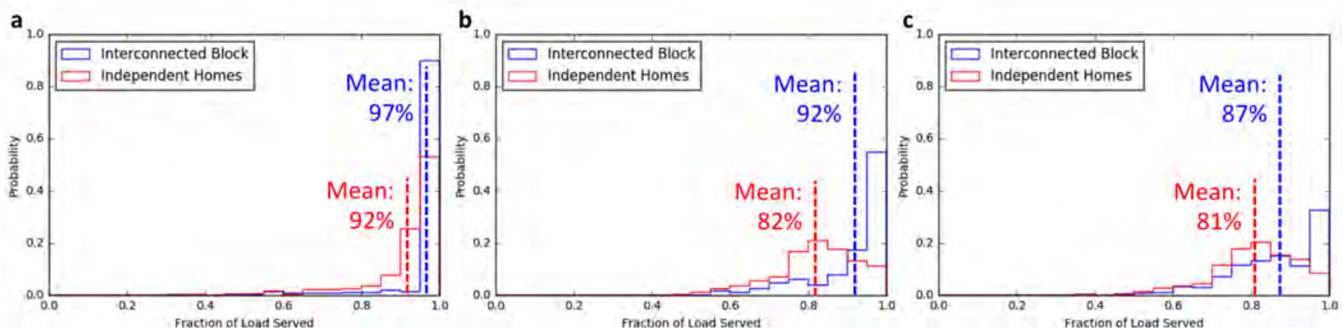

Figure 9: Distribution of fraction of load served for various islanding conditions, if each home operates as its own independent island (red) or if all 30 homes share power and storage resources (blue). Start time and duration of islanding are 0:00 and 1 day (a), 0:00 and 8 days (b), and 16:00 and 1 day (c). The mean of each distribution is labeled with a dotted line.

storage rate or capacity constraints. For the individual homes, the net load surpassed the storage charge or discharge rate limit an average of 820 hours of the year, and as much as 2100 hours of the year for one of the homes. This was reduced to 410 hours of the year for the aggregated block.

We must recall that this analysis was performed under the assumptions that all loads on the island are of equal priority and can be disconnected at any moment if necessary. With a more intelligent demand management scheme, we expect a similar fraction of load to be served over the course of an islanding event, but with a different distribution in time and with the most critical loads taking priority. While the mean fraction of load served is quite high even for independent homes, the minimum fractions served during the worst-case islanding events are much lower. Of the 8-day events starting at midnight, for example, 56% of load is served in the interconnected block in the worst-case event. During that same event, 49% of load would be served in the independent home scenario, and for 4 of the homes less than 30% would be served. Under these conditions it is likely that even relatively important loads would need to be shed at some homes. Therefore, aside from increasing the probability of meeting 100% of its load, an EcoBlock's electrical infrastructure would ease the selective disconnection of non-critical loads, rather than risking a complete outage in case local resources are not adequate. The ability to intelligently adapt loads to available resources would substantially mitigate the impact on customers. Furthermore, block-level aggregation could help ensure that the distribution of energy among residents is fair, by equalizing the availability and cost of power among households that may have differing available roof space for PV.

To determine whether the statistical aggregation benefits extend beyond the block level, we created a second simulated EcoBlock using a second set of 30 homes located in the same city. The generation and storage were scaled to have the same ratios relative to load as for the first EcoBlock. The self-sufficiency of these two blocks were then compared against an aggregated "double block" in which the two were allowed to share power and storage resources as needed. As seen in Figure 10, the two blocks perform similarly—as expected given that the same PV and storage sizing process was used for both—and only a very small increase in self-sufficiency is observed when they are connected. Aggregation of geographically distributed PV systems has been shown to reduce variability on short timescales because cloud transients affect only a few systems at once [16], [17]. Here, though, we consider longer timescales (the hourly time step) because the large energy storage resource can mitigate the minute-to-minute variability. The greater correlation across geographic areas at this longer timescale, plus the great reduction in load variability that has already occurred at an aggregation level of 30 homes, combine to give minimal statistical aggregation benefit at the two-block level. Since connecting multiple blocks into a larger island is challenging from the perspectives of safety and legality—it requires energizing utility infrastructure between blocks, for example—we conclude that it is not likely to be worthwhile for urban residential blocks. We note that in some settings, islands with dimensions larger than a city block may offer greater advantage. These may include commercial or industrial settings, where individual customers' load profiles may differ greatly, rural areas with large

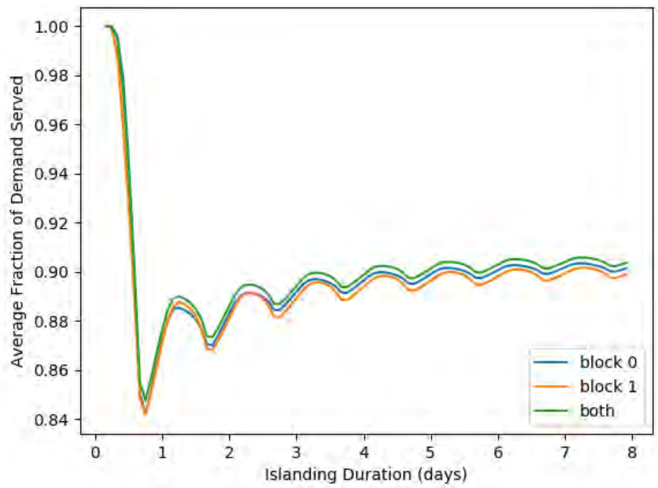

Figure 10: Mean fraction of demand served during islanding vs. islanding duration, for a start time of 16:00, for two simulated EcoBlocks and for the aggregated double block where both are connected together.

distance between customers, or very high population density areas where there is not enough space for large energy storage or rooftop PV installations on every block. It may be of interest to determine the marginal benefit in self-sufficiency as a function of the number of customers or geographic size of the island and how that depends on the load type and location.

Planned islanding

Besides coping with a fault on the main grid, another use case for adaptive islanding is to keep customers powered during planned maintenance of grid infrastructure. In the planned islanding case, we can assume the storage can be charged completely beforehand since the start time is known in advance. The objective is then to find the optimal start time, given a particular duration of maintenance, that minimizes the fraction of load shed. This analysis was performed by running the self-sufficiency simulations for all possible start times, with a given islanding duration corresponding to a particular type of maintenance.

For simple maintenance activities such as replacing a distribution power pole, outages of around 4 hours are typical. Since the storage capacity of the EcoBlock was designed to provide 4 hours of power, 100% of demand in the simulated EcoBlock was met during a 4-hour planned islanding scenario, for any start time, on every day of the year. More substantial maintenance activities such as replacing substation equipment may require up to 16 hours of work at a time. Therefore, the self-sufficiency of the simulated EcoBlock was also evaluated under a 16-hour planned islanding scenario. In this case, the EcoBlock was still fully self-sufficient with many of the start times. As shown in Figure 11, only for start times in the afternoon (1:00 pm to 9:00 pm) is the EcoBlock at risk of load shedding. The particular days that are not self-sufficient with afternoon start times are almost all in the late summer or early fall, when peak load is high due to high temperatures but generation does not extend long into the evening.

These results imply a new set of guidelines for scheduling maintenance on circuits with high penetration of EcoBlocks. Today, maintenance activities are often scheduled to take place in the middle of the night to minimize the nuisance for customers. These results show that maintenance on EcoBlock circuits could instead take place during daylight hours without causing outages, potentially improving safety and convenience for lineworkers. Additionally, forecasts for irradiance (affecting generation) and temperature (affecting load) should be taken into account when scheduling maintenance. Maintenance starting in the afternoon should be avoided whenever possible, especially for more work-intensive jobs and on days where low generation and significant air-conditioning load are expected.

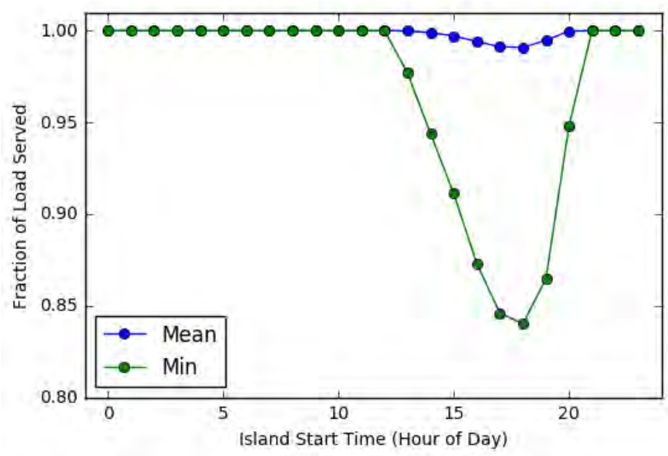

Figure 11: Mean and minimum fraction of load served during a 16-hour planned islanding scenario as a function of islanding start time.

5.3 Conclusions

The conclusions drawn from the simulated EcoBlock, summarized here, can be applied to the proposed EcoBlocks in California. First, aggregating homes at the block level offers significant improvements in self-sufficiency relative to each home operating as an independent island. Second, while letting only a subset of loads participate in a DC island increases the fraction of load that can be served reliably, self-sufficiency is excellent even if all loads participate in the island, due to the large generation and storage resources. The simulated EcoBlock was fully self-sufficient during the majority of simulated islanding events, even with durations as long as 8 days. Furthermore, in addition to the 14 electric vehicles already on the simulated EcoBlock, there was enough excess generation to charge several more on most days if they are plugged in during daylight hours. Although load was the highest in the summer due to the air conditioning demand, overcast winter days made up most of the events requiring significant load shedding. We expect the same for the Oakland EcoBlock, where air conditioning needs are far less than in Austin. Since major outage events most often result from storms [26], the need to island may coincide with cloud cover a disproportionate amount of the time. Therefore, although the results show that little load shedding is needed on average, it is worth having the ability to shed large amounts of load during storm events. Finally, since the starting amount of stored energy matters greatly, especially for short islanding events, we recommend controlling the flywheel to maintain a minimum stored energy while connected to the grid, in case islanding needs to occur. This minimum energy should depend on the time of day, demand response capabilities of the EcoBlock loads, and perhaps weather forecasts. Overall, our analysis shows that, with real data for residential household loads and PV generation, the EcoBlock design principles—large generation and storage capacity, coupled with demand response—produce a highly self-sufficient islandable microgrid.

6 Suggestions for future work

Our work has focused on evaluating the potential design choices for EcoBlocks from the perspectives of grid impacts and scalability. To move from the hypothetical evaluation stage to deployment, decisions and progress need to be made in many areas of the design, including:

- Selection of the EcoBlock topology from among the scenarios in Figure 1, and selection of corresponding hardware
- Design of the EcoBlock's protection system, which will be particularly challenging if DC

- Selection of the control architecture, objectives and signals that will be used to control devices within the EcoBlock, both for short-term stability and long-term energy balancing
- Selection of the control architecture, objectives and signals that will be used to influence the behavior of EcoBlocks within the grid, particularly control over net power while grid-connected and rules for islanding
- Development of a data analytics and visualization framework to improve grid operators' situational awareness that is scalable to large numbers of EcoBlocks
- Deeper investigation of the economic, legal and regulatory changes that would enable the most effective operation and scaling of EcoBlocks.

Quantitative evaluation of EcoBlock performance and impacts will be more accurate once these choices have been made. At the same time, simulation results can help inform the design choices. This suggests the need for a holistic, iterative approach where designs are adjusted based on simulation results and vice versa. For example, the self-sufficiency analysis in Section 5 could be made more realistic for the prototype EcoBlock through the use of:

- Oakland EcoBlock customer meter data
- A more realistic demand response model, such as one that includes generation and load forecasts and prioritization of loads
- Models for the control of EV charging as an additional form of demand response
- A time-varying statistical distribution of the storage state of charge at the start of islanding, derived from the operating strategy of the EcoBlock while connected to the grid.

We plan to develop this analysis further as a tool for optimally sizing energy storage resources according to certain self-sufficiency criteria. Furthermore, the potential impacts of grid-connected EcoBlocks on power system performance characteristics—such as voltage variation, load factor, overloading, and losses—can be determined quantitatively using power flow simulation tools such as GridLAB-D. This analysis would run time-series simulations representing each EcoBlock as a single time-varying net power injection at its PCC, and could be used to estimate the dependence of these impacts on:

- Number and location of EcoBlocks
- Feeder characteristics such as voltage, size, impedance, level of imbalance: there are a number of real and realistic feeder models available for such simulations
- EcoBlock operating strategy: could validate the effectiveness of a particular strategy or help identify best-performing strategies.

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APPENDIX H: ECOBLOCK WATER SYSTEMS

APPENDIX K: ECOBLOCK WATER SYSTEMS

Geography

Climate

While indoor water needs are largely independent of location, outdoor water demands are heavily climate dependent. Because of summer irrigation demands East Bay Municipal Utility District (EBMUD) provides customers with roughly 200 million gallons daily (mgd) from June through August as compared to ~120 mgd in the January through March period (EBMUD 2015). Irrigation demands depend heavily on climate. The primary factors affecting this demand are:

1. Precipitation—both the amount and timing (intensity and seasonal distribution)
2. Evapotranspiration (ET)—the rate at which water tends to evaporate and/or be taken up by plants and transpired
3. Water demands of particular plants

Irrigation demands tend to decrease with increasing precipitation and increase with increasing ET. Tables 1 and 2 show monthly average rainfall and reference evaporation (ET_0)[1] data for eight California cities. There is considerable variability—average annual rainfall in Eureka is almost seven times that of Bakersfield, while Eureka's annual ET_0 is only a bit more than one-half of Bakersfield's. Though annual ET_0 minus annual rainfall (P) permits a qualitative assessment of relative irrigation demands, annual differences summed across monthly ET_{net}s are more instructive.

$$ET_{net} = k_c * ET_0 - P \qquad \text{(Eq. 1)}$$

where k_c is a measure of the water demand for a specific landscape type and ET_{net} represents the monthly irrigation demand (when ET_{net} is greater than 0). In July a typical lawn ($k_c = 0.7$) in Eureka would typically require ~2.6″ of irrigation water. The same lawn in Bakersfield would require about 6″. Over the course of a year the Bakersfield lawn would require 31″ of irrigation water, while the Eureka lawn would require 9″. A comparable lawn in Oakland would require 20″.

Table 1: Average Monthly Rainfall in Selected California Cities

City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Oakland	4.7	4.5	3.4	1.4	0.8	0.1	0.0	0.1	0.2	1.4	2.9	4.5	24
Eureka	6.5	5.6	5.3	3.3	1.8	0.8	0.2	0.3	0.6	2.2	5.6	8.1	40
Sacramento	3.6	3.5	2.8	1.1	0.7	0.2	0.0	0.0	0.3	0.9	2.1	3.3	19
Bakersfield	1.1	1.2	1.2	0.5	0.2	0.1	0.0	0.0	0.1	0.3	0.6	1.0	6
Santa Barbara	4.4	4.6	2.9	1.2	0.3	0.1	0.0	0.0	0.2	0.9	1.8	3.0	19
San Diego	2.0	2.3	1.8	0.8	0.1	0.1	0.0	0.0	0.2	0.6	1.0	1.5	10
Redding	5.9	5.5	4.4	2.5	1.9	0.7	0.1	0.2	0.6	2.1	4.5	6.3	35
Santa Rosa	6.3	6.1	4.7	1.7	0.8	0.2	0.1	0.1	0.5	1.8	4.3	4.5	31

(U.S. Climate Data 2017)

Table 2: Average Monthly ET_0 in Selected California Cities

City	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Oakland	1.5	1.5	2.8	3.9	5.1	5.3	6.0	5.5	4.8	3.1	1.4	0.9	42
Eureka	0.5	1.1	2.0	3.0	3.7	3.7	3.7	3.7	3.0	2.0	0.9	0.5	28
Sacramento	1.0	1.8	3.2	4.7	6.4	7.7	8.4	7.2	5.4	3.7	1.7	0.9	52
Bakersfield	1.0	1.8	3.5	4.7	6.6	7.7	8.5	7.3	5.3	3.5	1.7	0.9	53
Santa Barbara	2.0	2.5	3.2	3.8	4.6	5.1	5.5	4.5	3.4	2.4	1.8	1.8	41
San Diego	2.1	2.4	3.4	4.6	5.1	5.3	5.7	5.6	4.3	3.6	2.4	2.0	47
Redding	1.2	1.4	2.6	4.1	5.6	7.1	8.5	7.3	5.3	3.2	1.4	0.9	49
Santa Rosa	1.2	1.7	2.8	3.7	5.0	6.0	6.1	5.9	4.5	2.9	1.5	0.7	42

(CCR 2009)

Soils and Groundwater

The EcoBlock lies in an area referred to as the East Bay Plain groundwater basin, which is bounded on the east by the Berkeley Hills and on the west by San Francisco Bay. Groundwater is recharged in the hills east of the city and flows predominantly westward toward San Francisco Bay through unconsolidated Pleistocene alluvial sediment in the shallow upper aquifer, as well as through more indurated Tertiary sediment in deeper aquifers.

A 1998 study (Norfleet 1998) provides hydrogeologic information for sites in nearby Emeryville and Berkeley. The Berkeley subarea (where the EcoBlock is located) is essentially a single hydrogeologic unit, containing numerous alluvial fan deposits. None of the three primary East Bay aquifers (Newark, Centerville, and Fremont) are present within the Berkeley subarea (Norfleet Consultants 1998). The Norfleet study (page 23) states that "Even though the [Berkeley] subarea is filled mainly with gravels and sands, it is unlikely that there are notable groundwater supplies. This appears to be due to the limited natural recharge." Wells installed in this subarea "will have a high initial pumping rate, but high pumping will quickly deplete the aquifer (small sustainable yields)." Accordingly, different groundwater zones beneath the site are referred to as water-bearing zones rather than aquifers.

The Temescal Formation is described as an alluvial fan deposit comprised of interfingering lenses of clayey gravel, sandy silty clay, and sand-clay-silt mixtures. Total thickness of the sediments based on deep coring near the site is approximately 200 to 300 feet. The formation has been penetrated to a depth of 60 feet below ground surface (bgs) in Emeryville. In these borings, there are four general units (fill material, Unit A, aquitard, and Unit B). The shallowest unit is engineered fill that consists of sands, silts, and gravels with concrete fragments. This fill extends from ground surface and ranges from 0 to 4 feet in thickness. The fill material unconformably overlies Unit A (which includes the A-zone groundwater zone) which consists mainly of silty clay and clayey silt with discontinuous lenses of silty sand and sand from approximately 4 feet to 20 feet bgs. The lenses of silty sand and sand range in thickness from approximately 1 to 10 feet. Unit A is underlain by approximately 30 feet of silt and clay that acts as a local aquitard separating Unit A from Unit B. The aquitard includes lenses of clayey/silty sand ranging between 1 and 5 feet thick situated between 30 and 40 feet bgs. Unit B (which includes the B-zone groundwater) consists of primarily silty clay and clayey silt beginning at approximately 50 feet bgs. The total depth of Unit B has not been characterized. Similar to Unit A, Unit B includes discontinuous lenses of silty sand ranging between 1 and 3 feet thick situated between 50 and 60 feet bgs.

A review of the databases shown below found no record of significant contamination in the areas near the EcoBlock:

- Geotracker (https://geotracker.waterboards.ca.gov/)
- Envirostor (https://www.envirostor.dtsc.ca.gov/public/)
- Alameda County Environmental Health LUFT/SLIC Program (https://www.acgov.org/aceh/lop/index.htm)

There are no data on sites directly adjacent to or on the EcoBlock itself. A basic water quality analysis conducted in November 2017 of water taken from an EcoBlock well showed that the water meets all standards required for irrigation use (Anne Gates, personal communication 2017).

Existing Infrastructure

Water

Potable water is supplied to the EcoBlock by EBMUD, which serves 1.4 million water customers captured from 575 square miles of mostly undeveloped public and private watershed lands of the Mokelumne River. The water is collected at the Pardee Reservoir, 90 miles east of the Bay Area. EBMUD has water rights for up to 325 million gallons daily from the Mokelumne River watershed. In addition, local runoff is stored in several East Bay reservoirs for treatment and delivery to customers and to assure emergency supplies are available locally. In a year of normal precipitation, EBMUD uses an average of 21 mgd of water from local watershed runoff. EBMUD additionally has rights to up to 100 mgd from the Sacramento River in dry years through a contract with the U.S. Bureau of Reclamation.

Potable water is delivered to the EcoBlock via a potable water grid surrounding the block. The block has 34 water meters: 20 single-family residential meters, 13 multifamily residential meters, and 1 irrigation meter.

Stormwater

The EcoBlock has no piped storm drainage infrastructure. Roof downspouts discharge directly to grade. Runoff flows overland in the street entering Emeryville's storm drains a block or two west and south of the EcoBlock. These storm drains discharge into the bay to the south of Powell Street, near its intersection with West Frontage Road in Emeryville.

Wastewater

Wastewater generated on the block enters the sanitary sewer collection system which conveys wastewater to EBMUD's treatment plant near the San Francisco-Oakland Bay Bridge. The plant serves 685,000 people along the eastern shore of San Francisco Bay. EBMUD provides secondary treatment for a maximum flow of 168 mgd. Treating an average of 63 mgd, the plant can pass 320 mgd through its primary treatment system and 168 mgd through secondary treatment. Storage basins permit the plant to handle short-term hydraulic peaks of 415 mgd. Treated water is chlorinated (disinfection,) then dechlorinated (to protect marine life) before being discharged underwater 1 mile into San Francisco Bay. The plant generates renewable energy, produces a nutrient-rich soil conditioner, and provides highly treated reclaimed water for large water users.

Current Block Water Use

EBMUD provided 10 years of monthly water use data (2006–2016), for the block. Annual consumption appears to have dropped from about 2.5 million gallons in 2006 to 2 million gallons in 2016. Most of the drop seems to be associated with outdoor use (Figure 1).

Estimates of indoor and outdoor use were made by assuming indoor water is constant throughout the year and that there is no outdoor use from December through February. Annual outdoor use (Figure 1) and monthly outdoor use (Figure 2) were estimated by calculating the difference between the total water use minus the estimated indoor use.

Figure 1: EcoBlock Estimated Annual Water Use

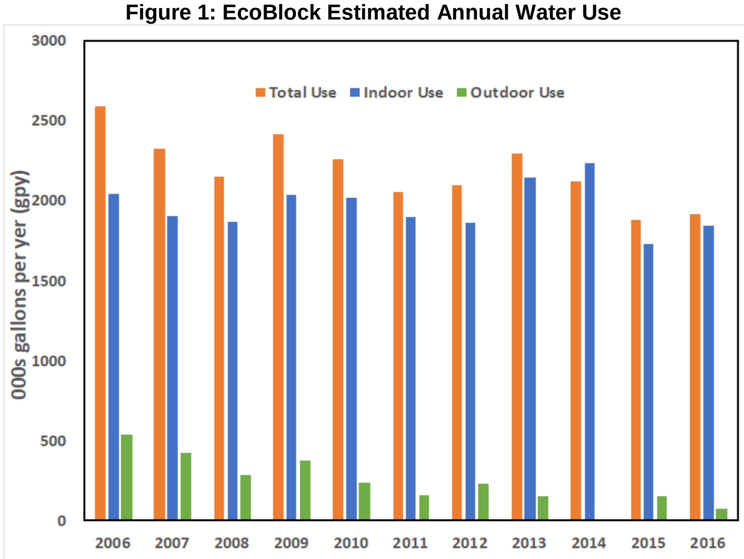
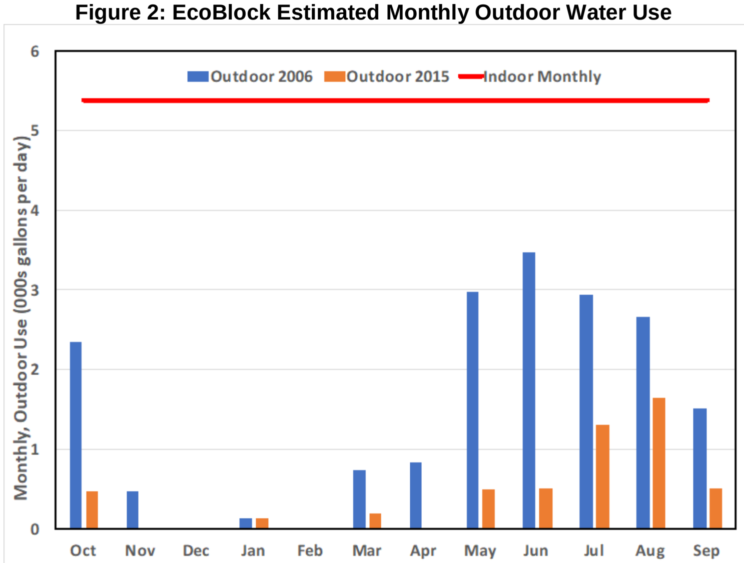


Figure 2: EcoBlock Estimated Monthly Outdoor Water Use



The EcoBlock's estimated per capita indoor water use of 50 to 55 gallons per day is consistent with residences that meet current water efficiency standards (tables 3 and 4).

Table 3: Water Fixture and Appliance Efficiency Standards

Fixture/Appliance	Current Federal Standard (Koeller 2016)	WaterSense / ENERGY STAR (Koeller 2016)	CalGreen (International Code Council)
Toilet	1.6 gpf	1.28 gpf	1.28 gpf
Bathroom Faucet	2.2 gpm	1.5 gpm	1.2 gpm
Kitchen Faucet	2.2 gpm	-	1.8 gpm
Showerhead	2.5 gpm	2.0 gpm	2.0 gpm
Laundry Machine	14 gpl	13 gpl	-
Dishwasher	5.0 gpc	3.5 gpc	-

Note: The laundry machine was assumed to have a tub volume of 3.0 cubic feet and an integrated water (IWF) of 4.7 for current standards and 4.3 for ENERGY STAR requirements (ENERGY STAR 2017; Koeller 2016).
gp_ --f—flush, m—minute, l—load, c—cycle

Table 4: Current, Estimated Indoor Water Use

Fixture	Flow Rate	Rate Units	Duration	Uses/day	gpcd[a]
Toilet[(1)]	1.3	g/flush	-	5.0	6.4
Bathroom Faucet[(2)]	1.2	g/min	0.50	3.0	1.8
Bath Tub[(3),(4),(5)]	18	g/bath	-	0.32	5.8
Showerhead[(1)]	0.8	g/min	7.8	0.69	11.0
Dishwasher[(4)]	3.5	g/cycle	-	0.32	1.1
Kitchen Faucet[(2)]	1.8	g/min	7.8	1.0	14.0
Laundry[(4)]	14	g/cycle	-	0.32	4.5
Leaks[(6)]	7.9	g/day	-	1.0	7.9
Total					**53**

[a] gpcd: gallons per capita per day
Sources: [1] Aquacraft 2016, [2] SFPUC 2017, [3] Heberger et al. 2014, [4] DeOreo et al. 2011, [5] Wilkes et al. 2005, [6] DeOreo et al. 2016

Alternate Water Sources

Efficiency

Indoor Water Use

The majority of urban water use can be attributed to residential (household) consumption (Heberger et al. 2014). Replacing outdated indoor water fixtures and appliances with new technologies that meet or exceed current efficiency standards can reduce interior water use significantly.

Current U.S. national standards for water use by type of fixture or appliance have been in effect following the introduction of EPActs 1992 and 2005, and the Energy Independence and Security Act of 2007 (Koeller 2016). Since the adoption of current federal standards, water-saving technologies have advanced considerably. The Environmental Protection Agency's (EPA) WaterSense program sets water efficiency and performance standards that are widely used. The program allows consumers to easily identify commercially available fixtures and appliances that meet WaterSense standards (U.S.EPA 2017). In addition to EPA's WaterSense program, the

U.S. Department of Energy's ENERGY STAR program offers guidance for identifying appliances that are not only water efficient, but energy efficient as well. Fixture upgrades available to homeowners include efficient dishwashers and showerheads, high efficiency toilets (HET), high efficiency laundry machines, and faucet aerators for kitchen and bathroom sinks (Cooley et al. 2016; Heberber et al. 2014; DeOreo et al. 2011). In keeping with the advancing technologies, California has adopted its own water efficiency and conservation measures as outlined in the 2016 California Green Building Standards Code (ICC 2016).

Outdoor Water Use

Outdoor water use can be reduced by: (1) converting lawns and other high water-use landscaping to native/drought-tolerant landscaping and (2) improving irrigation system efficiency.

Native Plants

Managing landscapes requires matching water supply to plant needs. The goal is to supply only the amount of water needed to maintain landscape health and appearance and avoid unnecessary application of water that exceeds plant needs.

Regulations have been developed that govern maximum water use and provide methodologies for estimating water demands for different taxonomic plant groups. In California, the Model Water Efficient Landscape Ordinance (MWELO)[1] governs the maximum applied water allowance (MAWA) for a given site. MWELO uses the Water Use Classification of Landscape Species (WUCOLS) guide, which was funded by the Water Use Efficiency Office of California (CCR 2009).

The key metric used to designate appropriate water application for a particular plant is the plant factor (PF), also known as water-use factor or crop coefficient (K_c) (Costello et al. 2000; Heberger et al. 2014). PFs are expressed as a percentage of reference evapotranspiration (ET_o) and range from 1.0 (100 percent) for high-demand plants to as low as 0.1(10 percent). Reference evapotranspiration (ET_o)[2] varies seasonally and by climate; hotter climates and seasons cause an increase in evapotranspiration, resulting in a corresponding increase in irrigation demand (tables 19 and 20).

Reducing irrigation demands at the household level can be achieved by replacing existing high-water use landscaping with native plants. California native plants require little water, resulting in an average water-use factor of 0.3, representative of low-water demand (Heberger et al. 2014). In addition to reduced water needs, native plants require lower application of fertilizers and pesticides, leading to less polluted runoff and healthier bodies of water downstream (DeOreo et al. 2011).

Efficient Irrigation Systems

In addition to introducing native plant species, homeowners can decrease irrigation demand via installation of timers and smart irrigation controllers, such as soil moisture sensors, and by switching from spray irrigation to drip irrigation technology.

Irrigation timers come equipped with watering schedules set to specific landscape type, but they can also allow homeowners to set their own watering schedules. Typically, they are set to control when to water (number of days per week) and how much to water to apply (number of minutes per day). In the case of irrigation times, these parameters need to be adjusted by the user, depending on seasonality (e.g., cool, warm, hot) (EBMUD 1991; DiFrancesco and Baker 2005).

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2 ETo is defined as water loss from a large field of cool-season grass 4 to 7 inches tall that is not water stressed.

Smart irrigation controllers improve irrigation efficiency by considering precipitation and soil moisture conditions. These smart controllers come in the forms of rain sensors (RS), weather–based irrigation controllers (WBIC), and soil moisture sensors (SMS) (Williams et al. 2014). Rain sensors are typically paired with automatic irrigation systems and prevent irrigation during rain events. Weather-based irrigation controllers automatically schedule a plant's watering needs based on weather data (e.g., humidity, temperature), collected via on-site weather sensors or from local weather stations. Soil moisture sensors read the soil moisture content near a plant's active root zone to determine irrigation needs.

Drip irrigation systems allow for water to be more effectively delivered to plant roots in comparison to spray irrigation, which typically lose more water to runoff and evaporation. Drip irrigation works well for new and existing plants, but is not typically recommended for lawns (EBMUD 1991). Delivering water uniformly and effectively across a lawn or similar root system via drip irrigation systems is difficult to accomplish, though it can be achieved with subsurface drip irrigation technology (EBMUD 1991).

EcoBlock Outdoor Water Use

Table 5 shows a preliminary analysis of projected irrigation needs on the EcoBlock. In determining irrigation needs, rainfall data and reference evapotranspiration (ET_o) values were obtained for the City of Oakland. Rainfall data were obtained from U.S. Climate Data and ET_o values from Appendix A of California's Model Water Efficient Landscape Ordinance (CCR 2009).

An average K_c value of 0.7 (average of optimum K_c for cool-season and warm season turfgrass) was used to estimate water demand assuming that irrigable area is mostly lawn cover (Haravandi et. al. 2009). Irrigation demand for landscape dominated by native plants (K_c = 0.3) is also shown (Heberger et. al. 2014). In addition, the analysis shows results for irrigation with spray (Irrigation Efficiency (IE) = 0.7) and drip irrigation (IE) = 0.9) systems. The EcoBlock's irrigable area is estimated to be 48,000 square feet (Table 1 of Chapter 4).

When average monthly precipitation exceeds actual evapotranspiration ($ET_L = K_c * ET_o$), no irrigation is required. Otherwise, Equation 2, adapted from Costello et al. (2000), was used to estimate irrigation demand for four scenarios:

$$\boldsymbol{Gal_{irrigation}} = \frac{(\boldsymbol{K_c} * \boldsymbol{ET_o} - \boldsymbol{Avg.Precipitation}) * \boldsymbol{Area_{irrigation}} * \mathbf{0.623}}{\boldsymbol{IE}} \quad \text{(Eq. 2)}$$

where 0.623 = conversion factor to gallons.

Table 5: EcoBlock Irrigation Scenarios

Mon	Eto, in/mo	Avg. Precip in/mo	High Demand, K_c = 0.7 Spray Irrigation, IE = 0.7		High Demand, K_c = 0.7 Drip Irrigation, IE = 0.9		Low Demand, K_c = 0.3 Spray Irrigation, IE = 0.7		Low Demand, K_c = 0.3 Drip Irrigation, IE = 0.9	
			Gal/mo	gal/day	Gal/mo	gal/day	Gal/mo	gal/day	Gal/mo	gal/day
Jan	1.5	4.7	0	0	0	0	0	0	0	0
Feb	1.5	4.5	0	0	0	0	0	0	0	0
Mar	2.8	3.4	0	0	0	0	0	0	0	0
Apr	3.9	1.4	57,000	1900	44,000	1500	0	0	0	0
May	5.1	0.8	118,000	3800	92,000	3000	31,000	1000	24,000	800
Jun	5.3	0.1	154,000	5100	120,000	4000	64,000	2100	50,000	1,700
Jul	6.0	0.0	180,000	5800	140,000	4500	77,000	2500	60,000	1,900
Aug	5.5	0.1	162,000	5200	126,000	4000	67,000	2200	53,000	1,700
Sep	4.8	0.2	135,000	4500	105,000	3500	53,000	1800	41,000	1,300
Oct	3.1	1.4	33,000	1100	26,000	800	0	0	0	0
Nov	1.4	2.9	0	0	0	0	0	0	0	0
Dec	0.9	4.5	0	0	0	0	0	0	0	0
Annual:	**42**	**24**	**839,000**		**653,000**		**292,000**		**228,000**	

Switching from lawn to native plants reduces demand by 65 percent. Increasing IE from 0.7 to 0.9 decreases demand by an additional 25 percent. Together they decrease annual demand by almost 75 percent.

Analysis of the water meter data provided by EBMUD (Figure 1) suggest that in recent years irrigation use has been 200,000 gallons per year or less, which indicates that native plants may already cover much of the block and many residents may be using drip irrigation systems.

Wastewater

Residential wastewater is a mixture that includes strong, highly contaminated components that are often reservoirs of infectious disease-causing organisms (toilet and kitchen wastewater). Other components, commonly called *greywater,* typically have lower contaminant levels and are less likely to transmit disease. In California residential wastewater can be reused only after receiving significant treatment (CCR 2018). Minimally treated greywater can be used for subsurface irrigation. If greywater is to be used for purposes where human contact is possible (e.g., toilet flushing, spray irrigation) it must be treated to meet the same standards as for full scale wastewater.

Wastewater Reclamation

Reclamation of sewage for non-potable uses at centralized treatment plants has a long history. In the Bay Area, wastewater utilities including Palo Alto, San Jose, and EBMUD provide tertiary treated waters to large water-using customers for irrigation, cooling, toilet flushing, and other non-potable purposes.

Aquacell, Living Machines, Nexus eWater, and others have built businesses around providing treatment systems for recycling sewage at building and district scales (Phoenix 2017; Living Machine 2012; Nexus e-water 2017).

California has strict water quality regulations/standards (commonly referred to as Title 22) regarding reclamation and reuse of sewage, especially where there is high potential for direct contact with humans or food crops (CCR 2018). The reclaimed water is distributed in purple pipes, systems must be designed and constructed to prevent connections between potable and reclaimed water pipes, system status and performance are closely monitored, and frequent, often daily, testing of produced water is required.

The potential of reclaiming sewage for potable (i.e., all) uses is currently receiving careful study by governments, regulators, the engineering community, and academics. Three primary factors are driving this interest (Tchobanoglous et al. 2011):

1. There is a need for additional water supplies.
2. Non-potable reclamation systems require development of an **additional, essentially complete,** infrastructure (e.g., storage, piping, pumping) that is highly capital intensive.
3. Advances in treatment technologies and real-time, online monitoring and control systems suggest that direct potable reuse systems can be designed, constructed, and operated in a manner that protects public health.

Greywater

Greywater is residential wastewater that does not contain its most contaminated components (toilets and kitchen wastewater). Greywater makes up around 40 percent of residential wastewater and includes wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, and laundry tubs (Allen et al. 2010).

Collected separately, greywater can be treated with systems similar to those used to reclaim regular wastewater and used for the same non-potable purposes. Greywater treatment costs (capital and O&M) can be lower because the wastewater is weaker and disease risks are lower. Some companies manufacture such products for the residential market (Aqua2use 2018; Nexus eWater 2018). In retrofit situations like the EcoBlock, the costs of installing the piping required make the overall system costs prohibitive.

Many jurisdictions allow reuse of (essentially) untreated greywater in subsurface irrigation/dispersal systems where the risk of people contacting the water is very low. This greywater diversion, sometimes termed *laundry to landscape* can:

1. Reduce potable water demands, lowering water bills
2. Reduce strain on municipal sewer systems, treatment systems, and septic tanks
3. Reduce wastewater treatment energy and chemical demands
4. Recharge groundwater and return nutrients to the soil.

California's greywater code is found in Chapter 15 of the California Plumbing Code (CPC) (as of 2017; previously it was in Chapter 16). The code describes three types of systems:

1. Clothes Washer System (also known as laundry to landscape): A graywater system utilizing only a single domestic clothes washing machine in a one- or two-family dwelling. This method cannot use a secondary pump and relies either on the washing machine pump or gravity to irrigate the garden areas.
2. Simple System: A graywater system serving a one- or two-family dwelling with a discharge of 250 gallons (947 liters) per day or less. Simple systems exceed a clothes washer system.
3. Complex System: Graywater systems that discharge over 250 gallons (947 liters) per day.

A construction permit is not required for a clothes washer system that does not require cutting the existing piping, provided it is in compliance with Section 1603A.1.1 of the code. Construction permits are required for Simple and Complex systems, and require a plot plan with supporting data, drawings, and plans of the graywater system, and a site test by the agency after installation. In general, any irrigation system must be covered with 2″ of material to avoid human contact with greywater or soil irrigated by greywater. Greywater cannot be used to irrigate root crops or edible parts of food crops that touch the soil.

Greywater can provide a consistent, year-round source of non-potable water for irrigation. This is particularly beneficial in places like California that have highly seasonal rainfall patterns, which makes it difficult to harvest rainwater for irrigation without large amounts of storage.

Diverted greywater does not significantly offset potable water use in rainy months when there is little to no irrigation demand. It can, however, contribute to infiltration and groundwater recharge during wet periods.

The major limitation of greywater is that national greywater standards are not consistent, and not all states have adopted codes that facilitate use of greywater. System design and permitting can be complex and drive up costs, making the implementation of greywater systems (aside from laundry to landscape systems) economically challenging. In addition, given that most homes have combined plumbing, there are limited sources and uses of greywater in existing buildings.

Retrofitting existing homes for diversion systems more complex than laundry to landscape, or for greywater reclamation systems, is generally not economical because of the costs associated with providing additional piping in the house to collect graywater, and in reclamation systems, to distribute it to toilets, and possibly laundry machines. Providing this piping is much cheaper in new construction, and several companies have built businesses to serve this market (Aqua2Use 2018; Bio-Microbics 2018; Nexus e-water 2017; Phoenix 2017). Their offerings include graywater diversion systems as well as reclamation systems that produce highly treated water that can be used for surface irrigation, toilet flushing, and laundry.

Groundwater

In 2010, daily U.S. groundwater withdrawals averaged approximately 79 billion gallons; slightly more than 20 percent of total water usage. Groundwater withdrawals in California were about 13 billion gallons per day, roughly one-third of the state's total water usage. Irrigation dominates water use (both surface and groundwater) in the state, but close to 3 billion gallons of groundwater were used daily by those providing water for domestic uses, representing roughly 45 percent of the total for this category (Maupin et al. 2014). In the early twentieth century the East Bay had thousands of working wells that provided over 10 million gallons of water daily (Norfleet 1998).

> *"Groundwater was a major part of water supply to the East Bay area from the 1860's to 1930. During that time there was a continuous struggle to locate and develop both ground and surface waters to serve the growing population. By the early 1920's, it was recognized that local groundwater and surface water supplies had reached their limits, and water would have to be brought in from outside the Bay Area. After years of planning and construction, Sierran water entered the area in the spring of 1930. However, instead of continuing to be part of the water supply, municipal well fields were shut down and forgotten.*
>
> *We estimate that in the range of 15,000 wells were drilled in the Study Area between 1860 and 1950. The majority of these were shallow (less than 100 feet deep), but some were up to 1000 feet deep. Few of these wells were properly destroyed."* (Norfleet 1998; p. 65)

Systems for extracting, treating, and distributing groundwater are widely used and well understood. The potential for utilizing groundwater is heavily site dependent. Important considerations include the following:

1. Depth to groundwater table, which affects well-drilling costs and pumping energy required to extract water
2. Aquifer permeability, which affects the rate at which water can be extracted
3. Contamination, which can make waters unfit for use or very difficult and expensive to purify
4. Recharge rate, which is the rate at which water is added to the system; if extraction rates exceed recharge rates, the system is not sustainable in the long term

Until 2014, groundwater use in California was only lightly regulated. To counter problems that have arisen in groundwater basins across the state, the California legislature passed three bills known collectively as the Sustainable Groundwater Management Act, creating "a statewide framework for sustainable, local groundwater management" (CDWR 2018). As the act is implemented, Groundwater Sustainability Plans (GSP) will be developed by Groundwater Sustainability Agencies (GSA) responsible for its planning and implementation. The EcoBlock is located in the East Bay Subbasin. EBMUD has taken over the responsibility of being the GSA for the basin (EBMUD 2015).

Precipitation

It is customary to divide precipitation into two categories: rainwater and stormwater. Precipitation is rainwater until it reaches a ground-level surface, where it becomes stormwater. This division is used because

- Falling rain is typically uncontaminated
- Aboveground surfaces (roofs, primarily) are generally free of contamination
- Ground-level surfaces often contain contaminants (such as oil, metals, and fecal matter) that are picked up by the stormwater
- Soil and other particles picked up by stormwater make it more difficult to treat

Stormwater

Stormwater runoff is the portion of water that is not retained (infiltrated or evapotranspired) on site by soils and vegetation. In urban contexts, stormwater runoff collects pollutants such as trash, chemicals, oils, and sediment that can harm downstream rivers, streams, lakes, and coastal waters. Population growth and urbanization increases the amount of pollutants in stormwater runoff, as well as the rate and volume of runoff. These changes in hydrology and water quality "can result in habitat modification and loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion" (USEPA 2018).

The National Pollutant Discharge Elimination System (NPDES), "authorized by the Clean Water Act regulates water pollution by regulating point sources that discharge pollutants into waters of the United States" (U.S. EPA 2007; U.S. EPA 2018). In California, the NPDES program is implemented by the State Water Resources Control Board (State Water Board) and the nine Regional Water Quality Control Boards (Regional Water Boards). The City of Oakland is a co-permittee[3] of the Alameda Countywide Clean Water Program's Municipal Regional Stormwater NPDES Permit (MRP) (Alameda County 2017). The MRP requires that new development and redevelopment projects, as defined by Provision C.3.b.ii of the MRP, control stormwater and stormwater pollutant discharge using approved methods. Regulated projects generally include public and private projects that create and/or replace 10,000 square feet or more of impervious surface; single-family homes that are not part of a larger plan of development are specifically excluded, however.

The Clean Water Program requires use of Stormwater Best Management Practices (BMPs) that attempt to mimic the site's predevelopment hydrologic patterns by slowing runoff, increasing infiltration and evapotranspiration. These strategies are typically referred to as *low-impact development* (LID) or *green stormwater infrastructure* (GSI). In addition, stormwater BMPs are designed to improve water quality by preserving and re-creating natural landscape features that filter stormwater and remove pollutants. Stormwater harvesting can be used as a detention/retention BMP; however, lower water quality typically makes stormwater a less

3 Along with 14 Alameda County cites, Alameda County, the Alameda County Flood Control and Water Conservation District, and the Zone 7 Water Agency.

desirable source than rainwater for harvesting, treatment, and use. In addition, collection from ground plane surfaces can be more challenging and expensive to implement than from rooftops, given the need for belowground storage and pumps.

It is impossible to isolate the impacts of stormwater management on a particular block from upstream and downstream systems. As such, stormwater management should be evaluated at a watershed scale, giving consideration to interactions with the piped storm drain network and surface water and groundwater systems.

Rainwater

Rainwater is typically a high-quality water source (Helmreich and Horn 2009; Che-Ani et al. 2009). This is especially true, when as is standard practice, the first increment of a storm's rainfall is diverted from storage/use. This first flush carries away anything that has accumulated on the roof since the previous storm (Helmreich and Horn 2009). One foot of roof runoff from 1,000 square feet (ft^2) of roof could meet approximately 250 days of an individual's indoor water needs (in a water-efficient house) or meet a year's worth of irrigation needs for 500 to 1000 ft^2 of yard in Oakland. Harvesting potential, dependent on precipitation, varies greatly across California (Table 1) and also shows substantial interannual variability for any particular location.

On January 1, 2017, Appendix K of the 2016 Plumbing Code became part of the California Plumbing Code (CCR 2016). Where local governments adopt this portion of the code individual homeowners can legally use rainwater for potable uses. Collection, storage, treatment, and distribution systems must meet code requirements and the homeowner must also show that the water produced is of potable quality. The treatment trains suggested in Appendix K use well-established technology.

Analysis of Rainwater's Potential to Meet the EcoBlock's Potable Water Needs

Three rainwater-based systems for meeting (at least a portion) of the EcoBlock's potable water needs were analyzed. Two systems capture and store rainwater, treat it, then send the treated water into the home. In one system the water is treated and then used at the individual residence (Rainwater Harvesting for Potable Use with Treatment at the Individual Residences). In the second, water is sent to a central facility for treatment and returned to the residences for use (Rainwater Harvesting for Potable Use with Block-Scale Treatment).

In the third system (Rainwater Harvesting for Direct Potable Reuse) rainwater is a key component of a direct potable reuse system (Tchobanoglous et al. 2011; Englehardt et al. 2013). With this system, all wastewater generated on the block would be collected and treated to drinking water levels and returned to the block's residences. Stored rainwater would be used to make up for losses (such as leaks) and to counter salt build-up in the water (Englehardt et al. 2013). Currently direct potable reuse systems (DPR) are not permittable in California, and it is unlikely that block residents would favor such systems if they were. However, there is considerable interest in them, and research being conducted on them. Additionally this rain-based system would be an integral part of the only way the block could achieve net zero water.

To assess the potentials of these systems, 17 years of daily, Oakland rainfall data were analyzed in combination with expected water demand.

The EcoBlock's average annual rainfall is around 22 inches—a bit more than 2 million gallons annually for the block. Rainfall is highly seasonal with 80 percent of the rain falling from

November through March. There is also great year-to-year variability—8 inches fell in water year 2004; 35 inches in 2006. About 25 percent of the rain falls on the block's roofs (an average of ~500,000 gallons/year).

Figures 3 and 4 show the results of the analysis. Figure 3 shows results for the first two systems (Rainwater Harvesting for Potable Use with Block-Scale Treatment and Rainwater Harvesting for Potable Use with treatment at Individual Residences). Over the 2000–2017 period, the potable rainwater systems could have met, on average, 100 to 125 days of the block's needs with storage capacity of 30 thousand to 50 thousand gallons.

Over this same period, 150 thousand gallons of storage could meet all the EcoBlock's indoor water needs, except for a few days in the driest years for the rainwater-based direct potable reuse system (Rainwater Harvesting for Direct Potable Resuse) (Figure 4).

Figure 3: Days/Year Indoor Water Use Supplied with a Potable Rainwater System

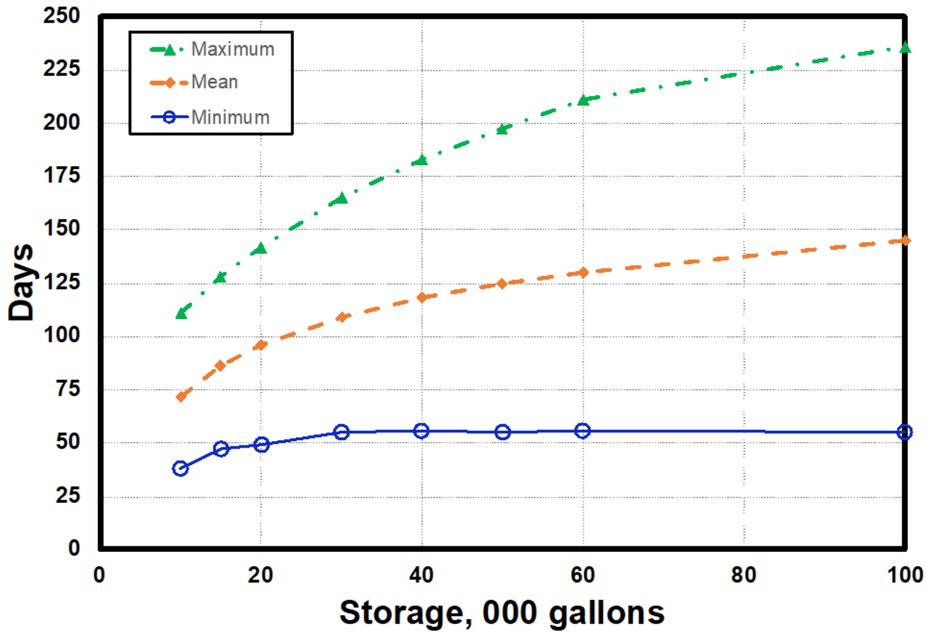
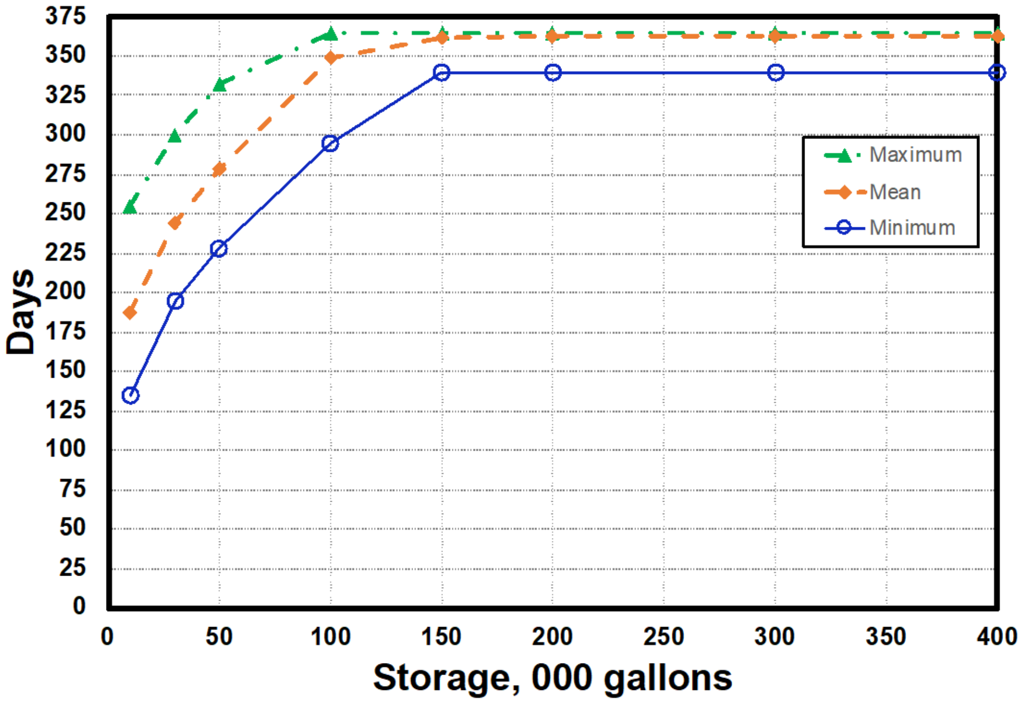


Figure 4: Days/Year Indoor Water Use Supplied with a Rainwater-Based DPR System



Alternate Water Systems Analyzed

The sections below provide detailed information on the systems analyzed in Chapter 4 (see Table 4-6)

Background Information

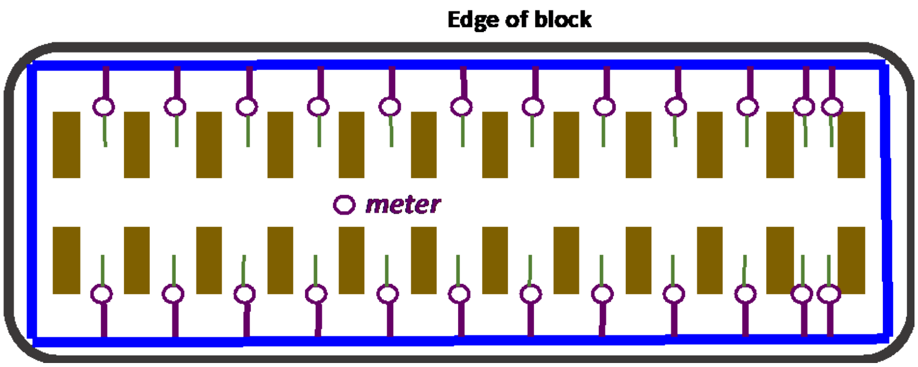
Block-Scale Piping

Several of the systems discussed in Chapter 4 require block scale piping:

- Sewer Mining for Irrigation
- Groundwater for Irrigation
- Groundwater for Potable Use
- Rainwater Harvesting for Potable Use with Block-Scale Treatment
- Rainwater Harvesting for Direct Potable Reuse

Each set of block scale piping (Figure 5) includes perimeter piping that runs around the block (blue), and piping and piping that connects perimeter piping to the residences. All of the systems that require block scale piping have one set that distributes water to the homes. The two block-scale rainwater based systems (Rainwater Harvesting for Potable Use with Block-Scale Treatment and Rainwater Harvesting for Direct Potable Reuse) also require collection piping that transports water from homes to the treatment facility.

Figure 5: Generic Block Scale Piping



The potable rainwater harvesting system with block-scale treatment requires a collection system that brings captured and stored rainwater to the treatment plant. The rainwater harvesting direct potable reuse system requires two sets of collection piping—one for the stored rainwater and one to collect and transport sewage to the treatment facility.

Approximately 1,700 feet of piping is required to circle the block. Connecting each property to a set of block piping will require about 75 feet of piping (block-meter connection plus meter-property connection).

System Components

This section outlines the components of each of the alternate source water systems considered for the EcoBlock

Greywater Diversion

Though it is technically feasible to use all greywater sources, costs (replumbing) and permitting barriers for systems other than laundry to landscape are high. Because of these factors the analysis considers the use of laundry greywater for subsurface irrigation only, and only for single-family homes and two-unit buildings.

Figure 6 illustrates a typical laundry-to-landscape configuration. Typical system components include:

1. Three-way diversion valve that allows for diversion of the water to the irrigation system or sewer system
2. An autovent/air vent, which is installed at the high point in the line to prevent accidental siphoning of water from the washing machine
3. One-inch high-density polyethylene (HDPE) distribution tubing
4. An underground emitter box
5. Ball valves (to adjust the irrigation rate)
6. A mulch basin, which is designed to receive and distribute the greywater to the plant root zone. The mulch basin should be sized so that no ponding of the greywater occurs on the surface of the soil/mulch.

Figure 6: Laundry-to-Landscape Schematic (*Greywater Diversion*)

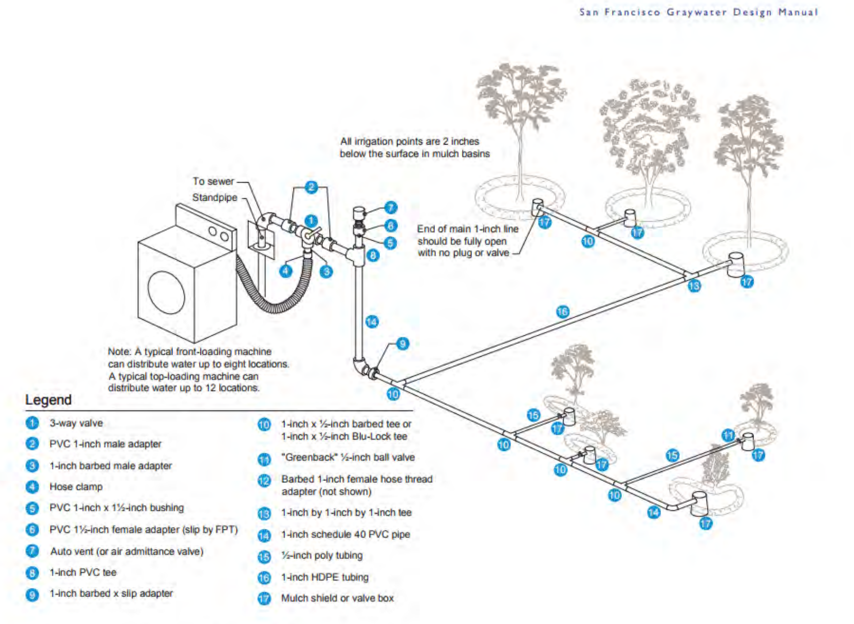


***Figure 3**. Laundry-to-landscape overview. Source: Clean Water Components.*

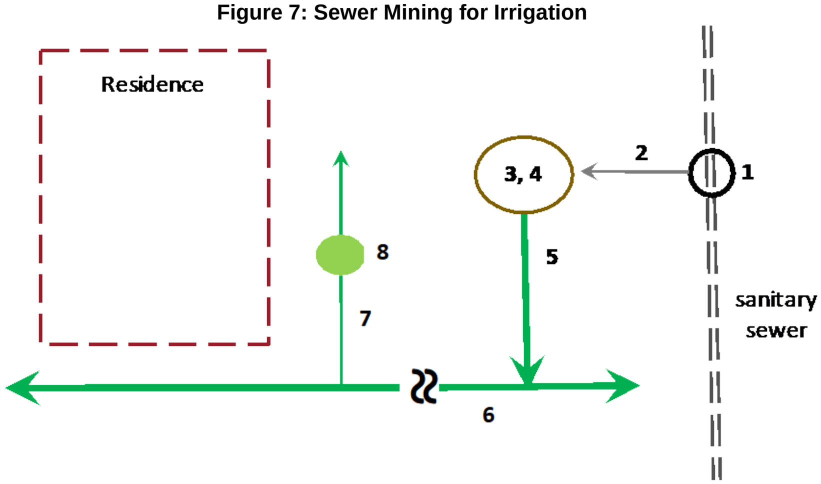
Source: San Francisco Graywater Design Manual (SFPUC 2018)

Sewer Mining for Irrigation

For sewer mining for irrigation, wastewater is extracted from a sewer line in the street next to the block, treated to a high degree of purity, and used for irrigating yards and gardens on the block. System requirements include the following (Figure 7):

1. A means to divert wastewater from a sewer at a manhole
2. Piping to get wastewater from the sewer to the treatment facility
3. A treatment system to produce high-quality reclaimed water from wastewater
4. A pump to distribute water to residences
5. Piping from the treatment plant to the distribution piping
6. Distribution piping that encircles the block
7. Piping from the block's distribution piping to each property
8. A meter to quantify each property's use

Figure 7: Sewer Mining for Irrigation



Groundwater

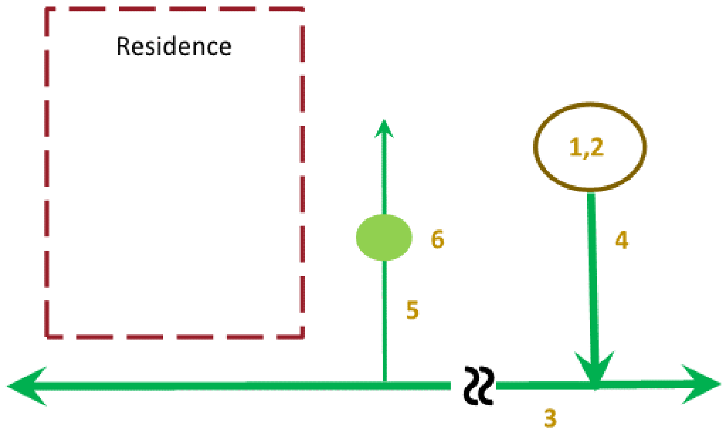
Two systems using groundwater were considered. The first would provide water for irrigation. The second would produce potable water to be used for all purposes (Groundwater for Potable Use). An existing well on the EcoBlock may be usable. If water quality and yield are sufficient, groundwater could be used for all purposes or just irrigation.

Groundwater for Irrigation

The primary components of the system would be as follows (Figure 8):

1. Well
2. Pump
3. Distribution piping that encircles the block
4. Piping from the well to the distribution piping
5. Piping from the block's distribution piping to each property
6. A meter to quantify each property's use

Figure 8: Groundwater for Irrigation

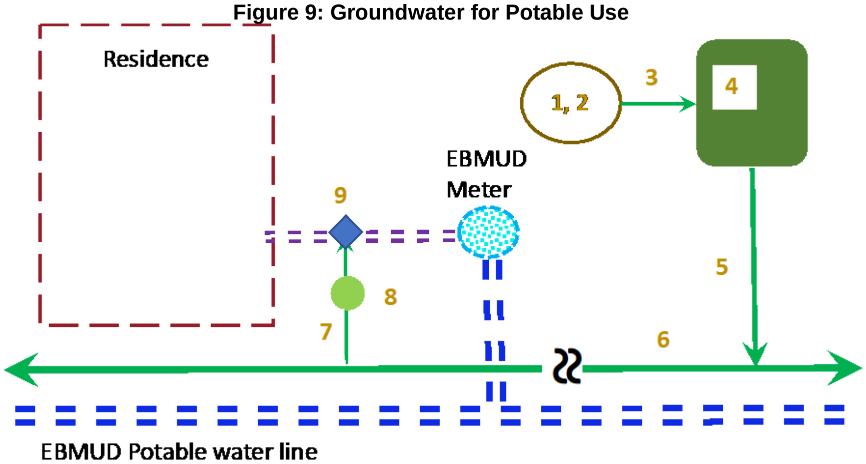


Groundwater for Potable Use

The primary components of the system would be as follows (Figure 9):

1. Well
2. Pump
3. Piping to treatment facility
4. Treatment facility
5. Piping from the treatment facility to the distribution piping
6. Block-scale distribution piping
7. Piping to each property
8. A meter to quantify each property's use
9. A connection to the residence's existing piping

Figure 9: Groundwater for Potable Use



Rainwater

Four different systems using rainwater were considered. In the simplest, rainwater is collected from a roof, stored, and used to irrigate adjacent landscape (Rainwater Harvesting for Irrigation). In the second, rainwater is collected, stored, and treated to potable standards at individual residences and used there (Rainwater Harvesting for Potable Use with Treatment at Individual Residences). In the third, rainwater is captured and stored at individual residences, but it also includes transport and treatment at a central facility followed by return to the residences (Rainwater Harvesting for Potable Use with Block-Scale Treatment). The fourth system considered is a direct potable reuse (DPR) system (Englehardt et al. 2013; Tchobanoglous et al. 2011) (Rainwater Harvesting for Direct Potable Reuse). Here, as with the rainwater harvesting for potable use with treatment at individual residences system, rainwater is transported and treated at a central facility. However the facility also would receive wastewater generated on the block, treat the wastewater to potable levels, and mix this highly purified wastewater with rainwater for use to meet all indoor domestic needs.

Rainwater Harvesting for Irrigation

Each property would be equipped with an aboveground storage tank. The roof would have a collection system, including gutters, first flush diverters, etc. to feed the tank. Irrigation water would feed from the tank via gravity or by a small pump. The primary system components would be as follows (Figure 10):

1. Rainwater storage tank
2. Collection system (gutters, first flush diverter, etc.)
3. Distribution pump (optional)

Figure 10: Rainwater for Irrigation

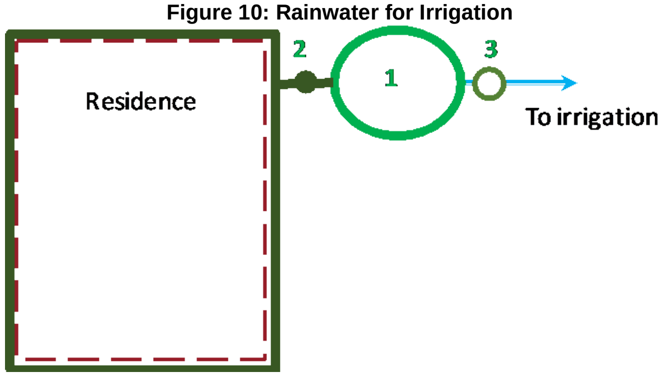


Table 6 of Chapter 4 outlines the costs of two rainwater irrigation systems. They differ only in the size of the storage tanks (1,000 or 10,000 gallons).

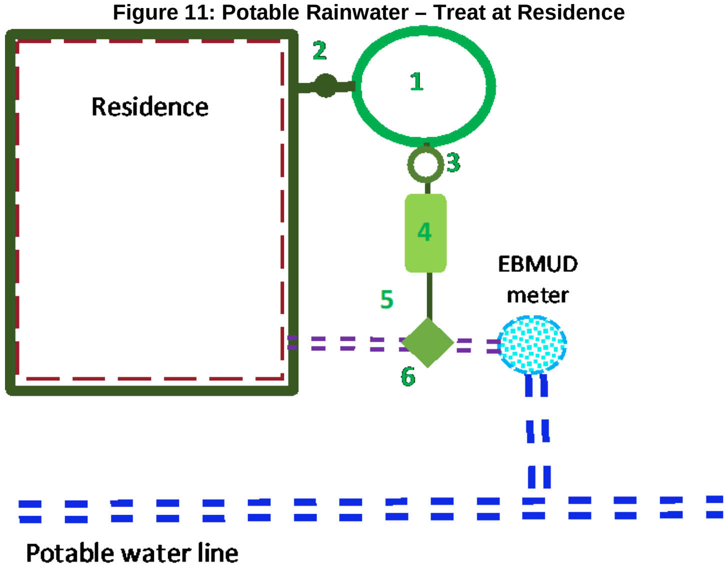
Rainwater for Potable use

Two configurations were considered. In both cases rainwater would be collected and stored at individual properties (exactly as in the rainwater for irrigation (Rainwater for Irrigation system). In the first, stored rainwater would be treated and used at the at the property where it is collected (Rainwater Harvesting for Potable Use with treatment at Individual Residences). In the second, the stored rainwater would be pumped to a central facility, treated, and pumped back to the homes (Rainwater Harvesting for Potable Use with Block-Scale Treatment). In the second system, rainwater from all the homes would be commingled, treated, and utilized by all homes on the block.

Required components for rainwater harvesting for potable use with treatment at individual residences include the following (Figure 11):

1. Rainwater storage tank
2. Collection system (gutters, first flush diverter, etc.)
3. Distribution pump
4. Treatment system
5. Piping to the potable water line
6. Connection to the existing potable water system

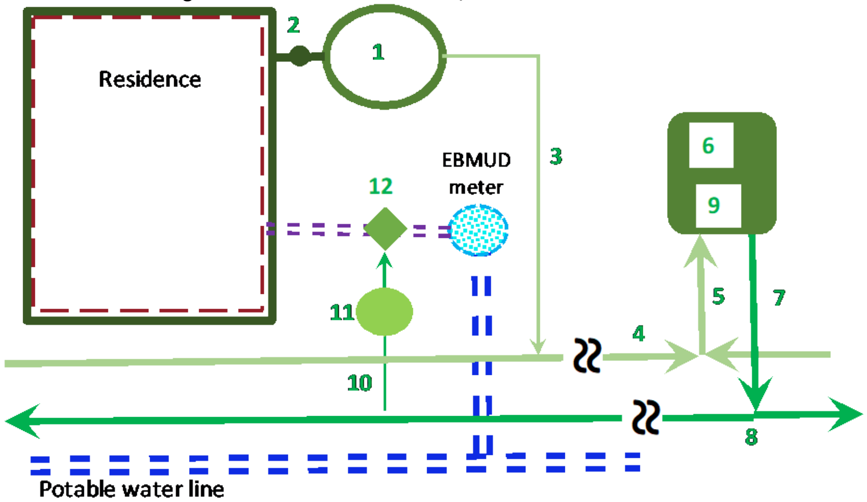
Figure 11: Potable Rainwater – Treat at Residence



Required components for rainwater harvesting for potable use with block-scale treatment include the following (Figure 12):

1. Rainwater storage tank
2. Collection system (gutters, first flush diverter, etc.)
3. Piping from the tank to the collection piping system encircling the block
4. Block encircling the collection piping
5. Piping from the block collection system to the treatment facility
6. Treatment system
7. Piping from the treatment system to the distribution piping system encircling the block
8. Block encircling the distribution piping
9. Pump(s) to
   a. Draw water from the tanks
   b. Move water through the treatment system
   c. Distribute water to the homes
10. Piping to the home
11. Meter to quantify the property's use
12. Connection to the existing potable water system

Figure 12: Potable Rainwater, Block-Scale Treatment

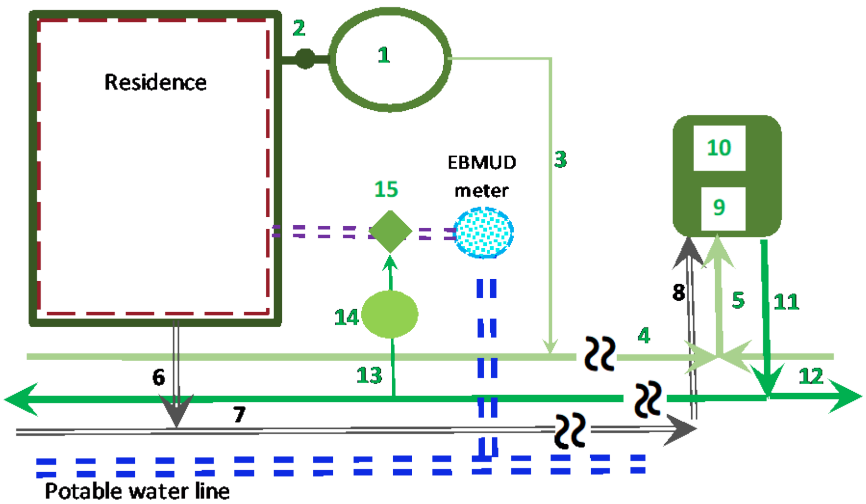


Rainwater Based Direct Potable Reuse

This system, based on the work of Englehardt et al. (2013) requires the following (Figure 13):

1. Rainwater storage tank
2. Collection system (gutters, first flush diverter, etc.)
3. Piping from the tank to the collection piping system encircling the block
4. Block collection piping
5. Piping from the block collection system to the reclamation facility
6. Sewer from each building to a sewer line encircling the block
7. Sewer line encircling the block
8. Sewer connection to the reclamation plant
9. Reclamation system
10. Pump(s) to
    a. Draw water from the tanks
    b. Move water through the treatment system
    c. Distribute water to the homes
11. Piping from the treatment system to the distribution piping system encircling the block
12. Distribution piping encircling the block
13. Piping to each building
14. A meter to quantify each property's use
15. Connection to the existing potable water system

Figure 13: Rainwater-based Direct Potable Reuse



System Capital Costs

Greywater Diversion

Table 6 shows estimated capital costs for a laundry to landscape greywater diversion system. Systems would be installed at individual homes, at a cost of about $280 dollars per home; $7400 for the block as a whole.

Table 6: Capital Costs: Greywater Diversion

unit	# units	$/unit	Component	$, 000	% total
#	27	$175	Kit	$4.7	64%
#	27	$100	Piping/Mulch	$2.7	36%
			Total	**$7.4**	**100%**

Sewer Mining for Irrigation

Table 7 shows capital costs for a sewer mining system that reclaims wastewater for use as irrigation water.

The cost categories for the sewer mining system include:

- Treatment, which are the costs associated with the systems that purify the wastewater
- Building, which is the share of construction costs for the facility that would house the wastewater treatment facility and the central flywheel facility
- Manhole, which includes sewer manhole modifications to allow extraction of wastewater
- Force Main, which is the system to transport wastewater from sewer to treatment plant
- Block Piping, which is the piping that goes around the block

- House Piping, which includes connections from the block piping to the home
- Water Meters, which will be installed on the house piping lines
- Storage, which is required to deal with variations in irrigation demand

Table 7: Capital Costs: Sewer Mining for Irrigation

unit	# units	$/unit	Component	$, 000	% total
#	1	$570,000	Treatment	$570	47%
#	1	$180,000	Building	$180	15%
#	1	$125,000	Manhole	$125	10%
#	1	$48,000	Force Main	$48	4%
ft	1700	$95	Block Piping	$162	13%
ft	2025	$55	House Piping	$111	9%
#	27	$300	Meter	$8.1	1%
gal	5000	$0.50	Storage	$2.5	0%
			Total	$1,210	**100%**

Groundwater

Groundwater for Irrigation
Table 8 shows estimated capital costs for a groundwater for irrigation system.

Table 8: Capital Costs: Groundwater for Irrigation

units	# units	$/unit	Component	$, 000	% total
#	1	$10,000	Well	$10	3.4%
#	1	$3,000	Pump	$3	1.0%
#	1	$1,000	Treatment	$1	0.3%
ft	1700	$95	Block Piping	$162	55%
ft	2025	$55	House Piping	$111	38%
#	27	$300	Meter	$8.1	2.7%
			Total	**$290**	**100%**

The well and pump are required to extract water from the ground. The extracted water may require some treatment before use.

Groundwater for Potable Use
Table 9 summarizes costs associated with the groundwater for potable use system. “Connect” costs refer to costs of tying into the residences’ existing potable water lines while ensuring that there can be no flow into EBMUD’s system.

Table 9: **Capital Costs: Groundwater for Potable Use**

units	# units	$/unit	Component	$, 000	% total
#	1	$10,000	Well	$10.0	3.1%
#	1	$3,000	Pump	$3.0	0.9%
#	1	$22,000	Treatment	$22	6.7%
ft	1700	$95	Block Piping	$162	49%
ft	1950	$55	House Piping	$107	33%
#	26	$500	Connect	$13	4.0%
#	26	$300	Meter	$7.8	2.4%
gal	5,000	$0.5	Storage	$2.5	0.8%
			Total	**$330**	**100%**

Rainwater

Rainwater Harvesting for Irrigation

Two rainwater harvesting for irrigation systems are shown below. The first (Table 10) assumes that 1,000 gallon storage tanks are installed at each residence. The second (Table 11) assumes that 10,000 gallon storage tanks are installed. Miscellaneous costs include, the costs of gutters, first flush diverters, etc.

Table 10: Capital Costs for Rainwater Harvesting Systems for Irrigation – 1,000 Gallon Tanks

units	# units	$/unit	Component	$, 000	% total
#	26	$1,000	Misc	$26	40%
gal	26000	$0.50	Storage	$13	20%
#	26	$1,000	Installation	$26	40%
			Total	**$65**	**100%**

Table 11: Capital Costs for Rainwater Harvesting Systems for Irrigation – 10,000 Gallon Tanks

units	# units	$/unit	Component	$, 000	% total
#	26	$1,000	Misc	$27	14%
gal	260000	$0.50	Storage	$135	71%
#	26	$1,000	Installation	$27	14%
			Total	**$189**	**100%**

Rainwater Harvesting for Potable Use

Two systems were analyzed for potable rainwater harvesting. In the first, rainwater would be captured and stored and then treated at the residence and used there (Table 12). In the second, (Table 13) the rainwater would be transported to a central facility, treated, and returned to the users. Costs associated with the central facility (Building) are included for this option.

Table 12: Capital Costs for Potable Rainwater Harvesting Treated at a Residence

units	# units	$/unit	Component	$, 000	% total
#	27	$1,000	Treatment	$27	13%
#	27	$1,000	Misc	$27	13%
#	27	$500	Connect	$14	6%
#	27	$1,000	Pump	$27	13%
ft	1350	$55	House Piping	$74	34%
gal	40000	$0.50	Storage	$20	9%
#	26	$1,000	Installation	$27	13%
			Total	$220	**100%**

Table 13: Capital Costs for Potable Rainwater Harvesting Treated at a Central Location

units	# units	$/unit	Component	$, 000	% total
#	1	$20,000	Treatment	$20	2.3%
#	1	$180,000	Building	$180	21%
#	27	$1,000	Misc	$27	3.1%
#	27	$500	Connect	$14	1.6%
#	1	$10,000	Pump	$10	1.2%
ft	3400	$95	Block Piping	$320	37%
ft	4050	$55	House Piping	$220	26%
#	27	$300	Meter	$8	0.9%
gal	50000	$0.50	Storage	$25	2.9%
#	27	$1,000	Installation	$27	3.1%
			Total	**$850**	**100%**

Rainwater Harvesting for Direct Potable Reuse

Table 14 summarizes estimated costs for a rainwater-based direct potable reuse system. The analysis is based on a system developed by Englehardt and coworkers (Englehardt et al. 2013).

Table 14: Capital Costs for a Rainwater-based Direct Potable Reuse System

unit	# units	$/unit	Component	$, 000	% total
#	1	$800,000	Treatment	$800	42%
#	1	$180,000	Building	$180	9.5%
#	27	$500	Connect	$14	0.7%
ft	5,100	$95	Block Piping	$480	25%
ft	6,075	$55	House Piping	$330	17.4%
#	27	$300	Meter	$8.1	0.4%
gal	150,000	$0.50	Storage	$75	4.0%
			Total	**$1,900**	**100%**

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APPENDIX I: DECISION-MAKING FRAMEWORK

DECISION MAKING FRAMEWORK

Criteria Descriptions

TECHNICAL

LEGAL + FINANCIAL

CATEGORY	SUBCATEGORY	DESCRIPTION / METRIC USED
LIFECYCLE COST	Capital / First Costs	Upfront cost to build and furnish systems
	Ongoing O&M Costs	Costs associated with maintenance of systems
	Revenue	Value of water offset by systems
REPLICABILITY / SCALABILITY	Replicability/Scalability: Ability to scale solution to City of Oakland	As noted
	Replicability/Scalability: Ability to Transfer solution to other locations in CA & elsewhere	Feasibility for locations in Southern California, rural suburbs, etc.
FOOTPRINT & SITING	Size of footprint for all infrastructure & components	Area required for siting systems (above or below ground)
	Siting constraints, difficulty	Other considerations that make system difficult to replicate/scale elsewhere
EASE OF MAINTENANCE AND OPERABILITY	Time Burden	Time committment required from users to keep systems running
	Technical Experience	Technical experience required by specialist to maintain systems
MUNICIPAL TO STATE POLICIES AND PLANS	*Advances permits, codes and procedures?*	*Not included due to feedback from Water Team (canceled out impact that Legal/Financial was meant to incorporate)*
UTILITY MODEL	*Provides a new model for distributed water management for public utilities?*	*Not included due to feedback from Water Team (canceled out impact that Legal/Financial was meant to incorporate)*
INSURANCE & FINANCING	*Access to capital markets*	*Not enough feedback received*
	Access to Green Bonds	*Not enough feedback received*
	Ability to fund at scale	*Not enough feedback received*
	Ability to insure and bond	Ability to insure system for future operator failures.
FEASIBILITY OF OWNERSHIP MODEL	Legal and financial complexity of ownership model	Difficulty in setting up a legal entity, or engaging public utilities to assist in ownership and maintenance
	Community Acceptance of ownership model	Community acceptance of legal entity/ownership setup

SOCIAL & ENVIRONMENTAL

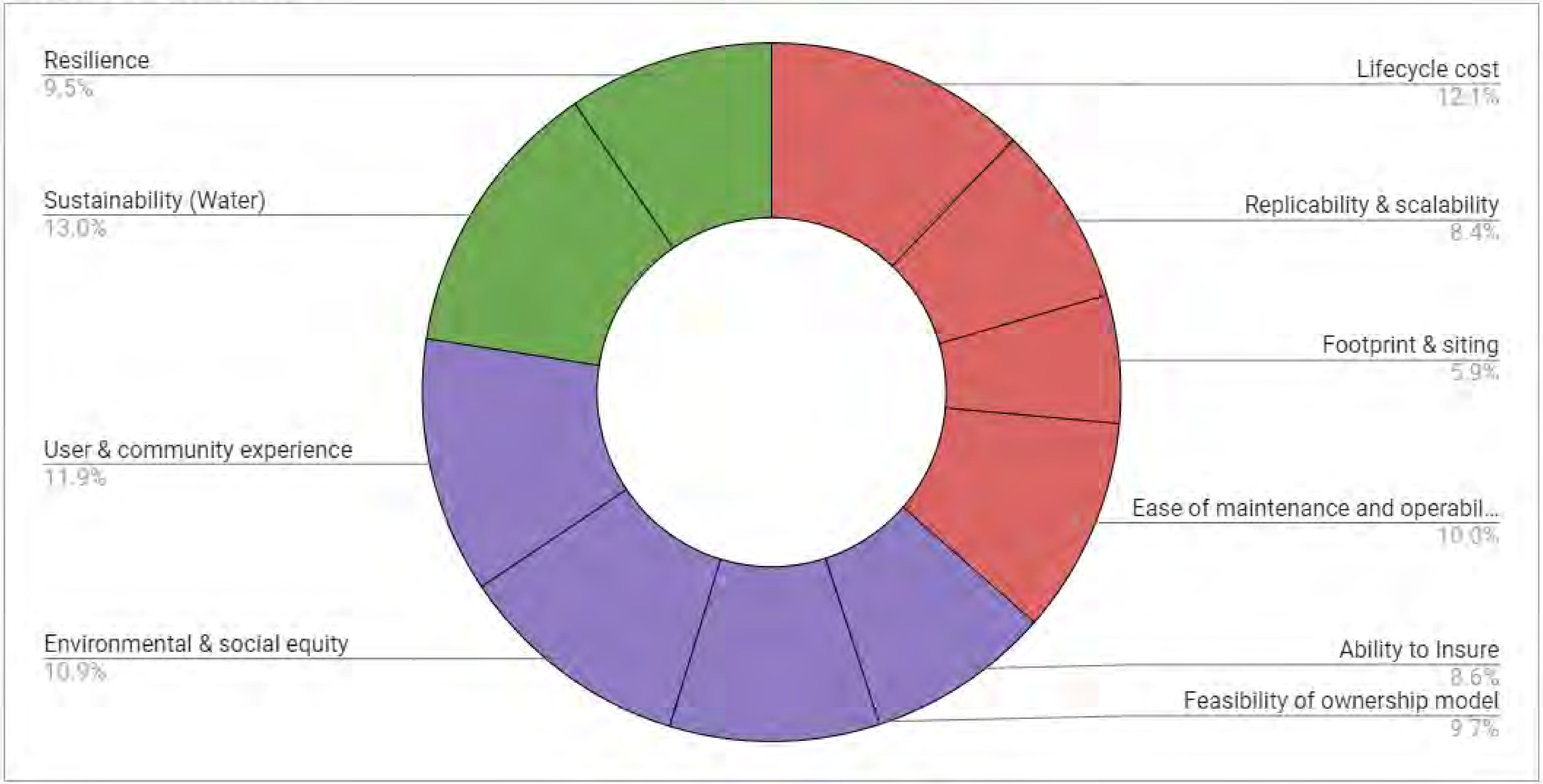
CATEGORY	SUBCATEGORY	DESCRIPTION / METRIC USED
SOCIAL AND ENVIRONMENTAL EQUITY	Visible and physical restorative components	Visual appeal and associated restored habitat/vegetation
	Transferability to other neighborhoods in need	Low maintenance, large payback for communities that do not have time to manage a water system
USER AND COMMUNITY EXPERIENCE	Public health, safety and security	Risks associated with water supply to the public
	Educational value	Visibility within community and uniqueness of solution
	Community acceptance	Theoretical response from homeowners
SUSTAINABILITY	Water Sustainability	Gallons of potable demand offset from local water utility
	Energy	*Considered as an add-on consideration, however not a driver for water systems decision-making*
	Carbon Footprint	*Considered as an add-on consideration, however not a driver for water systems decision-making*
	Materials	*Considered as an add-on consideration, however not a driver for water systems decision-making*
RESILIENCE	Addresses water scarcity	Reduces community dependence on seasonal rains and/or extended droughts
	Addresses seismic risk	*Considered as an add-on consideration, however not a driver for water systems decision-making*
	Provides local emergency water supply	Provides an additional source of water that could be used in case of an emergency (earthquake, fire, etc)
	Addresses flooding risk	Provides positive impact for downstream stormwater systems
	Positive impact on local utility service provision	Reduces stress on existing sewer, water, and storm drainage systems

SHERWOOD DESIGN ENGINEERS

DECISION MAKING VALUES AND RANKINGS			
CATEGORY / Evaluation Criteria		Value	% Weight
1	**Technical**	**43.7**	**36.4%**
1.1	Lifecycle cost	14.6	12.1%
1.2	Replicability & scalability	10.0	8.4%
1.3	Footprint & siting	7.1	5.9%
1.4	Ease of maintenance and operability	12.0	10.0%
2	**Legal & Financial**	**21.9**	**18.3%**
2.1	Ability to Insure	10.3	8.6%
2.2	Feasibility of ownership model	11.7	9.7%
3	**Environmental & Social**	**54.3**	**45.3%**
3.1	Environmental & social equity	13.1	10.9%
3.2	User & community experience	14.2	11.9%
3.3	Sustainability (Water)	15.6	13.0%
3.4	Resilience	11.4	9.5%
	Total	120.0	100%

SHERWOOD
DESIGN ENGINEERS

CRITERIA WEIGHTING



APPENDIX J: TYPES OF COSTS, SAVINGS, AND REVENUE

Appendix J lists some of the various types of costs, savings, and revenues that the EcoBlock business model will need to account for.

One-time Costs

- **Residential Energy Efficiency Retrofits:** Insulation, windows, etc. All EcoBlock proposals rely heavily on energy-efficiency retrofits. These upgrades come at cost to individual homeowners.
- **Residential PV:** EcoBlock designs also utilize rooftop solar as a means of reducing resident's energy demands. The panels are a one-time capital cost with equipment, installation, and connection costs, as well as ongoing maintenance costs. Depending on the flexibility of the ownership model, the cost of the panels may fall to homeowners via private financing, homeowners via their property tax bill, or third parties.
- **High Efficiency Appliances:** Other EcoBlock designs propose high-efficiency appliance retrofits. The appliances are a one-time capital cost incurred by each homeowner. It is likely that this cost would fall to individual homeowners, although it may be bundled as a property tax bill.
- **Water Efficiency Retrofits:** Similar to other efficiency retrofits, high-efficiency water fixtures are one-time capital expenses with potential maintenance and replacement costs.
- **Rainwater Harvesting and Storage:** Rainwater harvesting and storage infrastructure includes rooftop hardware and storage tanks. It is unclear whether these costs would be individual or communal.
- **Gray water treatment and reuse:** Some EcoBlock proposals include gray water systems. Depending on the system, gray water system costs may accrue to the individual homeowner or to the community-entity.
- **Stormwater management infrastructure:** Stormwater management infrastructure may accrue as a one-time cost to individual homeowners or to the community-entity, depending on the type of infrastructure and the legal structure for ownership.
- **Trees and landscaping:** Green infrastructure and landscaping will accrue to individuals and to the block, depending on the type of installation and the location. Some EcoBlock landscaping upgrades will occur in the public right-of-way.
- **EV chargers:** Electric vehicle chargers will likely be installed in the right-of-way and treated as a community cost.
- **Flywheel:** The EcoBlock designs propose an energy storage flywheel as part of the community's electric infrastructure. The flywheel will likely be placed on private, third-party property (an industrial lot adjacent to the block). Possible costs associated with the flywheel include capital cost, operations and maintenance, insurance, leasing or purchase of the third-party's property, interconnection costs, and end-of-life removal costs. It is likely that the flywheel costs would accrue to the community, unless a third-party agreed to own and operate the facility.

- **Microgrid/Energy Distribution Backbone:** The shared energy system of the EcoBlock relies on a local distribution grid built in the public right-of-way. It is likely that the cost of the distribution system would accrue to either a community district or another non-resident entity, such as a third party or an actual utility.
- **Software:** The EcoBlock is a smart block that will utilize numerous systems to optimize performance. There will likely be software costs associated with the operation of the different assets.
- **Sewer Mine/DPR facility:** Technical teams propose a water efficiency-plus system that could include a "sewer mine" to demonstrate direct potable reuse (DPR). Costs associated with the DPR facility will likely accrue to the community or a third-party organization versus individual homeowners. In addition to initial capital costs, the DPR facility will also incur long-term operations and maintenance costs, as well as insurance costs.
- **Costs of Interconnection:** Each new EcoBlock system will need to interface with the existing home and utility infrastructure. There may be a cost associated with interconnection.
- **Permitting:** There will be permitting costs associated with the first EcoBlock project, as well as any ensuing EcoBlock deployments. Permitting cost is one category where the state could decrease costs by waiving fees for EcoBlock/decarbonized projects.
- **Legal/Transactional Costs:** The EcoBlock is a complicated legal entity created through layers of ownership and property rights. Given the complexity of retrofitting an entire block, it is likely that ensuing EcoBlock projects might have steep legal fees and transactional costs. Early organizational/ownership structures may want to focus on how to decrease long-term complexity and encourage EcoBlock scaling.
- **Labor:** All EcoBlock infrastructure will include a labor and installation cost.
- **Trench:** The EcoBlock utility trench will be a substantial project cost.
- **Street surfaces and sidewalks:** Street and sidewalk improvements are a major element of the proposed EcoBlock project and could represent a significant project cost.
- **Poles for Utility Distribution Infrastructure:** Some project design proposals include use of the existing utility poles, which could represent a project cost for use, replacement, or removal.

Ongoing and Recurring Costs

- **Commodity and Delivery Costs of Electricity:** Each EcoBlock resident has electricity bills, which include the cost of electricity and the cost of the distribution system required to deliver the electricity. Their bills may include other charges tied to their consumption of electricity. The EcoBlock may eliminate their utility payments; however, it is likely that some charges will remain. As such, the costs of electricity supply, capacity, and delivery will inform the EcoBlock Business Model.
- **Commodity and Delivery Costs of Water:** Each EcoBlock resident is currently a customer of East Bay Municipal Utility District (EBMUD). Their utility bills include water supply and delivery. The EcoBlock may augment usage, but it is likely that customers will need to remain connected to the system and that part of their demand will still be met by the utility.

- **Sewer services:** EBMUD charges for sanitary sewer conveyance and treatment. While the EcoBlock proposal may reduce its resident's sewer load, they will still remain connected and may incur a system connection and use cost.
- **Finance:** The EcoBlock business model will incur a cost of capital that will inform both the cost of the project and its attractiveness to investors.
- **Insurance:** Insurance of the various EcoBlock systems may be a substantial cost incurred over the lifetime of the facility. Some of the infrastructure is not yet widely accepted, and as a result insurance may be more expensive for early EcoBlock project deployments.
- **Operations and Maintenance:** O&M of the various EcoBlock systems will affect the long-term revenue of the EcoBlock Business model.

Cost Savings

Cost savings are value streams that homeowners could capture against their existing expenses.

- **Commodity Energy and Water Savings:** EcoBlock cost is recouped through the lifetime energy and water efficiency savings on utility bills.
- **Wastewater, non-potable, sewer reduction fee savings:** Decreases in water uses lead to savings on sewer fees, which are charged based on water use.
- **Income tax write-off:** By paying for home improvements as part of a property tax assessed financing tool, the homeowner reduces their utility bill, transforming it into an expense that can be written off from federal income taxes.
- **Demand Reduction Induced Price Effect (DRIPE):** DRIPE is a measurement of the value of demand reductions in terms of the decrease in wholesale energy prices, resulting in lower total expenditures on electricity or natural gas across the grid. DRIPE might create some kind of value stream at high volume EcoBlock penetration.

Actual Revenue Streams

Actual revenue streams are sources of income that could be itemized and sold into another market, or used to compensate third-party participants. Actual revenue streams could improve the overall payback period of the EcoBlock.

- **EV Charging:** The EcoBlock organizational entity might benefit by selling electricity through its EV charging stations.
- **Aggregation for Demand Response:** A third-party provider might be able to aggregate EcoBlock appliances (e.g., air conditioners) and cycle them to create a demand response product.
- **Deferred Water System Costs:** Some jurisdictions offer credits to projects that defer water utility system investment and increase resiliency. Some projects may be eligible for credits or grants related to deferred capital expenditure costs.
- **Rainwater Harvesting:** Similar to water efficiency, rainwater harvesting represents an avoided utility bill cost.
- **Energy Storage Arbitrage:** A savvy flywheel operator could buy off-peak and sell on-peak. It is unclear how this arbitrage would interact/interfere with local solar generation.

- **Carbon Credits:** There may be a possibility to somehow package carbon reductions and sell them into a carbon market. This value stream is uncertain due to the low price of carbon, and questions as to whether the EcoBlock would qualify as an offset to an allowance.
- **Distribution System Cost Reductions:** Targeting EcoBlock development to stressed areas of the grid could generate the equivalent of deferred distribution grid capital investment by reducing overall demand. Policy reforms could allow EcoBlock customers that pay to reduce their grid dependence through the EcoBlock to receive a share of the benefit they bestow on other ratepayers.
- **Flywheel as a deployable grid resource:** A fleet of flywheels in aggregate could be used to mitigate transmission congestion by storing energy off peak for use closer to the end user during on-peak hours. EcoBlocks at scale might be able to relieve transmission grid congestion. It is not clear what scale or other arrangement would make a fleet of flywheels an ISO resource.

Policy-based Value Streams

- **Resiliency:** There may be a quantitative argument for EcoBlocks as resiliency (probabilistic rates of failure versus the utility rate of failure). If a hard number for resiliency cannot be attached, there is a qualitative argument for the climate resiliency of the distributed water and energy system.
- **Groundwater Banking:** Groundwater recharge may not be a quantitative value stream, but EcoBlocks may be able to provide a benefit to sustainable groundwater management.

APPENDIX K: ADDITIONAL OWNERSHIP AND ORGANIZATIONAL MODELS

Several configurations of asset ownership could have a dramatic impact on the EcoBlock financing model. This appendix includes brief descriptions of additional models that are not discussed in full in the report but could potentially be applicable to the EcoBlock.

Government Ownership

Government ownership of the EcoBlock should be considered, even if the question proves unwieldy or unpopular. Other jurisdictions may be more amenable to a sustainable EcoBlock, and the model could be applied to government-owned housing such as military housing or assisted living communities.

EcoBlock Utility

It is possible that the certain improvements of the EcoBlock project, specifically its distribution system components, might subject it to CPUC jurisdiction as a public utility. If this is the case, it may fundamentally change the organization of the entity and its relationship to the resident customers. There are several outstanding questions as to how a block-level utility would be organized and operate.

Third-Party Operators: “Thin” versus “Thick” Operators

Another possible arrangement is that a resident entity owns the EcoBlock infrastructure, but a third-party is contracted for operation, maintenance, repair, and replacement. Such an operator could be minimally responsible, tending only to regular maintenance (“thin” operations); or the operator could be deeply involved in the operation of the block, operating the infrastructure, accepting liability for the installations, and more (“thick” operations). Regardless of whether the EcoBlock had a “thin” or “thick” operator, there would still need to be a separate entity binding the block residents and their property to the lifetime installations and the agreement.

Community Solar via EcoBlock Trust

Pacific Gas and Electric sponsors the Enhanced Community Renewables (ECR) project. Through the ECR, a customer subscribes to a portion of the output of a project directly through a developer, and PG&E delivers an equivalent amount of energy to the customer. All three parties share in a single transaction allocating distribution and energy costs.

In the particular case of the EcoBlock, the EcoBlock Trust would own and operate a solar project and, while the electricity would be funneled through PG&E, the properties on the block could secure access to the electricity and remain PG&E customers.

Microgrid Pilot Project

The EcoBlock would be developed as a full partnership with PG&E, subject to CPUC approval.

APPENDIX L: GREEN BONDS REPORT COMMISSIONED BY OAKLAND ECOBLOCK PROJECT

Green Bonds report commissioned by Oakland EcoBlock Project

Table of Contents

Introduction

The following report introduces the role of green bonds to finance climate-friendly urban infrastructure, the market practice of green bonds in the municipal space in the US, and examines a potential EcoBlock criteria and issuance options for a green bond to finance the EcoBlock developments.

The report has been developed by the Climate Bonds Initiative with the support of the University of Berkeley. This first draft has been prepared for review by the EcoBlock project and will be finalised for inclusion in the EcoBlock Master Plan to be submitted to the California Energy Commission in January 2018.

Green bond market development

What is a green bond

Green bonds are just like traditional bonds with one distinguishing feature: proceeds are earmarked for projects with environmental benefits, including climate change mitigation and adaptation, air pollution and water quality. The green label is a discovery mechanism for investors, which enables them to identify green investments with limited due diligence. By doing so, a green bond label reduces friction in the market and facilitates growth in climate-aligned investments.

For investors, green bonds can:

- Balance financial returns with environmental benefits
- Satisfy Environmental, Social and Governance (ESG) requirements or green investment mandates
- Enable direct investment in the 'greening' of brown sectors
- Enable hedging against climate policy risks

For issuers, green bonds:

- Provide an additional source of green financing
- Match asset maturity with project life
- Improve investor diversification and attract buy and hold investors
- Enhance reputation
- Attract strong investor demand leading to oversubscription

How to issue a Green Bond

There are 5 simple steps to issuing a green bond.

1. Identify qualifying green projects and assets

In the case of Eco-block, the total cost of project would be included.

2. Arrange independent review

External reviews can cost between USD5,000 and USD30,000 depending on the size of the portfolio and complexity of the assets; this is often a relatively small price compared to the cost of the bond issuance. Climate Bonds approved verifiers can be contacted for more information.

3. Set up tracking and reporting

The issuer must establish procedures for tracking and reporting the use of proceeds. If the issuer has already issued green bonds such a system will be already in place.

4. Issue the green bond

The usual steps apply here as with other conventional bonds, such as working with an investment bank or advisor on the structure and getting a credit rating.

5. Monitor use of proceeds and report annually

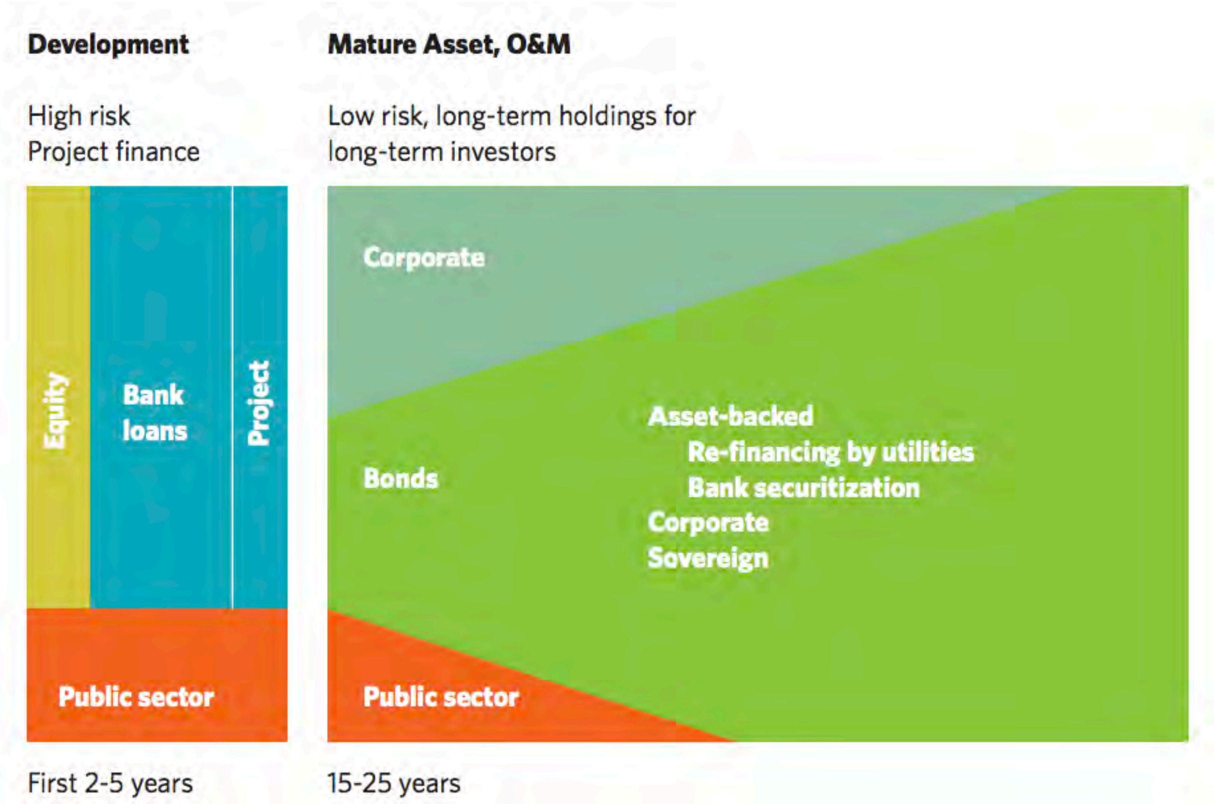
At least annually, a public report confirming the funds are still allocated must be issued. In the case of Eco-block this can be done yearly until all the funds have been invested in the project.

Steps 1-3 and 5 are specific to the *green* aspect of the bond and are necessary to meet investor expectations and transparency best practice for green bond issuers; the first 3 focus on pre-issuance requirements and are usually carried out at the same time as step 4. If the assets are complex the external review could take more time but this should not be the case for Eco-block projects.

Financing and re-financing

As traditional bonds, green bonds can be used to both finance new assets or refinance existing assets. Green bonds can therefore include portfolios of new assets, assets to be refinanced or mixed portfolios.

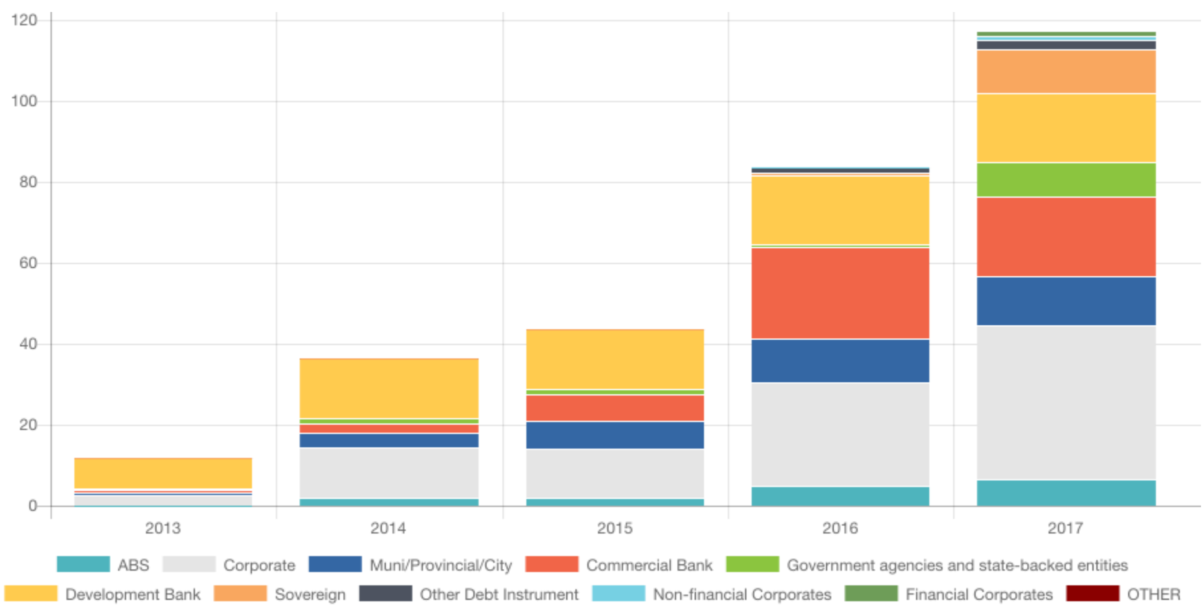
Bonds have an important role in the capital cycle, refinancing more expensive bank loans when the projects enter a lower risk operational phase. This allows banks to more quickly recycle the funds into new projects and increase the pipeline of green lending. Refinancing and obtaining lower-cost debt is particularly attractive for low-carbon infrastructure assets as they have a particularly low operating risk post-construction compared to the construction phase, so the cost of capital for low-carbon projects before and after construction could be significant.



Source: Scaling up green bond markets for sustainable development, Climate Bonds Initiative, 2016

Green bond market growth

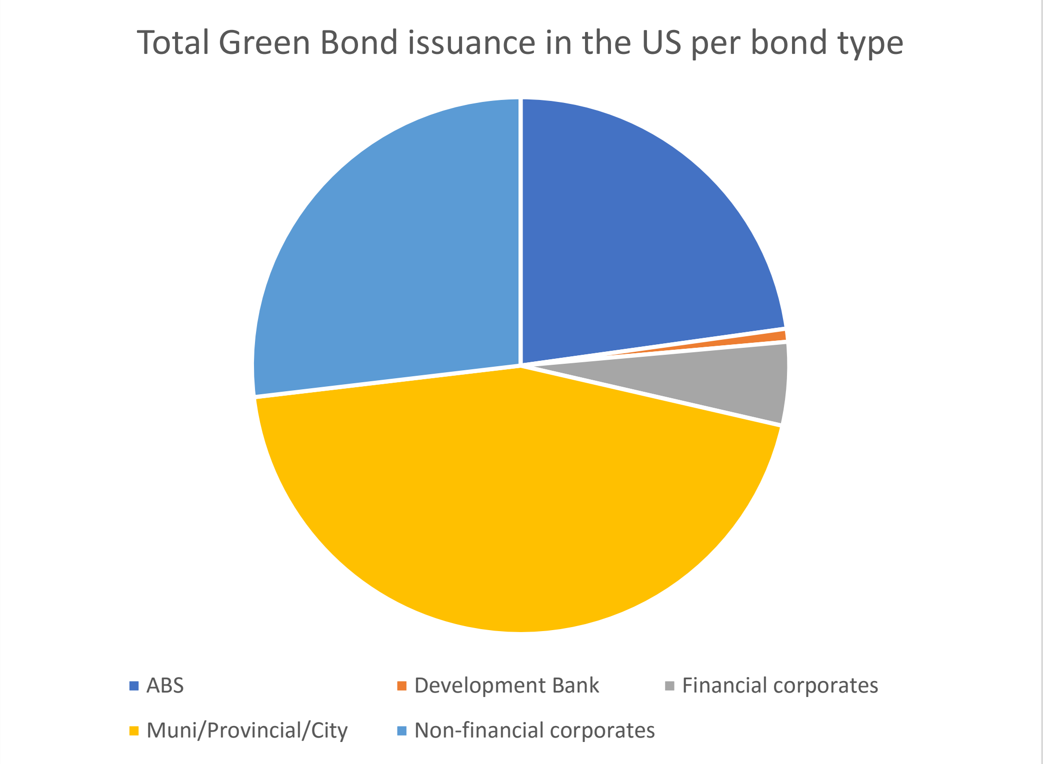
The green bond market has been growing exponentially over the past few years. Initiated by development banks in 2007, corporates started entering the market in 2012 with issuance gradually growing and tripling from 2013 to 2015 and doubling again in 2016, with developing countries, notably China, entering the market and issuance reaching USD81 billion. 2017 is already setting a new record with issuance so far having surpassed the USD100 billion landmark. The market is increasingly diversifying in terms of issuers, geographies, bond types, use of proceeds and currencies.



Source: Green bonds issuance as of December 12th 2017, Climate Bonds Initiative, 2017

The US muni Green bond market

Currently the largest market in terms of green bonds outstanding, the US green bond market is dominated by issuance from municipal entities (see graph below). Few corporates have joined the market so far, with the notable issuances of USD 1 and 1.5 billion from Apple.

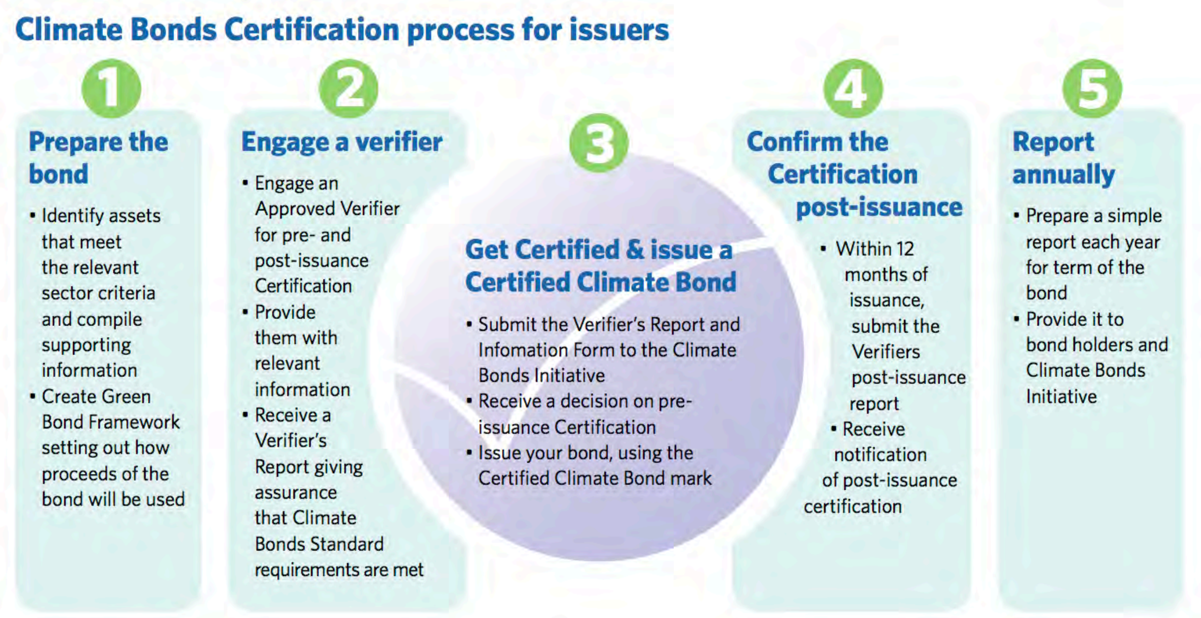


Source: Green bonds issuance as of December 12th 2017, Climate Bonds Initiative, 2017

The US green bond market is a voluntary market, meaning the issuer can label the bond as green without being subject to additional regulatory requirements. However, good practice both in the US and other markets across the globe has given rise to external reviews of the green credentials of the bond, which add a layer of transparency on the use and management of proceeds and gives comfort to investors. There are different types of labelling practices currently adopted by market players:

- Self-labelling: no external review is provided. This practice characterised 100% of the market in 2013 but is now pertinent to less than 50% of the market share. Several green municipal bonds have been issued without external review given their obligation to issue at par and the fear that the cost of the review may compromise this norm.
- Second party opinion: a bespoke review of the green credentials of the bond by an external party. This has been utilised by corporate issuers as well as muni bond issuers. Second party opinions characterised more than 20% of the market in 2016 and more than 30% in 2017.
- Certification: a third-party assurance model where the green credentials are verified by an independent party against an existing framework. The international Climate

Bonds Standard & Certification Scheme is the only such framework for green bonds. Examples of certified climate bonds include issuances from the San Francisco Public Utilities Commission, the Metropolitan Transport Authority, The New York State Housing Finance Agency, the Los Angeles County MTA and the City and County of San Francisco.



According to a recent report from Moody's, the share of US municipal green bonds with an external review has increased from virtually none in 2013 to 43% of the market in 2017, as a result of increasing market diversification and investor demand growth.

Green securitisation

Almost one quarter of the US green bond market is characterised by the issuance of green asset-backed securities (ABS). Several ABS have been issued in the American market by Property Assessed Clean Energy (PACE) financing providers in California.

Property Assessed Clean Energy (PACE) is a financing mechanism that enables low-cost, long-term funding for energy efficiency, renewable energy and water conservation projects. PACE financing is repaid as an assessment on the property's regular tax bill. Programmes are established locally; state legislation is passed to authorise municipalities to establish PACE programmes. The annual energy savings for a PACE project usually exceeds the annual assessment payment, so property owners are cash flow positive immediately.

California first enabled PACE in 2007, amending State laws to allow PACE financing for renewable energy and energy efficiency improvements to homes and businesses. In 2010 a state's Loan Loss Reserve Fund for residential PACE programmes was set up. Since then, PAS has financed over USD 2 billion for clean energy improvements throughout the State through 12 active programmes in operation.

One of the largest green PACE bond issuers is Renovate America which, through its Home Energy Renovation Opportunity (HERO) programme, issued USD 1bn of green securitised PACE loans in 2016. The environmental credentials of the ABS were reviewed by Sustainalytics and Renovate America also committed to provide impact reporting to investors on the impacts for energy, water, renewable energy and GHG reduction of the funded assets[1].

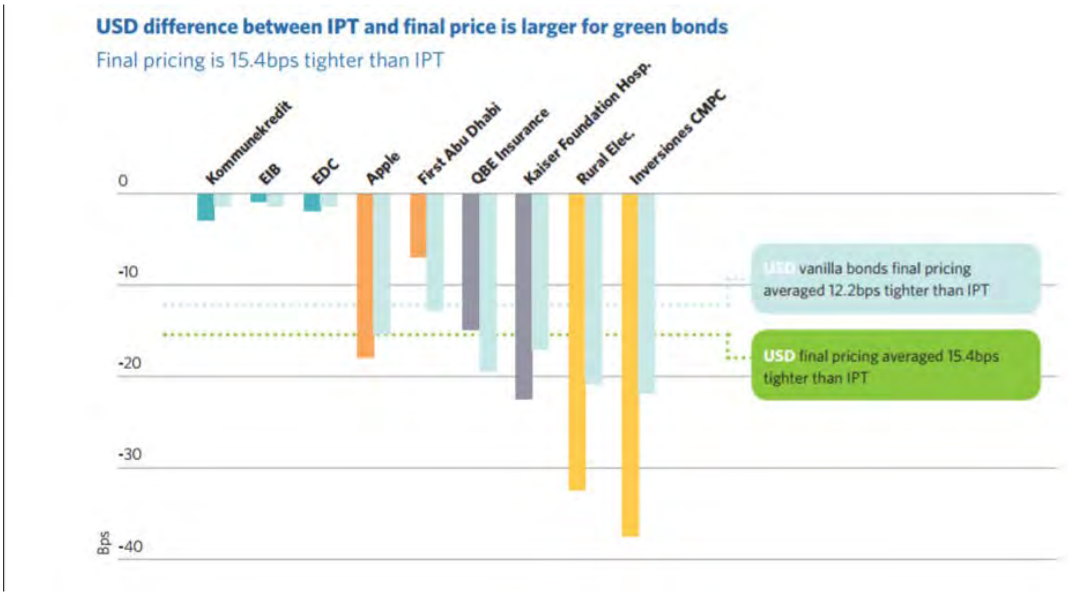
The PACE programmes available for Oakland, CA:

- CaliforniaFIRST: a financing programme for residential and commercial properties administered by Renew Financial allowing property owners to finance the installation of energy and water improvements on homes or businesses through the issuance of a municipal bond, which can then be paid back as a line item on the property tax bill. In 2016 Renew financial issued a USD115m securitised PACE bond.
- PACE Funding: a financing provider operating through a statewide municipal platform which allows up to 15% of a property's value to be financed for energy efficiency, renewable energy, seismic improvements and water conservation upgrades. The financing creates an assessment line on the property and is repaid as semi-annual instalments on the property tax bill.
- Ygrene: financing for renewable generation, energy efficiency and water conservation upgrades to both residential and commercial property owners with no upfront costs through PACE financing. Ygrene Energy Fund issued USD117.6 million worth of securitised PACE loans as green bonds.

Summary of pricing research

The Climate Bonds Initiative, in partnership with PAX, Rabobank and Obvion, has conducted analysis on the green premium issuers have anecdotally spoken about since the first corporate issuance in 2013. Analysis of green bonds issued in EUR and USD with an issue size >USD200m found that at issuance final pricing is consistently lower than initial price talk and oversubscription is the norm. A green discount at issuance has been noted in some of the issuances.

[1] https://www.climatebonds.net/2016/07/mkt-update-roaring-wk-gb-mkt-renovate-america-1st-labeled-green-abs-201m-2nd-review-big



Importantly, better performance in secondary markets has been observed for all green bonds when compared to their market indices[2]. These benefits for both issuers and investors are thought to be primarily driven by unmet demand for green debt which currently characterises the green bond market.

Green Bonds for EcoBlock

EcoBlock includes all climate-aligned assetss so how can it tap into the green bond market and how can this model be scaled up? As a first step, this section will look at creating a standard for EcoBlock and then options for green bond issuance to finance Eco-blocks in Oakland, California.

An EcoBlock Standard

An EcoBlock standard, outlining the environmental characteristics of the key components of the EcoBlock model can help scale up the development of sustainable blocks, districts and cities, facilitate funding and guide cities as to the type of infrastructure they need to develop in order to fit into science-based definitions of low-carbon and climate-resilient.

In the green bonds market domain, the Climate Bonds Standard and Certification Scheme is increasingly used by issuers to assess the climate credentials of a green bond. This is a Fair Trade-like scheme that serves to notify investors, governments and corporates that the underlying assets are compliant with a 2-degree pathway. The Climate Bonds Standard includes sector-specific science-based criteria developed by a group of technicians, tested against a group of industry players and finally vetted by investor groups sitting on the Climate Bonds Standard Board. The process is coordinated by the Climate Bonds Initiative, who acts as the secretariat for the Standard and the roll-out of sector-specific criteria. To date, guidance has been developed for low-carbon buildings, low-carbon transport, geothermal, wind, solar and water. Criteria for bioenergy, hydropower, land use and waste are under development.

[2] For further information visit: https://www.climatebonds.net/resources/reports?field_report_type_tid=583&field_report_language_tid=All

The Ecoblock framework could harness the work carried out under the Climate Bonds Standard and create a standard for Eco-block by combining the sector criteria for;

- Low-carbon buildings
- Water
- Solar Energy
- Low-carbon Transport

The scope of each criteria is expanded in Annex I.

The EcoBlock will offer monitoring and verification of energy, water and transportation information for each block. This could help track avoided carbon emissions from the switch from gas to renewables for electricity production and water use. Reporting to investors would be strong and based on actual rather than estimated environmental performance.

Green bond options for EcoBlock districts

Green financing for EcoBlock districts can be carried out through several options:

- Green bond issued by a Mello-Roos district

Mello-Roos districts can issue municipal bonds to help finance project costs and impose a special tax on the district to pay debt service on bonds. The development of the Eco-block would therefore be paid by the home-owners of the district by their repayment of the bond through the special tax.

This public financing for EcoBlock can be more efficient than conventional financing from banks or private capital markets because it can provide better interest rates and lower the borrowing cost of bonds issued by the distric, provide better borrowing terms, and allow for debt transference to new homeowners.

In utilising Mello-Roos, the EcoBlock district(s) would constitute the district and impose a special tax, approved by residents, to finance the improvements to energy and water efficiency and developments of electrified transport. The usual size of Mello-Roos districts and whether it can be applied to one Ecoblock or more would have to be investigated.

- Explore PACE financing for home improvements

PACE financing through CaliforniaFIRST, PACE funding or Ygrene for the home improvements in the block could be explored. The impact on the tax payer would be minimal as the investment is repaid through energy savings on the bills. Eligible PACE financing projects in the State should be investigated to assess whether these could include all the technologies included in the EcoBlock (such as street lighting and electric vehicles for example) or only partially. Home owners of the EcoBlock would have to take out PACE loans to be repaid through their tax bill. The lender of the loan would then securitise these repayments and issue a green bond in the capital markets.

- Green muni bond issued by Oakland municipality

The municipality of Oakland could raise a green bond to finance the development of EcoBlocks. This option would be particularly useful in the case of greenfield districts being developed. For brownfield investments, the bond could be repaid by capturing the increases in property tax which would result from the increment in land value following the improvements in energy and water efficiency. This practice has been used elsewhere in the US to repay transport and redevelopment of neighbourhoods[3]. This option can be further developed and the thesis tested with the Oakland municipality.

Conclusion

The report provides an overview of the role of green bonds to finance climate-friendly infrastructure and the opportunity for the development of an EcoBlock standard and options for a green bond issuance to finance the EcoBlock development(s).

An EcoBlock standard could be developed to facilitate investments in such developments and guide cities on what type of innovative districts they should be supporting. A Standard could be developed by combining existing standards for solar, buildings, transport and water from the existing Climate Bonds Standard which provides clear guidance on the eligibility of assets for a 2-degree world.

Options for a green bond issuance to finance an EcoBlock development include exploring 1. the constitution of a Mello-Roos and imposing a special tax to finance the district developments, 2. PACE financing already institutionalised in California and 3. A green bond issuance from the municipality of Oakland.

As a next step the municipality should assess both the development of a Standard for EcoBlocks and the various financing options depending on who is intended the finance these developments (homeowners or the municipality) and whether existing financing schemes for renewable energy and energy efficiency can be leveraged for the large part of the project costs.

Annex I

Buildings Criteria

The Buildings Criteria of the Climate Bonds Standard are made up of several complementary component parts as follows:

- Non-Residential Buildings encompass Commercial Buildings and Public Buildings.
    - Commercial Buildings are those that that are intended to generate a profit, either from capital gain or rental income. Sub-categories of Commercial Buildings include but are not limited to offices, shopping centres, and hotels.
    - Public Buildings are those that provide public services and/or are occupied by a public authority. Sub-categories of Public Buildings include but are not limited to hospitals, schools, and libraries.
- Residential Buildings, i.e. buildings that are used or suitable for use as a dwelling.
- Public Spaces, i.e. social spaces that are generally open and accessible to people. Sub-categories of Public Spaces include but are not limited to roads, public squares, and parks. While public spaces do not relate specifically to buildings, they form part of the wider built environment and projects that improve the energy efficiency of such spaces (e.g. street lighting upgrades) may be eligible for certification.

Table 1 presents indicative building assets and associated use of proceeds that might be included in a Certified Climate Bond, subject to meeting the specific Criteria described in the remainder of this document. Table 1 is provided for illustrative purposes and is not an exhaustive list of every possible asset or use of proceeds that would be eligible.

Table 1: Potential Building Assets and Infrastructure

Potential Assets & Infrastructure	
Asset	Function
Offices	Commercial
Mix-use (Predominately Commercial)	
Single Family Homes	Residential
Multi-family Homes	
Mixed-use (Predominately Residential)	
Street lighting	Public Space
Misc energy uses (signs, stoplights)	

Note: Mixed-use buildings require additional review.
Source: Climate Bonds Initiative

These assets and use of proceeds are eligible for inclusion in a Certified Climate Bond if they meet:

- The mandatory Disclosure requirements (see section 5.1 of the Building Criteria for details); AND
- The Mitigation requirements (see section 5.2 or the Building Criteria or details); AND
- The Adaptation requirements (see section 5.3 of the Building Criteria for details)

Water Criteria

Current assets and infrastructure covered under the Water Criteria include engineered water infrastructure for the purposes of water collection, storage, treatment or distribution, or for flood protection or drought resilience.

These include water assets in the 'water sector' plus water infrastructure used in the operation, design, and function of a number of other industries, such as mining, manufacturing, power-generation, refinery systems, general cooling uses and irrigation as part of agricultural production. Investments related to water assets in these sectors are subject to these Water Criteria, with the exception of water assets in the fossil fuel and nuclear sectors as the Climate Bonds Standard and Certification Scheme does not support investments in these sectors.

Table 2 indicates use of bond proceeds that may be eligible for certification under the Water Criteria. In general terms, these use of proceeds encompass the financing or refinancing of the installation of new water infrastructure or water- use systems, or extension, enhancement or upgrades to existing infrastructure or water-use systems. The table provides illustrative examples and is not a comprehensive list of every possible water project or asset that would be eligible.

Table 2: Potential Water Assets and Infrastructure

Potential Assets & Infrastructure Asset	Function
Rainwater harvesting	Storage & Management
Storm water management systems	
Infiltration Ponds	
Aquifers storage	
Groundwater recharge	
Sewer systems	
Water recycling systems	Treatment
Wastewater treatment	
Manure/slurry treatment	
Drip/subsurface irrigation	Use

Note: The above are potential assets currently covered for certification by the Building Criteria. For assets and infrastructure not listed, additional routes to certification are possible. See Building Criteria: Establishing Performance Trajectories for further

To be eligible for inclusion in a certified bond, assets and projects must meet both the requirements of the Mitigation and the Adaptation & Resilience components.

These assets and use of proceeds are eligible for inclusion in a Certified Climate Bond if they meet:

- The Mandatory disclosure requirements (see Section 4.1 of the Water Criteria for details)
- The Mitigation requirements (see Section 4.2 of the Water Criteria for details)
- The Adaptation & Resilience requirements (see Section 4.3 of the Water Criteria for details)

Phase I of the Water Criteria covers the above mentioned engineered water infrastructure. Phase II, planned for 2016/2017 will cover nature based & hybrid water infrastructure.

Solar Criteria

Current assets and infrastructure covered under the Solar Criteria include solar generation and non-solar fuel use for the purposes of energy generation, renewable energy use, transmission, and/or distribution. The Solar Criteria of the Climate Bonds Standard are made up of two complementary component parts as follows:

- Solar generation: Eligible Project & Assets relating to solar energy generation shall be projects or assets that operate or are under construction to operate in one or more of the following activities:
  - Solar electricity generation facilities
  - Wholly dedicated transmission infrastructure and other supporting infrastructure for solar electricity generation facilities including inverters, transformers, energy storage systems and control systems.
  - Solar thermal facilities such as solar hot water systems.
- Non-solar fuel use: Eligible Project & Assets that have activities in solar electricity generation facilities or solar thermal facilities shall have a minimum of 85% of electricity generated from solar energy resources.

Table 3 indicates use of bond proceeds that may be eligible for certification under the Solar Criteria, In general terms, these use of proceeds encompass the financing or refinancing of the installation of solar energy generation, including transmissions and distribution infrastructure, solar thermal systems, including hot water systems, and facilities or assets procuring a substantial majority of their energy from solar energy. The table provides illustrative examples and is not a comprehensive list of every possible water project or asset that would be eligible. Table 3 is provided for illustrative purposes and is not an exhaustive list of every possible asset or use of proceeds that would be eligible.

Potential Assets & Infrastructure	
Asset	Function
Photovoltaic (PV) facility	Generation
Solar thermal facilities	
Distributed PV	
Distributed solar thermal	
Dedicated solar transmission	Distribution
Dedicated solar distribution	
Dedicated solar storage	
Fuel Switching (predominately solar)	Use

Table 3: Potential Solar Assets and Infrastructure

Note:
Source: Climate Bonds Initiative

Transport Criteria

The 2 Degree targets are used to guide the criteria by which transport assets are certified. The purpose of each of the criteria set out below is to classify projects and products according to whether they help achieve the per p-km or t-km 2 Degree thresholds. Please note the following when interpreting the criteria:

- Whenever an asset is deemed to have passed a criterion, it must also pass any other subsequent relevant criteria to qualify overall.
- The amount of coverage provided for each asset category merely reflects the level of detail required to distinguish between different cases, not the category's importance in terms of investment or mitigation potential.
- The likelihood of a particular transport mode being certified should not in any way be interpreted as a judgment that it represents a superior mitigation option on cost-effectiveness or any other grounds.

Because of the wide variety of different assets and projects that come under the scope of 'low carbon transport', we have provided some navigational aids to help the reader clearly identify how the range of relevant transport investments are covered by the criteria. More importantly, this will allow issuers to identify a package of investments that together will deliver a low carbon transport system. Table 4 indicates use of bond proceeds that may be eligible for certification under the Transport Criteria.

Table 4: Potential Transport Assets and Infrastructure

Potential Assets & Infrastructure	
Asset	Function
Electric vehicle	Transport
Public bikes	
Car sharing	
Hydrogen	
Electrification of public transport	Charging/Fuelling
Electric vehicle charging	
Low carbon fuelling	
Per passenger-kilometer and tonne-kilometer thresholds	Operations

Note: For additional details see Transport Criteria: Figure 1Summary of Land Transport Product and Projects.
Source: Climate Bonds Initiative

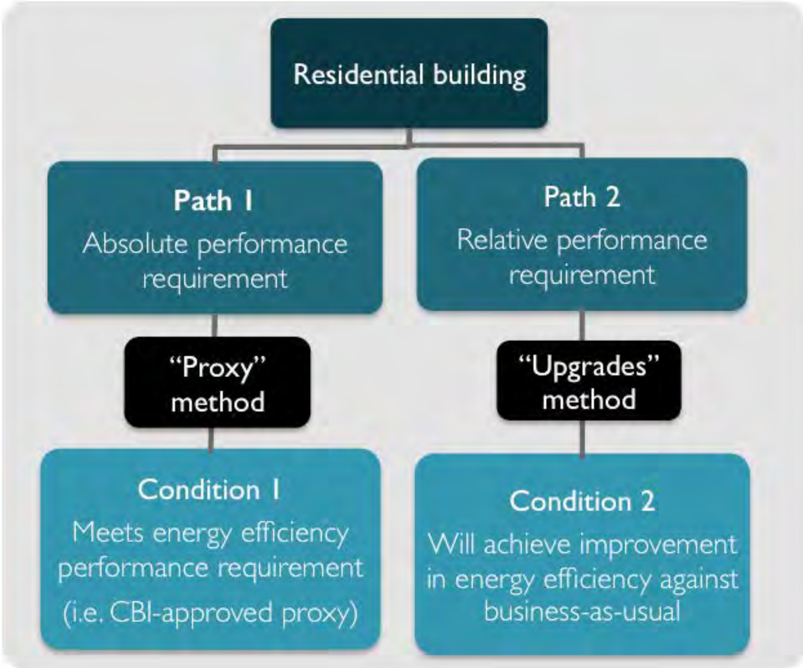
Residential Building Criteria

While there are a few routes to Climate Bond certification available for the EcoBlock Framework, one possible route is through the Residential Buildings Criteria. There are two routes to eligibility for inclusion of residential buildings in a Certified Climate Bond. These are that the building asset or portfolio:

1. Meets the emission intensity performance requirement (i.e. CBI-approved proxy)
2. Will achieve an improvement in emission intensity against a current building performance baseline.

The diagram below illustrates these eligibility pathways, with more information provided in the following sections.

Figure 1: Residential Compliance Options

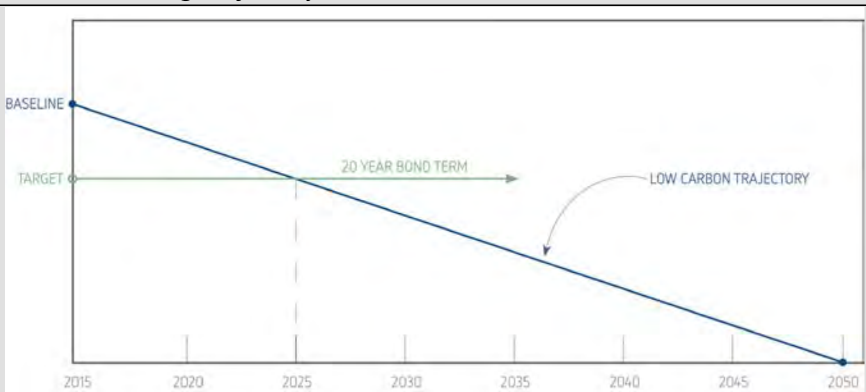


Note: The two compliance pathways are devised as market compatible strategies designed to determine those assets in compliance with the climate compatible "Low-Carbon Trajectory" (See call-out-box 1)
Source: Climate Bonds Initiative

Call-Out-Box 1: Low-Carbon Trajectory

At a fundamental level, the Building Criteria are based on establishing a "Low-Carbon Trajectory", certifying only those assets that meet this underlying principle.
The "emissions performance target" an issuer has to satisfy is determined based on an "Low-Carbon Trajectory" that starts with an "initial baseline emissions performance" of the top 15% of buildings in a city and declines to zero carbon emissions in 2050.
The "emissions performance target" is expressed on an annual basis in $kgCO^2$ terms and represents a level of carbon intensity (with square meters as the denominator for most building types). For instance, the emissions performance target for Sydney offices may be 78.2 $kgCO^2$/sqm per annum for a 10-year bond issued in 2015.
The "initial baseline emissions performance" is established using available emissions performance data on a representative sample of buildings in a city. Once set, it is not expected to be updated unless in exceptional circumstances. The two key circumstances that warrant a recalibration of initial baseline emissions performance are (1) when the size and quality of the underlying data set improves significantly and (2) when there is significant decarbonisation of the grid. CBI will undertake a review every 3 years to check for these two circumstances and whether they warrant a recalibration of initial baseline performance.

Figure 2: CBI Low-Carbon Building Trajectory to 2050



Note: The Low Carbon Trajectory is a simple decarbonisation pathway devised of an" initial baseline emission performance", a linear "low carbon trajectory" to 2050, and a year on year moving "emission performance target." The performance metric is kgCO2/m sq/year. While energy intensity and energy efficiency are important actors in decarbonisation, the reporting metric is in

Data Availability

As one can imagine, establishing an emission intensity baseline for each city and subsector of the building sector requires access to large data sets of individual building emissions performance. In those regions and cities with emission performance data robust and reliable enough to set an "initial baseline emission performance" for the individual sector (residential, commercial, etc.), this is the preferred compliance pathway supported by Climate Bonds. As tracking of individual residential assets emissions intensities is not yet common practice, the Criteria rely on establishing equivalent performance proxies available in the market.

Performance Proxies

As tracking of individual residential assets emissions performance is not yet common practice, the Criteria rely on establishing equivalent performance proxies available in the market. These proxies have been assessed on an individual basis for correlation between certification and low-carbon performance. Only those building codes, rating schemes, and certification standards in-line with Climate Bond's Low-Carbon Trajectory are eligible for approval as a performance proxy. On-going review of these proxies ensure they meet Climate Bonds year-on-year moving Emission Performance Target.

Condition 1: Meets the energy efficiency performance requirement (i.e. CBI-approved proxy)

A building must achieve a CBI-approved proxy for the top 15% most energy efficient buildings of its type in its local market. CBI establishes proxies by leveraging existing instruments such as building standards, codes, and rating schemes (e.g. LEED). The list of CBI-approved proxies for Residential Buildings is available in the document "Residential Buildings – Approved Proxies".

Table 5: List of Residential Performance Proxies available in the California Market

Regionally Proxies	
Proxy	Status
International	
LEED	
Regional	
Title 24	

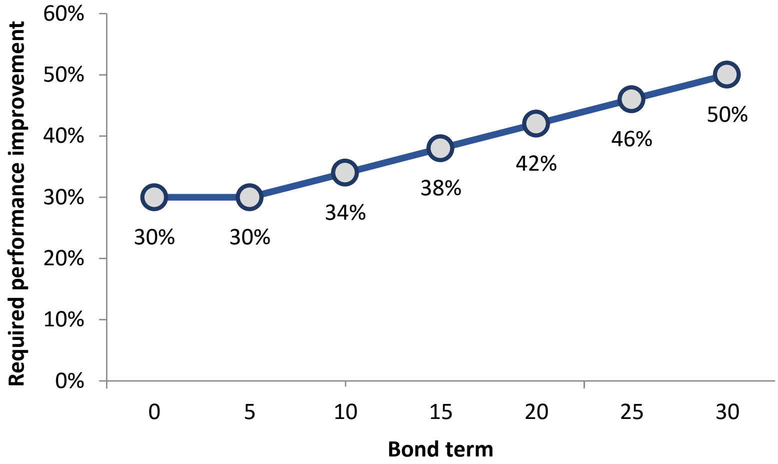
Note: These proxies have been assessed on an individual basis for correlation between certification and low-carbon performance. Only those building codes, rating schemes, and certification standards in-line with Climate Bond's Low-Carbon Trajectory are

Condition 2: Will achieve an improvement in energy efficiency against a current performance baseline

The building or project must achieve a minimum 30-50% improvement in emissions intensity against a current performance baseline AND an upgrade contract or agreement must already be in place with a contractor.

The required emissions improvement depends on the bond term, specified in the chart below:

Table 6: Require improvement in emission intensity



Note:

Source: Climate Bonds Initiative

[3] See for example the New York Hudson Yards development. The NY investment included the extension of a metro line, which had a great impact on the surrounding land value. This thesis will need to be further explored with the relevant Oakland municipality department.

APPENDIX M: CASE STUDY INTERVIEW

Figure 1: Interview Script Page 1

Oakland EcoBlock, Oakland – Final Case Study Interview Script

Preamble

I am conducting this interview to thoroughly document the process by which the interdisciplinary team arrives at (1) an optimum design of the integrated systems and components for the Oakland EcoBlock (OEB) demonstration project (2) specific design development documents, specification's and cost estimates; and (3) a schematic monitoring plan. I will seek to identify and document the ***key decision points*** in the critical path and the ***key constraints*** that informed them.

The case study intended to characterize the transformative nature of the OEB effort for a broad audience including residents, community leaders, regulatory officials, academics, and practitioners.

Questions (for technical project partner)

Background

(1) What organization do you work with?
(2) What is your job title?
(3) When did you first hear about the concept for an EcoBlock, specifically, a Net Zero Energy Retrofit Master Plan at the city block scale?
(4) When did you join the OEB team? Year? Month?
(5) What is your role on OEB team? What department/division are you in?
(6) How far along do you believe you are in the OEB planning process? 0, 50%, 90%?

Constraints and processes

(1) What do you see as the City, State and utility *legal constraints* (including the PUC regulations and mandates) to realizing the OEB?
(2) What do you see as the City, State and utility *zoning constraints* (including the PUC regulations and mandates) to realizing the OEB?
(3) What do you see as the City, State and utility *planning and entitlement constraints* (including the PUC regulations and mandates) to realizing the OEB?
(4) How do the existing City, State and utility processes help or hinder planning for the OEB? How are they likely to effect implementation of the OEB?

Community engagement process

(1) What are your priorities for community engagement?
(2) How will you evaluate the success of the community process?
(3) How should the project integrate the community's concerns and wishes?

Legal Framework

(1) What legal framework (city or other) will facilitate the construction, maintenance and operations of the OEB?

Energy, Electrical and Water Technical Focus

(1) How have you guided the technical development of the OEB?
(2) What do you believe the most critical decision making points have been in the technical development of the project?
(3) In your opinion, what do you believe are the issues associated with the following?
    a. Deep energy efficiency retrofits
    b. Electrical system

The interview script was created to standardize the information collected from the project team to document the actions taken in the Oakland EcoBlock case study.

Credit: Skidmore, Owings, & Merrill, LLP.

Figure 2: Interview Script Page 2

c. Water system

(4) In your opinion, what do you believe are the opportunities associated with the following?
   a. Deep energy efficiency retrofits
   b. Electrical system
   c. Water system

Innovative Business Models

(1) Have you guided the development of innovative business models? If so, how?
(2) Has your input helped the identification and analysis of alternative business models? If so, how?
(3) What are the cons of the City-led model? How about a utility led model, a 3rd party developer model or a homeowner's association model?
(4) What are the pros of the City-led model? How about a utility led model, a 3rd party developer model or a homeowner's association model?
(5) Are there any other models/alternative structures that might be worth investigating?

Design documents & specifications

(1) How have you been involved in the process of creating design development documents and specifications?
(2) What are the primary elements that should be described in design documents?
(3) What are the most important elements to specify?

Cost/Benefit analysis

(1) From the viewpoint of your area of expertise, what are the costs associated with the OEB?
(2) From the viewpoint of your area of expertise, what are the benefits associated with the OEB?
(3) What are the critical assumptions and variable that should be utilized, and why do you believe these should be chosen?

Instrumentation and monitoring plan

(1) Have you assisted with the preparation of the instrumentation and monitoring plan? If so, how?

Conclusion

(1) Are there other key decision points in the critical path of the Oakland EcoBlock that you believe should be highlighted?
(2) What key constraints informed these decision-making points?
(3) Is there anything else that you believe would be critical for *documenting the project process* and *enabling the retrofitting of additional city blocks to a Net Zero Energy standard*?

The script was administered to eighteen team members representing all major constituencies, including academic, research, municipal, utility, systems, outreach, and legal representatives.

Credit: Skidmore Owings & Merrill, LLP

APPENDIX N: OUTREACH MATERIALS

You are invited...

to continue the conversation with your neighbors about the EcoBlock

Please join your neighbors and the UC Berkeley team for a hands-on meeting to talk more about energy and water systems design. Help the team to idetify the best possible options for how an EcoBlock could be operated and maintained in the future. by sharing your questions and concerns about governance.

Saturday, August 12th
9:00 a.m. to 12:00 p.m.
Emeryville Center for Community Life
4727 San Pablo Ave, Emeryville, CA 94608

Children are welcome!
Coffee and light breakfast will be served.

RSVP to Zach Barr
zbarr@kearnswest.com

Hello, and thank you for your interest in this project.

The following pages will be familiar to you if you attended a recent meeting on the block. If you were unable to attend, we hope you will take a few minutes to review them and send us your comments about the various design elements that can serve as the "building blocks" of a sustainable and resilient neighborhood.

If you've already provided input, these pages are for your reference. We always welcome your additional ideas, questions and comments. Thank you again for your time.

Best regards,
The EcoBlock Team

Thank you for your input!

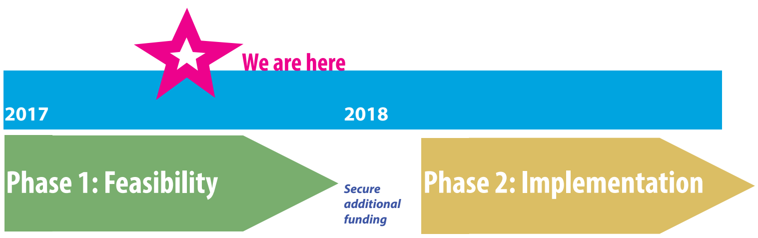
About this Project

What is an EcoBlock and why study it?

"EcoBlock" is a term used to describe a decentralized and highly resource efficient (low energy and water use) integrated design at the city-block scale. An ecoblock might seek to achieve zero-net energy, zero carbon emissions, low water usage, climate adaptation and resiliency.

Making our communities more efficient is hard to do house by house, but retrofitting at a neighborhood scale could be a better idea that is more cost and resource efficient. By starting at the block-level, we can test out this idea.

Could making neighborhoods more sustainable and resilient start block by block?



How long will this project take?

The California Energy Commission (CEC) has provided the funding for the first phase of this study. The project team will report back to them on the initial feasibility study phase of the project in early 2018. The CEC will then decide whether to provide additional funding to implement the most feasible design identified by this first phase.

Should the project team receive additional funding, the implementation phase of the project would be anticipated to begin later in 2018.

How can I help?

By sharing your input with the UC Berkeley team, you are making a significant contribution to the understanding of sustainable and resilient city design. We need to learn more about how people live in their homes now and how they want to live in the future in order to address the climate change challenges our communities face.

Do I have to participate?

No. Participation in any EcoBlock activity (meetings, surveys, interviews, etc.) is completely voluntary. If you choose to participate in an interview with the UC Berkeley Team your household will be compensated with $50.00. There is no compensation for meeting attendance at this time.

Where can I get more information?

The project team is always happy to hear from you!

For general questions:	Tony Nahas	anthony.nahas@berkeley.edu
	Zach Barr	zbarr@kearnswest.com or (415) 391 - 7900
To schedule an interview:	Emma Tome	etome@berkeley.edu

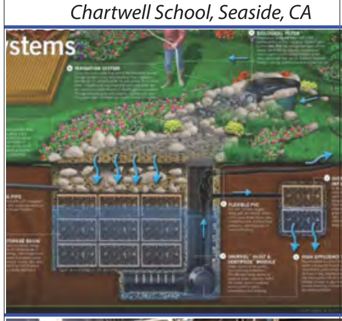
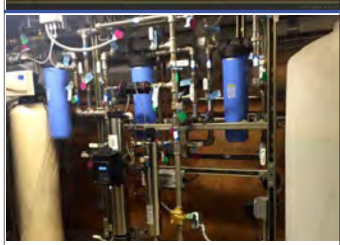
BERKELEY LAB CITY OF OAKLAND NASA

What does an EcoBlock look like?

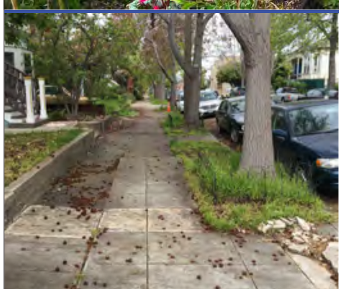
How can we use water more efficiently?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Fixture and appliance updates that reduce interior water use	
	Native planting in yards or gardens to reduce irrigation water use	
	Efficient irrigation, such as drip irrigation with tools to reduce water use like timers and smart sensors	
	Urine diversion toilets that separate and collect urine to recover nutrients for fertilizer	

What do we do when it rains?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Rainwater harvesting (from roofs) for irrigation of lawns and gardens at individual homes	
 *Rainwater harvesting system at Chartwell School, Seaside, CA*	Rainwater harvesting (from roofs) cleansed for non-potable interior use such as toilet flushing	
	Rainwater harvesting for groundwater recharge though infiltration	
 *Treatment system at Bullitt Center, Seattle, WA*	Rainwater harvesting (from roofs) for treatment to potable quality standard for all interior uses, including drinking water	

What other ways can we green the block?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Street trees to increase shade, wildlife, soil heath and reduce heat island effect	
	Community green spaces such as shared gardens, small parks and play areas to increase shade, wildlife, soil health and reduce heat island effect	
	Sidewalk and street paving improvements, and reduction of unnecessary paving	
	Alternative shared street design that prioritizes pedestrians and feature more planters and trees to manage stormwater	

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How can we manage stormwater better?

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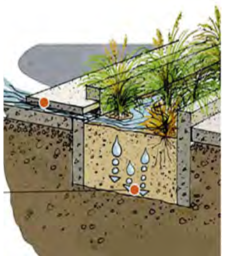
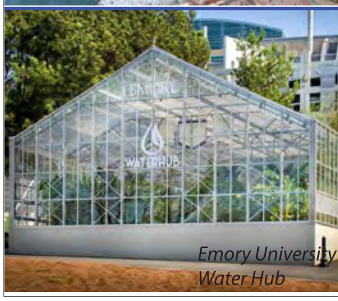
	Infiltration facilities to manage stormwater and promote groundwater recharge	
	Pervious paving surfaces to promote stormwater infiltration	
	Raingardens (bioretention) within the public right-of-way to manage stormwater	
	Raingarden (bioretention) on private properties to manage stormwater	

What does an EcoBlock look like?

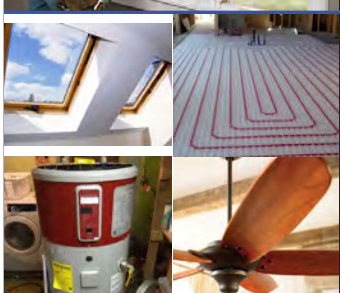
What should we do with our wastewater?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Greywater diversion from laundry machines, showers or dishwashers for irrigation	
 Emory University Water Hub	Reclaim and treat wastewater for non-potable uses (irrigation, toilet flushing, laundry)	

Are there other creative ways a block could manage water more efficiently?

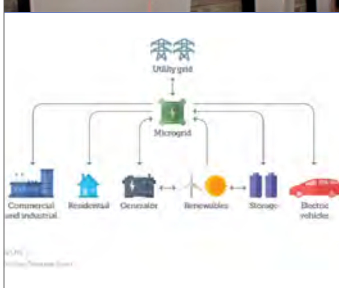
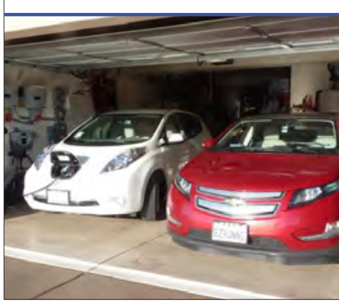
What does an EcoBlock look like?

How could we reduce energy use while improving health and comfort?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Insulate and air seal	
	Replace windows	
	Install new energy efficient heating, water heating and lighting	
	Install new energy efficient appliances	
	Indoor air quality ventilation systems	

What does an EcoBlock look like?

How can we produce, store and use energy?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Solar panels on roofs	
 	Energy storage (flywheels, Tesla power wall)	
	Microgrid	
	Electric vehicle charging	

What does an EcoBlock look like?

What other innovations might be included in an EcoBlock?

Design Element	Purpose	Is this design element a good fit for our block? Please share your comments and questions below.
	Smart LED street lights	
	Smart building technologies	

Are there other creative ways a block could use energy more efficiently?

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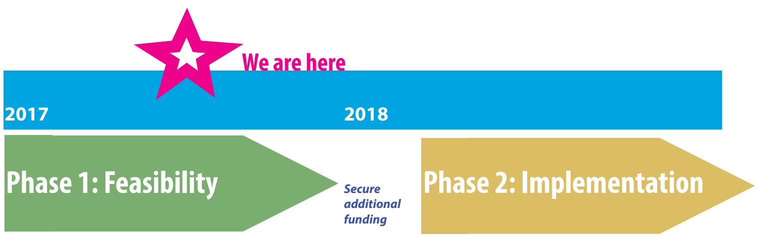

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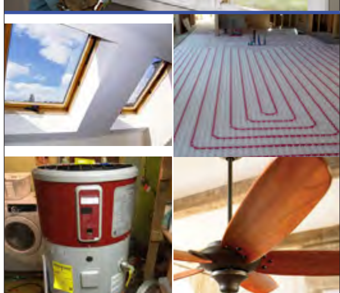	Install new energy efficient heating, water heating and lighting	
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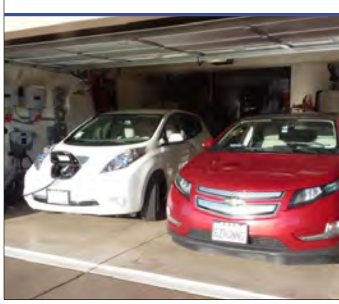	Electric vehicle charging	

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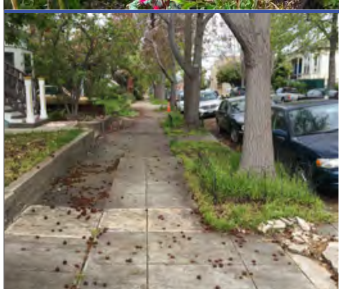	Sidewalk and street paving improvements, and reduction of unnecessary paving	
 *Shared Street in Santa Monica, CA*	Alternative shared street design that prioritizes pedestrians and feature more planters and trees to manage stormwater	

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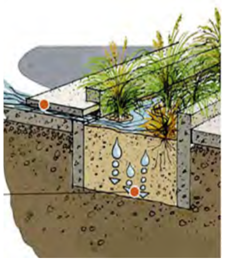	Infiltration facilities to manage stormwater and promote groundwater recharge	
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GREEN STREETS, CLEANER STORMWATER: A PRIMER

CUTTING THE CURBS

The quiet city of El Cerrito is loudly leading the way in the East Bay in tackling and treating the grime and grease and other pollutants that race off its streets into the storm drains—and eventually San Francisco Bay—when it rains. In two block-long stretches of San Pablo Avenue (one at Eureka; the other at Madison), the city cut the curbs to allow stormwater from the street to flow into several large planters. By slowing and holding onto the stormwater, the planters encourage pollutants in the water to drop out and be filtered by the microbes in the soil and plant roots. The plants themselves take up excess nutrients in the stormwater. Projects like these are sometimes called "green streets."

The El Cerrito planters were built below grade so that polluted water running off of the street and sidewalk will flow into them and be filtered before going into the storm drain system and the Bay. Photo by Lisa Owens Viani.

WHAT ARE GREEN STREETS AND HOW DO THEY WORK?

Green streets are streets where plants and soil are a visible part of the storm drain and gutter system. Designed to tie into the existing street and storm drain system, these green streets projects retain and filter stormwater while they beautify the street. A variety of green streets facilities—**stormwater planters, rain gardens, curb extensions** or **bulb-outs, bioswales,** and **vegetated swales**—are now being used by cities to treat pollutants in stormwater. All of these landscape features work by slowing the water down and either allowing it to infiltrate into the ground or to flow through slowly before it goes back into the storm drain system. The purpose is to hold onto the stormwater longer than in a traditional curb-and-gutter system so that pollutants can be filtered out. Whether stormwater **infiltrates** or **flows through** the landscape feature depends on the location and the goal of the project—and practical issues such as whether or not there are facilities, pipes, or conduit located beneath the surface.

Green streets are designed by engineers, who calculate the volume of water they want to treat. No matter what their size, green streets facilities all use the simple principle of letting plants and soil "do the work" to treat pollution. The city of Portland, Oregon and others have found that using plants and soil to treat stormwater can be less expensive than building and maintaining pipes and other "hard" structures. An added benefit of using soil and plants is that, unlike pipes and concrete, they offer habitat for birds, butterflies, and bees.

Plants like these in a Portland stormwater planter help catch and slow runoff while providing habitat for pollinators and birds. Photo by Lisa Owens Viani.

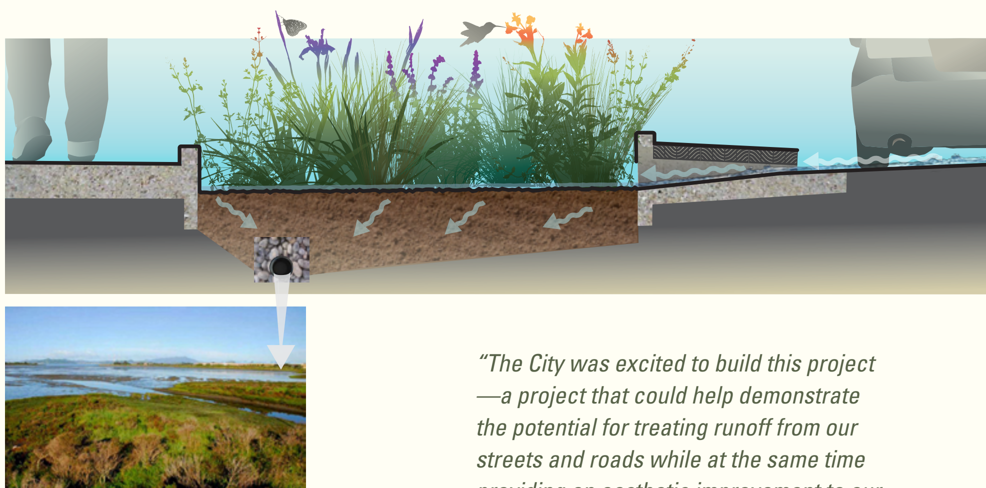


Illustration courtesy of Gates & Associates.

"The City was excited to build this project —a project that could help demonstrate the potential for treating runoff from our streets and roads while at the same time providing an aesthetic improvement to our urban streetscape. It's also exciting to see the interest this project is generating from all kinds of other parties such as Caltrans, clean water organizations, regulatory entities, and private consulting firms." –Jerry Bradshaw, Public Works Director, City of El Cerrito

Curb extensions aka **bulb-outs** (below) are often used on wide streets, and can help slow traffic, in addition to greening up a concrete- and asphalt-heavy landscape.

Stormwater from the street flows into this curb extension in San Bruno.

Rain gardens are often used in residential areas, at schools, or at city halls and other government offices, where there is usually room for bigger stormwater treatment facilities; the one below was built at El Cerrito's City Hall and takes runoff from the building's roof.

A rain garden at El Cerrito City Hall is planted with sedges, vine maples, and other natives.

A small residential rain garden in the city of Portland. Photo courtesy of Portland Sustainable Stormwater Division.

Brisbane built this rain garden at its City Hall. This photo (and the curb extension photo above left) courtesy of the San Mateo Countywide Water Pollution Prevention Program.

Bioswales are long, fairly shallow depressions in the earth that often use a curved or sinuous form to slow water, and are planted with native or non-native grasses and other vegetation. Like the other green streets facilities, bioswales treat stormwater from adjacent parking lots or roads. The one below filters runoff from a parking lot. Research from Portland, Oregon indicates that swales planted with native species filter more pollutants than swales planted with turf.

This bioswale filters runoff from the adjacent parking lot. Photo courtesy Kevin Robert Perry.

"The old way of managing stormwater was to put it in a pipe and forget about it. That approach doesn't recognize that stormwater can be an asset when it's integrated into building and site design." –Tom Liptan, City of Portland, Sustainable Stormwater Division

Eco-roofs and **green walls** are two additional, innovative and attractive ways of treating stormwater. **Eco-roofs** are roofs on top of which a layer of plastic has first been installed (to prevent water damage), and then a shallow layer of soil and plants added. When rain falls on a traditional hard roof, it often races off into gutters and into the storm drain system—and San Francisco Bay. When rain falls on an eco-roof, it is slowed, absorbed, and filtered.

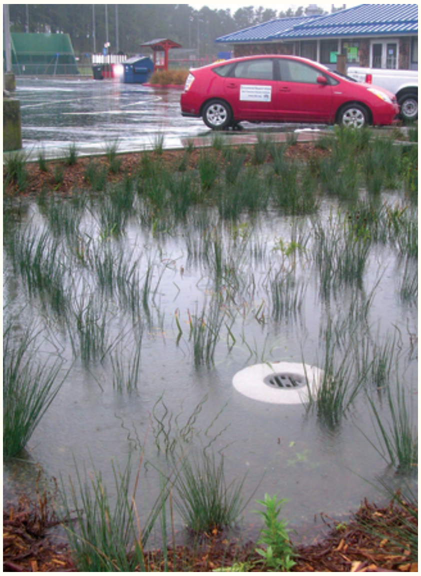
One of Portland, Oregon's many eco-roofs, blooming with sedum. Photo courtesy of Tom Liptan.

Green walls also filter water that sheets off of roofs before it can make its way to the street. Both eco-roofs and green walls can provide habitat for birds and pollinators. Birds have begun nesting on some eco-roofs in Portland, Oregon.

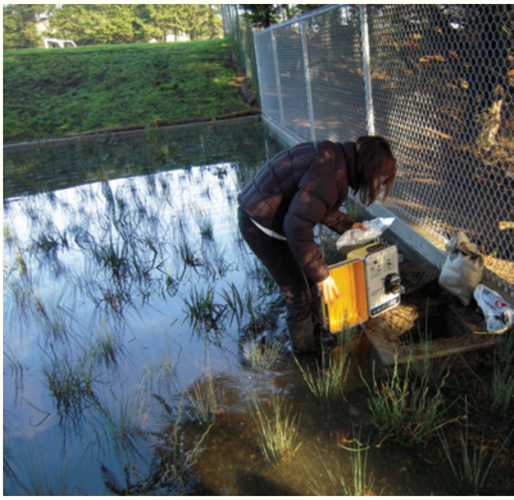
Green walls like this one at a motel in Portland, Oregon can slow and filter runoff from roofs. Photo by Lisa Owens Viani.

THE SCIENCE OF GREEN STREETS

The San Francisco Estuary Institute (SFEI) recently found that a rain garden installed next to a parking lot in Daly City, California reduced PCBs and mercury in the runoff by 40 percent, and pollutants from motor oil, diesel, and asphalt called PAHs, as well as heavy metals, including zinc, copper, lead, and nickel, by over 80 percent. Most of this pollution comes from cars and other vehicles. In El Cerrito, scientists are testing for copper, mercury, PCBs, pesticides, and other contaminants.



This rain garden in Daly City treats polluted water from an adjacent parking lot. Photo above and below by SFEI.



SFEI scientists study how much pollution the Daly City rain garden filters.

RETHINKING OUR STREETS

All of these landscape features—sometimes called "LID" (for **low impact development**) or **"green infrastructure"**—can be used in both urban and in residential settings, beautifying streets, calming traffic, and offering habitat.

Kevin Robert Perry, of Nevue Ngan, author of the award-winning *San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook*, which can be downloaded at www.flowstobay.org, says green streets can start as simply as planting street trees—and be as advanced as curbless streets, where stormwater simply sheetflows into green streets treatment devices. "We need to go back and reverse our auto-oriented infrastructure and rethink our streets," says Perry.

Photo courtesy of Kevin Robert Perry.

Hear podcast interviews on these topics at www.sfestuary.org/podcast/

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. (Gov. Code Section 7550, 40 CFR Section 31.20.)

SAN FRANCISCO ESTUARY PARTNERSHIP

San Francisco Estuary Partnership
1515 Clay Street, 14th Floor
Oakland, CA 94612
(510) 622-2304
www.sfestuary.org

In downtown Portland, a planter adds greenery to the streetscape while treating stormwater. Photo by Lisa Owens Viani.

This residential street in Milwaukie, Oregon has no curbs, just a concrete border. Polluted runoff sheets off the road into the planter where it is filtered. Photo courtesy of Kevin Robert Perry.

"Retrofitting green streets is not just about managing stormwater but is equally about creating streets that promote biking, walking, and transit and doing it in a way that makes our communities far more aesthetic and livable. Retrofitting streets for livability is probably one of the most important aspects in creating healthy and vibrant communities, because streets, good or bad, often define the character of our neighborhoods. In retrofitting neighborhoods with green streets, we have the opportunity to transform a neighborhood's character and do it in such a way that also helps the environment at multiple levels." –Kevin Robert Perry, Nevue Ngan

Design Element Topic	Detailed comments by meeting	Key Take-aways (All meetings)
How can we use water more efficiently?		
Fixture and appliance updates	Already in Place Best if showerhead can allow the option of high pressure or an option Example of 90 second shower in Australia No comments made No comments made	Many residents have already made upgrades and residents are interested in maintaining control over the choice of fixture or appliance.
Native Planting	Already in have it. Great! No comments made No comments made No comments made	There seemed to be a general consensus on this, aside from residents who already have native plants.
Efficient Irrigation	How will this be installed? I have this at my place. No comments made No comments made No comments made	People seem in favor of this, but would like to know more about the installation and how to make it efficient neighborhood-wide.
Urine Diversion	Already in Place Toiliet, sewage mysteries (help!) What to do when it rains? No comments made No comments made No comments made	There seem to be some major sewage problems in different areas of the neighborhood.
Rainwater harvesting /roofs for irrigation	Building shoots out water (from storm pipe) that ruins retaining wall Example of 90 second shower in Australia No comments made No comments made	There is a desire to conserve rainwater and find ways of stopping leaks and make water more efficient throughout the neighborhood.
Rainwater harvesting for lawn/garden	My school does this work! (great) Storage would be problematic-prefer graywater No comment made No comments made No comments made	There is an interest in conserving rainwater, but questions of how to store.
Rainwater harvesting for non-potable	Yes There was overflowing sewage during rains this year Really want low flow toilet No comments made No comments made	General support among this section, with a desire to solve sewage problems throughout the neighborhood.
Rainwater for groundwater recharge/infiltration	Yes No comments made No comments made Sidewalks in disarray. Sewer pipes need transplanting. Street	Concerns about general infrustrature needs related to sewage, water, and pipes.
Rainwater harvesting (from roofs) for potable quality standards	Yes Not sure if I would trust for drinking water No comments made What are the costs for potable water? Using water? Is it subsidized?	Questions related to cost and quality of potable water, with a

(including drinking water)	Where water comes from matters (Ex: Sequioa) because of taste, No comments made	reluctance to use it for drinking water.
What are other ways we can green		
Street trees	Native trees/plants for conservation. No comments made Trees could increase property value Need more street trees	High support for street trees, native trees, with the hope of increasing property values.
Community Green Spaces	Yes. Interested and willing. Community garden (safety issues?/in larger neighborhood?) Community garden nearby, but not available No comments made	Overall interst with questions about access and safety.
Sidewalk Improvements	Yes Have improvements already Would we have to continue to maintain the sidewalks? Currently, neighborhood streets not completely walkable No comments made	There is a need for sidewalk upgrades in neighborhood, aside from select parts of neighborhood that have been
Shared Streets (Alternative)	Yes. Community garden (safety issues?/in larger neighborhood?) Need something to walk to. How do we connect this clock to others in the larger neighborhood Walkable neighborhoods seem far from transportation/Interested in No comments made	In favor of walkability, but not at the expense of alientation from transit and other neighborhoods.
How can we manage storm water better?		
Infiltration Facilities	Good idea! No comments made No comments made Water not draining well from warehouse Storm water pools in street	More irrigation issues raised, along with discussion of current systems.
Pervious paving	This is very important to me No comments made No comments made No comments made	Limited feedback in this area
Raindardens-public right-of-way	Fantastic idea! No comments made No comments made No comments made	Limited feedback in this area, outside of meeting 1.
Raingarden on private property	Yes What to do with rainwater No comments made Street parking a concern (room for rain water) No comments made	Questions on use of rain water and where to store it.
What should we do with our		
Greywater Diversion	Hard to use as much H20 as we have on this block Great idea. Great Combining greywater with rainwater is possible Look at greywater management in more arid enviornments like, AZ	High interest in greywater use efficiently.
Reclaim and treat wastewater	Concerned Re: ability to re-sell with new technologies Would we really need this with greywater? Hard to feel comfortable/ Great How does this water work for laundry? Is that desirable? Would need more than half the block to do wastewater. No comments made	Level of discomfort with treating and using wastewater, in addition to questions about the block reaching consensus about using it.
How can we reduce energy use		
Energy Storage	Grid is more practical Meeting 2: No comments made Meeting 3: I've always wanted a Telsa	Interencein relying on a an independent energy source,

	No comments made	with a back-up.
Insulate and Air Seal	Not insulated at all on Marshall street (lots of street noise) and need	
	No comments made	
	Yes	
	No comments made	Limited feedback in this area
Replace Windows	Yes	
	No comments made	
	Yes	
	No comments made	Limited feedback in this area
Install new energy efficient heating and lighting	Not too many lights that our bedrooms have light pouring in.	
	Meeting 2: What about radient heat? Would be nice.	
	Yes	
	Warehouse heating is inefficient	Concerns about water heaters and warehouse efficiency.
	Water heating needs upgrade? How about on-demand heaters?	
	I like a gas stove	
Install new energy efficient appliances	Yes	
	What about gas? Do we have to give up gase stoves/dryers?	
	Yes	
	No electric stoves (prefer gas)	Preference for gas stoves.
Indoor air quality ventilation systems	Yes	
	No comments made.	
	Yes	
	No comments made.	Feedback somewhat limited.
Install new energy efficient heating and lighting	Yes	
	What about radient heat? Would be nice	
	Yes	
	Warehouse heating is inefficient	Concerns about water heaters and warehouse efficiency.
	Water heating needs upgrade? How about on-demand heaters?	
Solar Panels	Yes!	High interest in solar panels, as long as they could accomodate housing structure or roof improvements can be made.
	What if you already have solar?	
	Of course! (will these work on vault roofs?)	
	Warehouse heating is inefficient	
	Roof needs replacing or leaks	
Microgrid	No comments made	Reluctance about complete dependence on microgrid. Questions about price, regulation, and privacy
	Can you switch to regular utility, should systems fail?	
	Who manages data on microgrid?/Privacy concerns/Who profits?	
	Good that it can be a local supply source. What are regulations	
Electric Vehicle Charging	How would sharing work on block?/ Need for safe charging stations.	Many questions were related to cost and charging of EV's as well as how they would be shared on block.
	No comments made.	
	Concerned more people may be needed to spread out resources	
	Warehouse heating is inefficient	
	Cost involved?	
Smart LED Lights	Fantastic ideas, and what are the tradeoffs, pros/cons of each?	How do you balance these resources with other amenities like trees or other facets of the block that might work in
	No comments made.	
	How do these coordinate with more trees?	
	No comments made	
Smart Building Tech	What is the best time to use appliances?	Need more education in this area, as well as more information on how best to utilize energy efficient
	No comments made.	
	No comments made.	
	Need more info on this and EMF's	

KEY
July 12, 2017 Meeting (Meeting 1)
July 13, 2017 Meeting (Meeting 2)

July 19, 2017 Meeting (Meeting 3)
July 20, 2017 Meeting (Meeting 4)

Oakland Eco-Block Focus Group – Governance Questions
July 12, 13, 19 & 20, 2017

- What is the minimum level of participation needed? How does it proceed if someone on the block doesn't want to join?
- What is legally feasible for tenant upgrades?
- How would the block interact with other blocks within the neighborhood?
- How do you limit car sharing to the block?
- What is pricing like for improvements and operational costs? Who maintains improvements in public ROW?
- Who manages data on the energy usage and how would it be utilized?
- How would the block interact with the existing systems, could I turn a switch back to the old system if the Ecoblock system is down?
- As an owner with tenants, how can I participate? Are they capable of preventing my participation inthe EcoBlock?
- What is the liability for block-level systems?
- What is the funding timeframe?
- How will the infrastructure be maintained? What is the expected life cycle?
- Are zoning changes being considered?
- What are the plans to sell the resources we "farm" on the block (energy and water)?
- I don't like the condominium system. What about defaults, etc.?
- How will this be maintained over 30 years? Can we sustain it?
- People don't like HOA's (no reason given).
- For the microgrid, what are the regulations around pricing/operation of the system?

KEARNS & WEST Collaboration and Strategic Communications

MEMO: Oakland Eco-Block Focus Group Summary
July 12, 13, 19 & 20, 2017

The purpose of this round of outreach was to provide general project information to residents, to provide more detail about potential design elements and gather input from block residents on the viability of these elements for the Block. The meetings were conducted in an informal Focus Group setting.

Four identical meetings were held on the block July 12, 13, 19 and 20, 2017. The residents in attendance were generally supportive of the design elements the project team shared. This memo is to serve a summary of all four meetings focusing on like and wish activity, common themes and frequently asked questions. For a more detailed account of each meeting, please consult the respective meeting summary.

Notification Approach: All block residents received invitations via post card. For residents who had previously provided email addresses, they received an initial invitation, a follow-up for each meeting and a personalized email re-iterating the invitation if they had not attended or RSVP's during the first week.
Neighborhood attendees: 16 residents, 10 owners, and 6 renters

Agenda: The meetings were informal. Attendees were provided with a light dinner while project members provided an update and presented an overview of the information on the poster boards. Participants then engaged in activities and facilitated discussion designed to gather input on residents' existing view of their block as well as their wishes for the future. Additionally, input was gathered in the appropriateness of various design elements for the energy and water systems.

What do you like about your block now?

- Greenery
- Location
- Quiet
- Safe
- Familiarity with neighbors
- Parking

What do you wish to change?

- Bring in neighborhood art or murals
- Public transportation access
- Bike lane for increased safety and path for recreational use
- Cars speeding
- More opportunity for kids to play on the street
- Visible garbage
- Improved street lighting and safety
- Sidewalk conditions
- Water infrastructure (i.e. sewage system, irrigation system, and old pipes)
- Underground utilities
- Community space or garden for community activities
- More parking

Common Themes

- Support for design elements presented.
- Would like to retain the ability to customize design elements for their particular home.
- Concern voiced around wastewater treatment and storage, specifically black water and where excess water from the block that isn't used goes.
- Prefer gas for stove and dryer.
- Concern voiced about EMF from EV charging station and other block-level installations.
- Concern about governance and legal frameworks of block-level infrastructure.

Frequently Asked Questions:

- Will the EcoBlock require a minimum level of participation among residents? If so what is the number? How will you proceed if someone on the block doesn't want to join?
- What is legally feasible for tenant upgrades?
- What is the funding timeframe?
- How will the Ecoblock interact with other blocks within the neighborhood?
- How will you limit car sharing to the block? Will the block generate enough electricity to support the charging station?
- What is the pricing like for improvements and operational costs? Do we have to maintain improvements in public ROW like sidewalks and roads?
- Who manages data on the energy usage, whom would the data be given to and how would it be utilized?
- How would the block interact with the existing systems, could I turn a switch back to the old system if the Ecoblock system is down?
- What if I already have the energy retrofits?
- As an owner with tenants, how can I participate? Are they capable of preventing my participation in the EcoBlock?
- During construction, would I have to leave my house at all? Is there any way to mitigate impacts during construction, I work from home.
- What is the liability for block-level systems?
- How will the infrastructure be maintained? What is the expected life cycle?
- Are zoning changes being considered?
- What is the difference, if any, between an Ecoblock water system treatment and EBMUD's water treatment?
- Would this increase rent for tenants?

Oakland Eco-Block Resident July Focus Group #1

July 12, 2017

Staff Attendees:

Nora De Cuir	Kearns & West
Zach Barr	Kearns & West
Andrea Traber	Integral Group, Inc.
Christine Thomson	Skidmore Owings & Merrill
Norm Bourassa	UC Berkeley
Emma Tome	UC Berkeley

Neighborhood Attendees:

Katy Turner, Jim Meyersahm, Dan Sweet, Danielle Saunders, Catherine Norton

Water Efficiency:

How can we use water more efficiently?

Fixture and appliance updates	• Already in Place • Best if showerhead can allow the option of high pressure or an option to alleviate back pain • Yes, a good fit
Native planting	• Great! • Already have it
Efficient irrigation w/ timers/sensors	• How will this be installed • I have this at my place • Great! • Brilliant! Yes please.
Urine Diversion	• Toilet/sewage mysteries (help!) • What to do when it rains? • Yes-all.

What do we do when it rains?

Rainwater harvesting for lawn/garden	• Yes (3) • My school does this work—great!

	• Storage would be problematic- prefer graywater
Rainwater harvesting for non-potable	• Yes (4) • There was over-flowing sewage during rains this year
Rainwater for groundwater recharge/infiltration	• Yes (4)
Rainwater harvesting (from roofs) for potable quality standards (including drinking water)	• Not sure if I would trust for drinking water • Yes (3)

What are other ways we can green the block?

Street trees	• Yes (3) • Native trees/plants for conservation
Community Green Spaces	• Yes <3 • Interested and willing • <3 (heart)
Sidewalk Improvements	• Yes (3) • Have improvements already • Please
Shared Streets (Alternative)	• Yes (3)

How can we manage storm water better?

Infiltration facilities	• Yes (4) • Good idea! • 8 unit apt building: In winter, they have a sump that is needed in the mech. rm (illegible)
Pervious painting	• Yes (3) • This is very important to me
Raingardens- public right-of-way	• I like it • Great idea • Yes • Fantastic idea
Raingarden on private property	• Sure • Yes (3) • What to do with wastewater?

What should we do with our wastewater?

Greywater Diversion	• Please • OK • Great idea • Yes • Great • Hard to use as much H20 as we have on this block
Reclaim and treat wastewater	• Probably hard to get regulatory or neighborhood buy-in (4) • Yes- more education and public info • Would we really need this with greywater? Hard to feel comfortable • Yuck! • Concerned about black water • Concerned re: ability to re-sell w/new technologies • Support for eco-paradise • Applicable for small scale/harder for city-scale

Energy Efficiency

How can we reduce energy use while improving health and comfort?

Energy Storage	• Grid is more practical
Insulate and air seal	• Yes (3) • On Marshall street, walls are not insulated at all. We need insulation not just for temperature but to muffle noise between apartments and from the street. Would like walls and floors insulated.
Replace Windows	• Yes (4)
Install new energy efficient heating and lighting	• Yes (5) • Not too many lights that our bedrooms have light pouring in • Seems like a frivolous, basic idea. (Crime also a factor)
Install new energy efficient appliances	• Yes (3) • I like gas stove
Indoor air quality ventilation systems	• Yes

How can we produce, store and use energy?

Solar panel on roofs	• Hell yeah! • Yes (5) • Yes please (quiet would be great) • Only if the system doesn't make noise
Electric vehicle charging	• Can we see it? (like a Prius?) • Concerned about EMF. It seems electric cars and their charging stations would increase exposure to EMF, as would the energy storage units • Bike sharing/possible commute to BART too long • Curious at how sharing would work. Like it, but altruistic? • Yes. A station on block that is safe.

What other innovations might be included in an Eco-Block?

Smart LED street lights	• Fantastic! It's very dark on Marshall • Would love to understand how these various wonderful ideas have pros/cons or tradeoffs. Need more education, please.
Smart Building Tech	• When is the best time to use appliances?

What are other creative ways a block could manage more efficiently?

- Sea-level rise decentralizing services

What do you like about your block now?

- Love the tree-lined streets
- The neighbors/community (4)
- Backyard Gardens
- Good location/value

What do you wish to change?

- Needs more street lights (3)
- Needs more community space
- Needs more sidewalks (3)
- Needs street lights
- Needs to be safer
- Needs more community activities
- Needs more care for gardens/front lawns
- Needs more efficient use of street parking

When should we meet again?

Sat, July 29th – (4)

Saturday, August 5th – (0)

Saturday, August 12th – (1)

Oakland Eco-Block Resident July Focus Group #2-

July 13, 2017

Staff Attendees:

Nora De Cuir	Kearns & West
Zach Barr	Kearns & West
Andrea Traber	Integral Group, Inc.
Amy Dryden	
Maika Nicholson	UC Berkeley

Neighborhood Attendees:

Jason Young, Tracey Lien, Jill Hammond, Cheryl Deaner

Water Efficiency:

How can we use water more efficiently?

Fixture and appliance updates	• Example of 90 second shower in Australia
Native planting	•
Efficient irrigation w/ timers/sensors	•
Urine Diversion	•

What do we do when it rains?

Rainwater harvesting for lawn/garden	•
Rainwater harvesting for non-potable	• Really want low flow toilet
Rainwater for groundwater recharge/infiltration	•
Rainwater harvesting (from roofs) for potable quality standards (including drinking water)	•

What are other ways we can green the block?

Street trees	•
Community Green Spaces	• Community Garden (safety issues?)

Sidewalk Improvements	• Would we have to continue to maintain the sidewalks?
Shared Streets (Alternative)	•

How can we manage storm water better?

Infiltration facilities	•
Pervious painting	•
Raingardens- public right-of-way	•
Raingarden on private property	•

What should we do with our wastewater?

Greywater Diversion	• Great
Reclaim and treat wastewater	• Great • Is there a difference in how you treat H20 locally vs. EBMUD? • Would this increase rent?

Energy Efficiency

How can we reduce energy use while improving health and comfort?

Energy Storage	•
Microgrid	• Can you switch to regular utility, should systems fail?
Insulate and air seal	•
Replace Windows	• Love the idea of new windows!
Install new energy efficient heating and lighting	• What about radiant heat? Would be nice. •
Install new energy efficient appliances	• What about gas? Do we give up stoves/dryers? • Electric dryers are not good
Indoor air quality ventilation systems	
Solar panel on roofs	• What if you already have solar?
Electric vehicle charging	

What other innovations might be included in an Eco-Block?

Smart LED street lights	•
Smart Building Tech	•

What are other creative ways a block could manage more efficiently?

- 'Solar' clothesline (3) or 'Hills Hoist'
- I don't like the condominium system. What about defaults, etc.?
- What about waste/garbage? (can we do something on the block?)
- Are zoning changes being considered?
- Has public transportation been discussed?

Burning questions/thoughts

- Can't work at home with construction.
- Do I have to change/replace my landscaping?
- What can I do as a tenant to participate?
- How will it be maintained over 30 years? Cost? Can we sustain it?
- All good, but I'm not a home owner.
- Would I have to leave my house at any point?
- People don't like HOA's
- What about liability for block-level systems?
- What about having water switched off?

What do you like about your block now?

- Everything!
- Safety, water and energy improvements made.
- Trees and flowers
- More even sidewalks

What do you wish to change?

- Parts of street are poorly lit
- Sidewalks in bad shape
- Tree roots a problem
- Sewage overflow into street this winter (3)
- I'd love an irrigation system
- Need to put utilities underground
- Old Pipes/Infrastructure problems (3)
- Tree branches fall into sidewalks often
- Poor water pressure
- Would like water recycling

- Would like compostable toilets and other alternatives

When should we meet again?

Saturday, July 29th – (0)

Saturday, August 5th – (1)

Saturday, August 12th – (1)

Other times:

- August 19th – (1)
- Any time after August 19th – (2)

Oakland Eco-Block Resident July Focus Group #3-

July 19, 2017

Staff Attendees:

Ben Gettleman	Kearns & West
Zach Barr	Kearns & West
Monica Ayers	Kearns & West
Andrea Traber	Integral Group, Inc.
Norm Bourassa	UC Berkeley
Bruce Nordman	UC Berkeley
Scott Warner	Ramboll Environ
Alyson Goulden	Sherwood Design
Emma Tome	UC Berkeley

Neighborhood Attendees:

Jordan Bunnell, Margarita

Water Efficiency:

How can we use water more efficiently?

Fixture and appliance updates	•
Native planting	•
Efficient irrigation w/ timers/sensors	•
Urine Diversion	•

What do we do when it rains?

Rainwater harvesting/roofs for irrigation	• Building shoots out water that ruins retaining wall. (shoots out of storm pipe)
Rainwater harvesting for lawn/garden	•
Rainwater harvesting for non-potable	•
Rainwater for groundwater recharge/infiltration	•
Rainwater harvesting (from roofs) for potable quality standards (including drinking water)	• What are the costs for potable water? Using water? Is water subsidized? • What are the costs, given that water is not priced at its true cost?

	• Where water comes from matters (Ex: Sequoia) because of taste, algae, and temperature • Having water from your own source is good vs. that of a supplier, but cheap, consistent water is important. • Option of using your own energy vs. the grid is always a factor. If given the option, sustainability with a backup is great.

What are other ways we can green the block?

Street trees	• Could increase property value
Community Green Spaces	• Community garden nearby not available
Sidewalk Improvements	• Currently, neighborhood streets not completely walkable
Shared Streets (Alternative)	• Need something to walk to • How do we connect this block to others to tie together a larger neighborhood? • Walkable neighborhoods seem tougher to get to/are not accessible to BART (quality of life/property value important) • Interested in a bike share

How can we manage storm water better?

Infiltration facilities	•
Pervious painting	•
Raingardens- public right-of-way	•
Raingarden on private property	• Street parking a concern (room for rain water)

What should we do with our wastewater?

Greywater Diversion	• Combining greywater with rainwater is possible
Reclaim and treat wastewater	• Would help to cut line for non-potable water (toilet, irrigation).

	• Would need sinks drinkable from City. • Would need more than half the block to do waste-water. • How does this water work for laundry? Is that desirable? • How does this compare to desalination? • Where would waste water plants be? (Smaller ones for this block). How big are they?

Energy Efficiency

How can we reduce energy use while improving health and comfort?

Energy Storage	• I've always wanted a Tesla
Microgrid	• Who manages data on energy grid? Concerns about privacy and who would use this data and for what profit.
Insulate and air seal	• Yes
Replace Windows	• Yes
Install new energy efficient heating and lighting	• Yes
Install new energy efficient appliances	• Yes
Indoor air quality ventilation systems	Yes

How can we produce, store and use energy?

Solar panel on roofs	• Of course! (Will these work on our vault roofs?)
Electric vehicle charging	• Concerned this concept will require more people to spread out the resources (2)

What other innovations might be included in an Eco-Block?

Smart LED street lights	• How do these coordinate with more trees?

Smart Building Tech	•

What are other creative ways a block could manage more efficiently?

No information provided

Burning questions/thoughts

- Why was this block selected?
- Who manages data on energy grid? To whom would the data be given and how would it be utilized?

What do you like about your block now?

- Relatively quiet
- Parking
- Plants
- (Mostly) Friendly neighbors
- Close(ish) to Parks, Restaurants, Bars
- Walking Path

What do you wish to change?

- Need better access to public transportation
- Would like a community garden
- Need bike path
- Need a path that connects to Emeryville
- There is visible garbage

When should we meet again?

No information provided.

Oakland Eco-Block Resident July Focus Group #4-

July 20, 2017

Staff Attendees:

Nora DeCuir	Kearns & West
Zach Barr	Kearns & West
Monica Ayers	Kearns & West
Andrea Traber	Integral Group, Inc.
Norm Bourassa	UC Berkeley
Maika Nicholson	Sherwood Design
Emma Tome	UC Berkeley

Neighborhood Attendees:

Tim Lilly, Joey Wood, Francesco Pingitore, Christopher Hume, Francine Madrid, Judy Merrill

Water Efficiency:

How can we use water more efficiently?

Fixture and appliance updates	•
Native planting	•
Efficient irrigation w/ timers/sensors	•
Urine Diversion	•

What do we do when it rains?

Rainwater harvesting for lawn/garden	•
Rainwater harvesting for non-potable	•
Rainwater harvesting for groundwater recharge/infiltration	• Sidewalks in disarray. Sewer pipes need replacing. Street repaving (East Bay Mud)
Rainwater harvesting (from roofs) for potable quality standards (including drinking water)	•

What are other ways we can green the block?

Street trees	• Need more street trees
Community Green Spaces	•

Sidewalk Improvements	•
Shared Streets (Alternative)	•

How can we manage storm water better?

Infiltration facilities	• Storm water pools in street • Water not draining well from warehouse
Pervious painting	•
Raingardens- public right-of-way	•
Raingarden on private property	•

What should we do with our wastewater?

Greywater Diversion	• Look at greywater management in more arid environments, like Arizona
Reclaim and treat wastewater	•
	•

Are there other creative ways a block could manage water more efficiently?

- Roof gardens/Green roofs?
- 3-D 'vertical' gardens?
- Bee hives for the block? (what's the legality?)
- Both sides of the street impacted with parking
- White clay at street level is impervious to water

Energy Efficiency

How can we reduce energy use while improving health and comfort?

Energy Storage	•
Microgrid	• Good that it might become a local supply source. What are the regulations around price/operation? (2) • Would we have the same meters?
Insulate and air seal	•
Replace Windows	•
Install new energy efficient heating and lighting	• Water heater needs upgrade • On-demand heaters • Warehouse heating is inefficient

	• Heating + water heating seem generally popular •
Install new energy efficient appliances	• No electric stoves (prefer gas!) (2)
Indoor air quality ventilation systems	

How do we produce, store and use energy?

Solar panel on roofs	• Roof needs replacing • Re-roofing w/ solar panels could be more cost-effective • Can u contact HOA about roof leak?
Electric vehicle charging	• How do you limit the car sharing to the block? (2) • Maybe only needed if cost is (is not?) an issue • Quick charge for EV's? • Will the block generate enough electricity?

What other innovations might be included in an Eco-Block?

Smart LED street lights	•
Smart Building Tech	• Need more info on this? EMF's?

What are other creative ways a block could manage more efficiently?

- Infrastructure upgrades (in the street?)
- Green playgrounds to generate energy?
- Could the warehouse alone be an eco-building?
- NABAWCS- 'no boss.' Facilitate co-op and organizing methods
- Composting

Burning questions/thoughts

- Some folks might be cynical about the project's feasibility
- How to proceed if you have a diversity of attitudes about Eco-Block? (2)
- What is the total number of people that have been talked to about the project thus far? Where have you found agreement in the group?
- What is legally feasible for tenant upgrades?
- What is the funding timeframe?

- How do you blur the lines between Eco-Block and the other side (other neighborhoods?) (2)
- Getting people on board with different opinions is difficult

What do you like about your block now?

- My house (close to library, Berkeley Bowl, etc.)
- Judy and Jerry's Garden (makes me feel close to nature)
- I know my neighbors
- The kids feel safe

What do you wish to change?

- Add Neighborhood art or murals
- Access to closer public transportation
- More and safer bike lanes
- More kids playing outside.
- Cars racing east.

When should we meet again?

Saturday, July 29th – (0)

Saturday, August 5th – (4)

Saturday, August 12th – (0)

Other times:

- Weekdays after work, work well for me

You are invited...

to continue the conversation with your neighbors about the EcoBlock

Please join your neighbors and the UC Berkeley team for a hands-on meeting to talk more about energy and water systems design. Help the team to identify the best possible options for how an EcoBlock could be operated and maintained in the future, by sharing your questions and concerns about governance.

Saturday, August 12, 2017
9:00 a.m. to 12:00 p.m.
Emeryville Center for Community Life
4727 San Pablo Avenue
Emeryville, CA 94608

Children are welcome!
Coffee and light breakfast will be served.

RSVP to Zach Barr
zbarr@kearnswest.com
(415) 391-7900

How should we manage our energy systems?

Are you willing to use an induction electric range?

☐ yes ☐ no ☐ maybe, I would need more information

Please explain: ______________________________

____

____

____

Are you willing to select direct current (DC) compatible appliances?

☐ yes ☐ no ☐ maybe, I would need more information

Please explain: ______________________________

____

____

Are you willing to select efficient electric space heating and water heating unites for your home?

☐ yes ☐ no ☐ maybe, I would need more information

Please explain: ______________________________

____

____

Would you want to have electric storage at your house?(an example of this would be the Tesla Powerwall)

☐ yes ☐ no ☐ maybe, I would need more information

Please explain: ______________________________

____

____

Do you want to have solar panels on your house?

☐ yes ☐ no ☐ maybe, I would need more information

Please explain: ______________________________

____

____

____

How should we manage our energy systems?

When the power goes out, what are you most concerned about keeping powered?
Please number the items below 1-7 in order of their priority to you. "1" is highest priority.

______ Refrigerator
______ Heater
______ Stove
______ Hot water
______ Lighting
______ Small appliances
______ Personal electronics

Other:
____
____
____

How would you prefer that information about energy use, (such as how much energy buildings are using, and how much renewable energy is produced)be managed?

- ☐ Community managed data
- ☐ Utility managed data
- ☐ Third-party managed data
- ☐ I'm concerned about data management and would prefer to : ____________

____
____
____

What is your preference for electric vehicle management?
(Choose as many as apply)

- ☐ Shared electric vehicles, limited to use by the block
- ☐ Shared electric vehicles, open to the public with the potential to generate revenue for the block
- ☐ Electric vehicle charging capabilities for each property

How likely are you to purchase an electric vehicle for your next car?
(Choose as many as apply)

- ☐ Very likely
- ☐ Somewhat likely
- ☐ Not likely
- ☐ I would be more likely if my home were set up for EV charging
- ☐ I'm not interested in electric vehicles
- ☐ I don't use personal vehicles for transportation
- ☐ I already drive an electric vehicle

How should we govern an EcoBlock?

Please note your responses will remain anonymous. Please answer as many or as few questions as you like.

What role do you play on the block? I am a ☐ homeowner ☐ renter ☐ landlord (living on the block) ☐ landlord(living elsewhere)

How involved do you want to be in making decisions about the energy and water systems on the block?

Please mark your preference on the scale and write any comments in the space below.

"I don't want to spend much time thinking about this. I'd prefer if someone else handled the details..."

Not very involved ——— *Very involved*

"I am very interested in this and I'd be willing to spend a few hours a month on this..."

____

____

____

Would you be willing to pay a monthly or regular fee, bill or equivalent increase in property taxes for operations and maintenance if the cost were covered by savings on your utility bill?

☐ yes ☐ no ☐ maybe

Please explain: ____

____

____

____

____

____

____

How might you prefer to pay for these EcoBlock ongoing costs on a regular basis?

☐ all at once or annually ☐ monthly ☐ no preference

What other features increase convenience? ________________________

____

____

____

____

____

____

How should we govern an EcoBlock?

What kind of entity would you prefer be responsible for managing and making decisions about the EcoBlock systems?

Please mark your preference on the scales and write any comments in the space below.

Community Based Organization	*I would not be comfortable with this*	*I do not have a preference or a concern*	*I would prefer this*
Local Government Agency	*I would not be comfortable with this*	*I do not have a preference or a concern*	*I would prefer this*
Energy or Water Utility	*I would not be comfortable with this*	*I do not have a preference or a concern*	*I would prefer this*
Private Third-Party	*I would not be comfortable with this*	*I do not have a preference or a concern*	*I would prefer this*

If a private third party managed the EcoBlock, what characteristics would you prefer that they have?

- ☐ government certified
- ☐ utility certified
- ☐ non-profit requiring community participation
- ☐ for-profit (large, well-known company)
- ☐ for-profit (smaller energy services company)
- ☐ Other: ______________________

Please explain: ____

____

If a private third-party managed the EcoBlock, would you feel comfortable if they owned the infrastructure outside of the house, in addition to maintaining it? (could be subject to agreements with owners)

- ☐ yes
- ☐ no
- ☐ maybe

Please explain: ____

____

____

____

How should we govern an EcoBlock?

Which benefits of an EcoBlock are most important to you?

Please number the items below 1-6 in order of their priority to you. "1" is highest priority.

______ Having energy and water security in case of disaster
______ Improvements to my street like sidewalk repair and landscaping
______ Knowing that my home is "green"
______ Cost savings on utility bills
______ Opportunity for more transportation options like electric vehicles
______ Opportunity to rehabilitate an older home
______ Doing something groundbreaking
______ Other? Please explain:

____
____
____

What is your view of PG&E?

☐ positive
☐ negative
☐ no opinion

What is your view of EBMUD?

☐ positive
☐ negative
☐ no opinion

Any comments to share on your experience with utilities?

____
____
____
____
____
____
____
____

How should the benefits and costs of an EcoBlock be shared?

Please mark your preference on the scale below.

Tenant ——————————————————————— *Owner*

Long-term Operations and Maintenance

Please explain: ____
____
____
____
____

For Homeowners and Landlords

How willing are you to enter into an agreement that would "attach" to your property deed?

(An example of this type of arrangement that you might already have is an easement or an assessment)

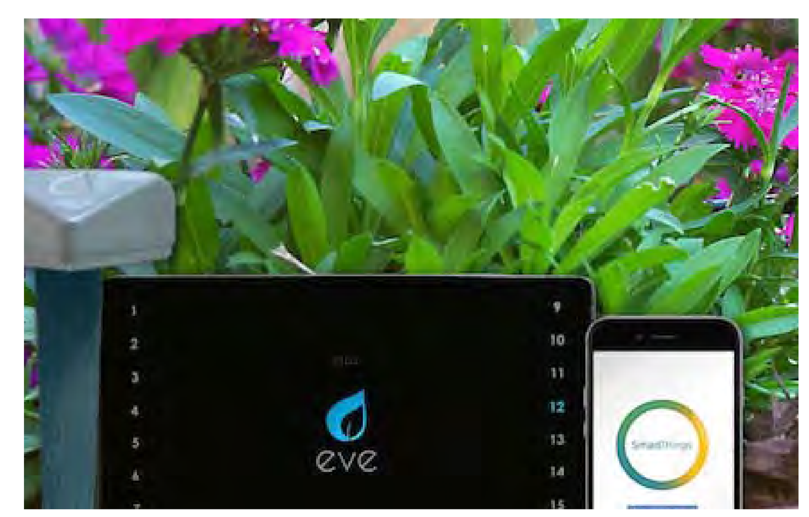
☐ I would consider this, but would need more information
☐ I am not interested in this at all
☐ I am generally comfortable with this type of agreement

Please explain: ____
____
____
____
____

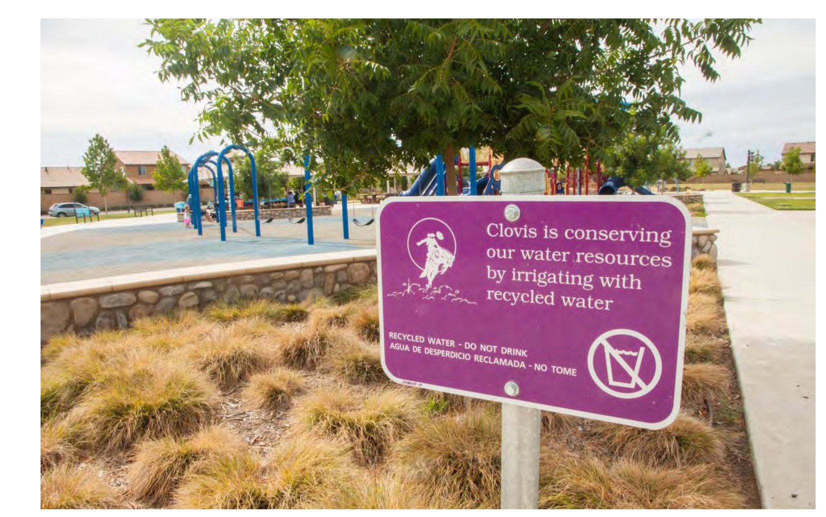
How should we make our homes more water efficient?

"I am interested in water conserving retrofits in my home to fixture upgrades."

"I'm interested in native plans and efficient irrigation systems to reduce water use in my garden."



"I'd be interested in using recycled water or harvested rainwater to reduce potable water demand."



For example, dual plumbing the home to allow for use of recycled water for toilet flushing rather than potable water.

Please place your dot on the scale to indicate your preference.

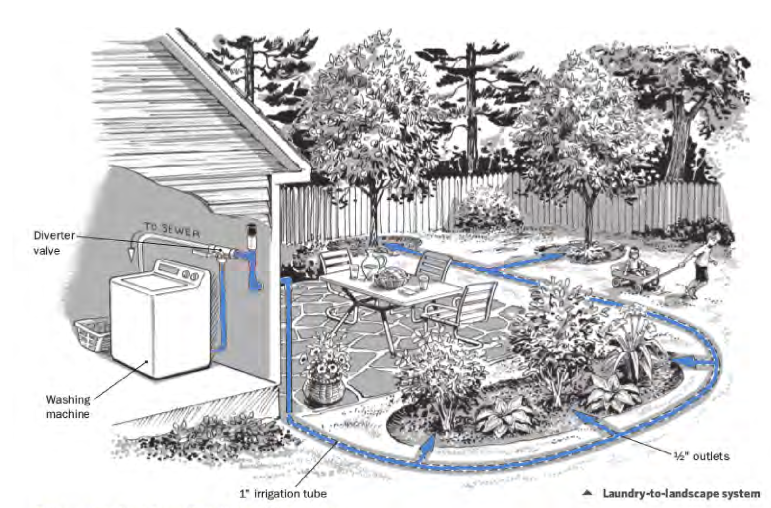
Least amount of change

Highest water conservation potential

How should we manage our wastewater?

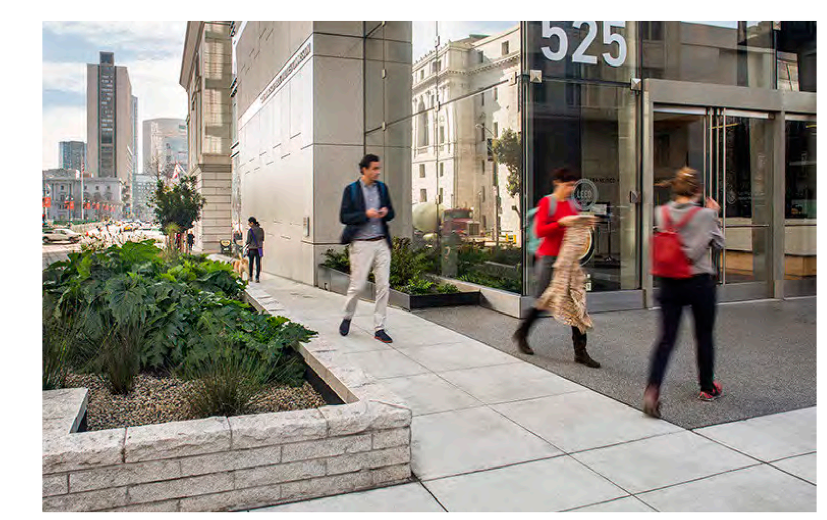
"I prefer to remain connected to the City's sanitary sewer."

"I am interested in options for managing greywater at my individual home."



For example, "laundry to landscape" diversion of greywater from laundry machines (or potentially showers, sinks) to use for irrigation.

"I am interested in wastewater treatment and recycling, serving the entire block."



For example, Emory University (top) and the San Francisco Public Utilities Commission building (bottom) use combined mechanical and plant-based treatment systems to recycle wastewater for toilet flushing and irrigation.

Please place your dot on the scale to indicate your preference.

Least amount of change

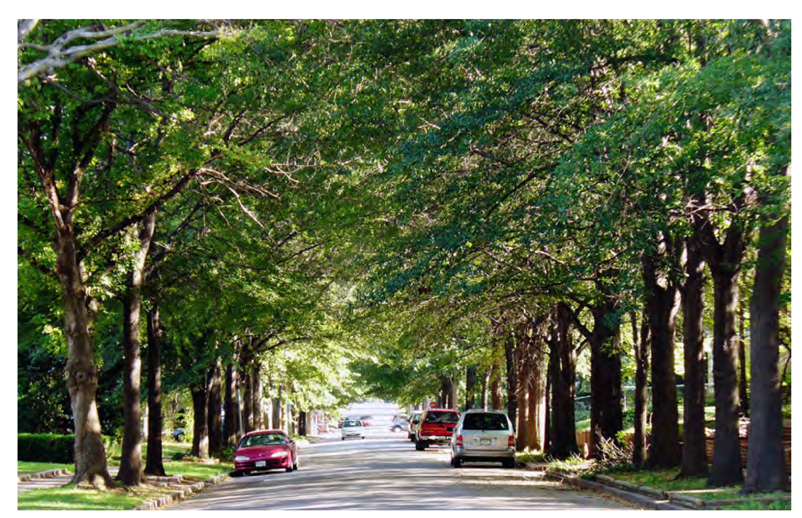
Highest water conservation potential

How can we green our streets and improve stormwater management?

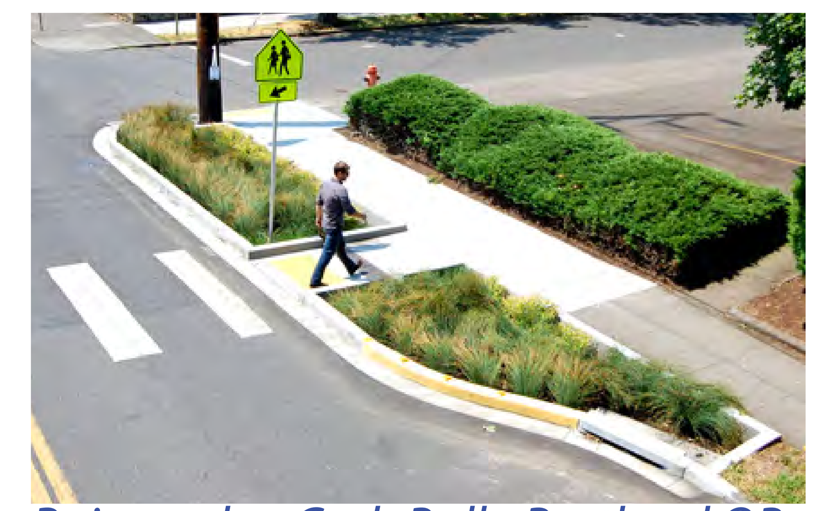
"I am interested in individual or shared raingardens on private property."

"I am interested in sidewalk improvements and the addition of street trees."

Porous pavement sidewalk



"I am interested in green infrastructure within the parking aisle in addition to sidewalk and landscaping improvements."



Raingarden Curb Bulb, Portland OR

Porous pavement parking, Portland OR

Potential for stormwater quality and infiltration.

"I am interested in a full green street redesign."

Complete Street, Santa Monica, CA

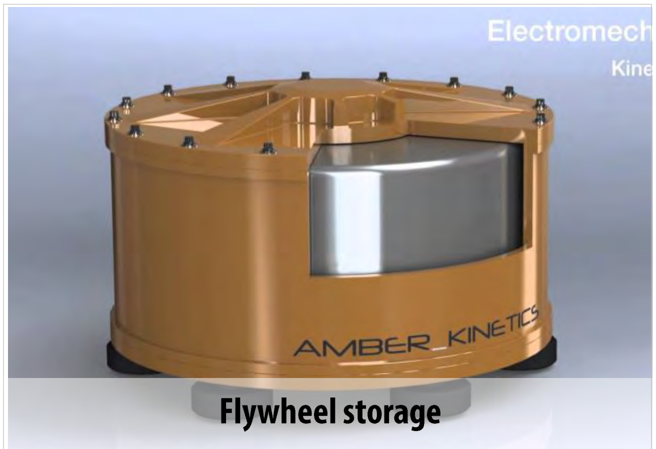
Complete Street, near Portland OR

Additional benefits such as public space.

Please place your dot on the scale to indicate your preference.

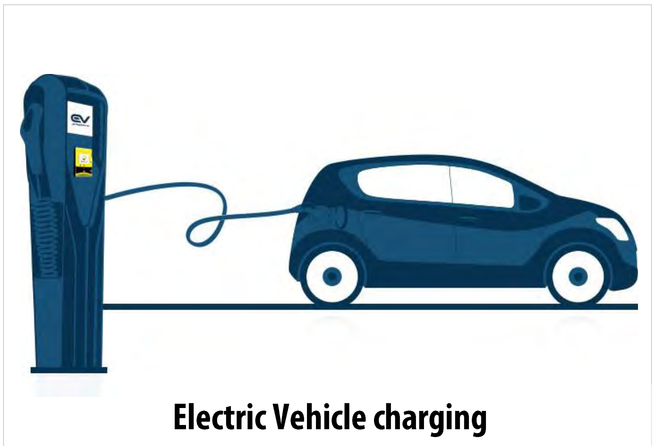
- *Least amount of change*
- *Least construction impact and cost*

- *Most construction impact and cost*
- *Highest potential impact on stormwater quality infiltration and flooding*



Flywheel storage

Wastewater treatment



Electric Vehicle charging

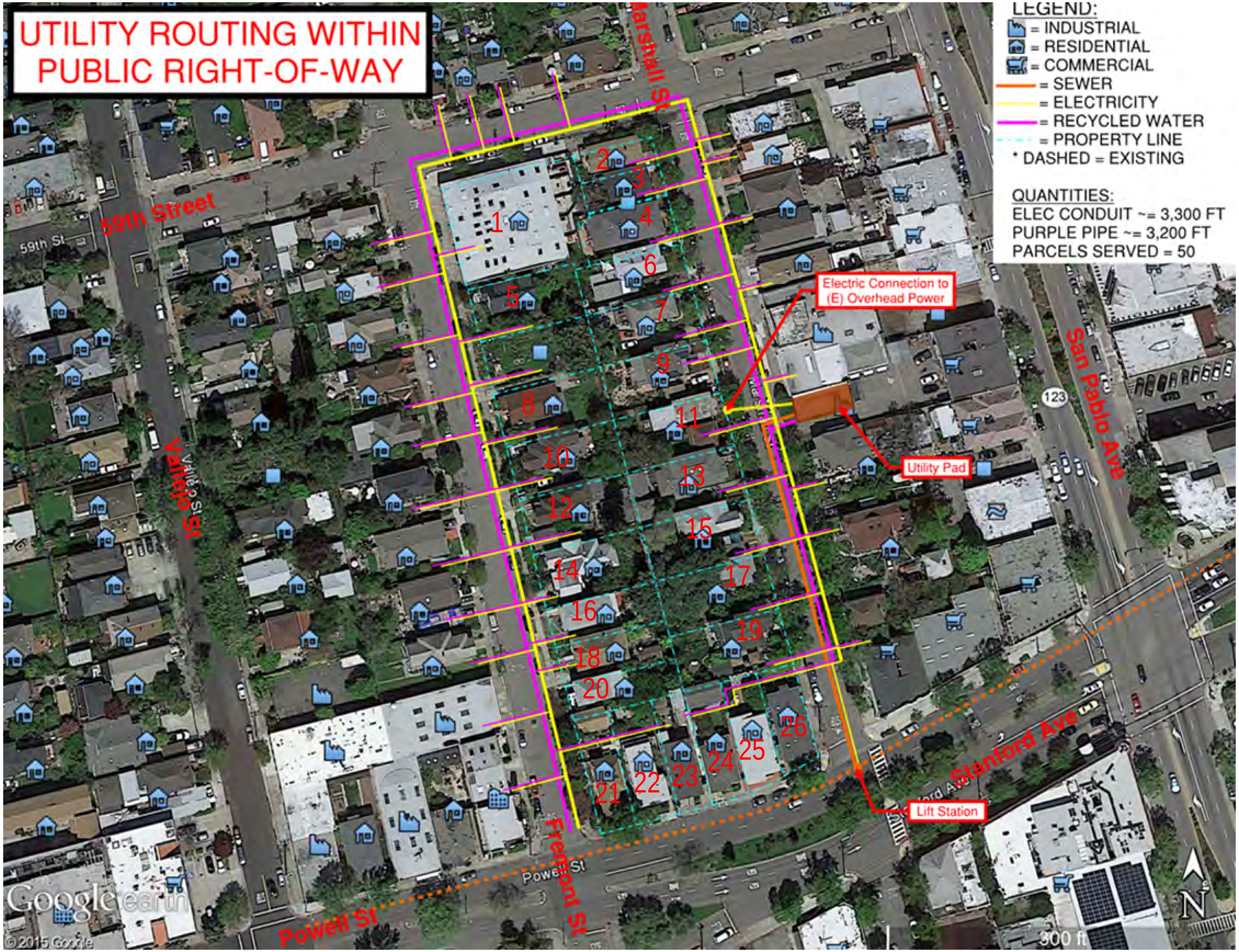

Blockwide non-potable distribution


Community Garden


Community rainwater harvesting


Raingarden

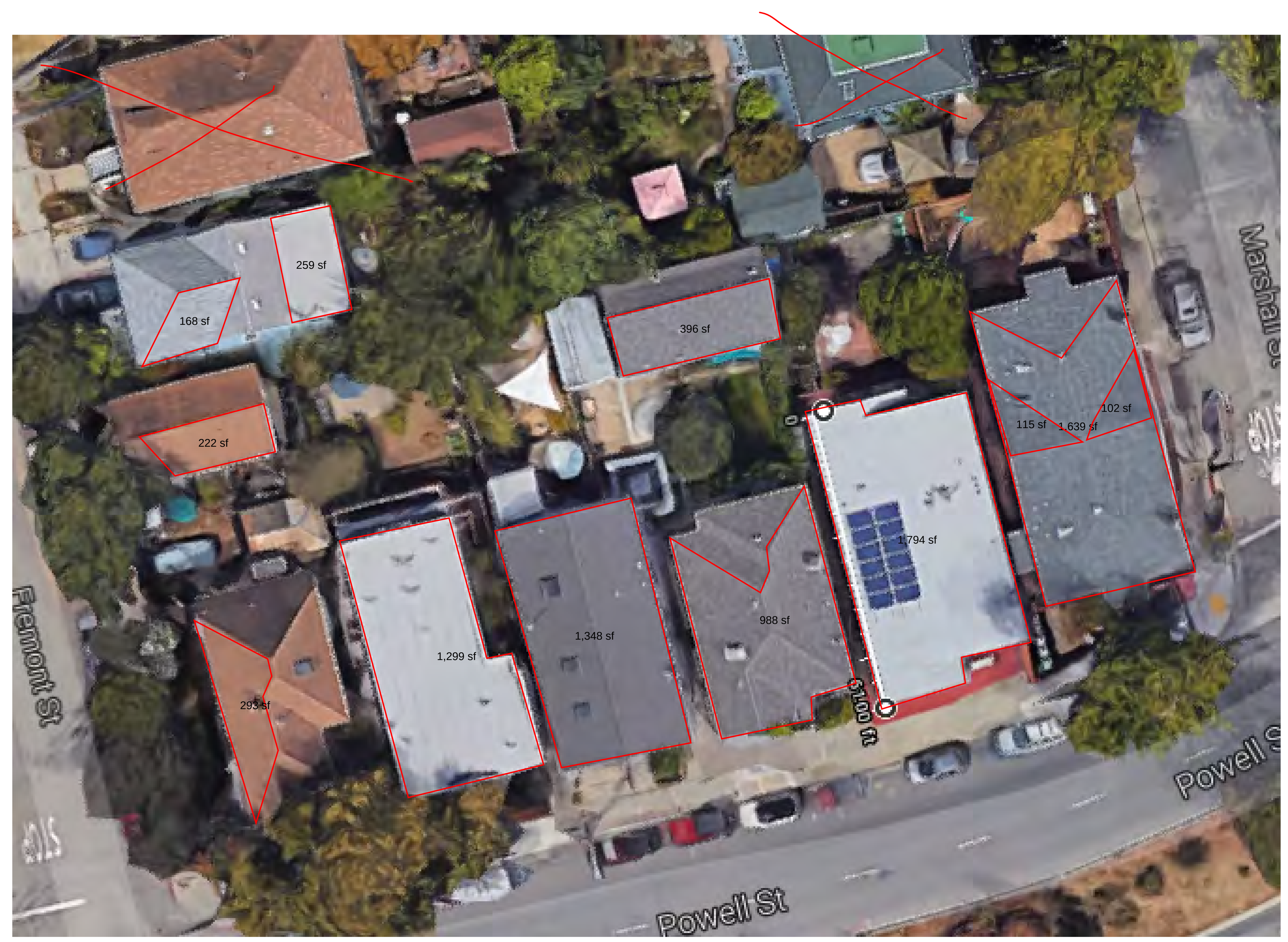
Other:



UTILITY ROUTING WITHIN PUBLIC RIGHT-OF-WAY
LEGEND:
= INDUSTRIAL
= RESIDENTIAL
= COMMERCIAL
= SEWER
= ELECTRICITY
= RECYCLED WATER
= PROPERTY LINE
* DASHED = EXISTING
QUANTITIES:
ELEC CONDUIT ~= 3,300 FT
PURPLE PIPE ~= 3,200 FT
PARCELS SERVED = 50
Electric Connection to (E) Overhead Power
Utility Pad
Lift Station
Marshall St
59th Street
59th St
Vallejo St
San Pablo Ave
123
Stanford Ave
Powell St
Fremont St
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
300 ft
N
Google earth
© 2015 Google


59th St
59th St
Marshall St
Marshall St
Fremont St
Fremont St
709 sf
590 sf
1,371 sf
415 sf
378 sf
404 sf


Marshall St
Fremont St
Fremont St
677 sf
418 sf
1,351 sf
744 sf
354 sf
397 sf
240 sf
128 sf
645 sf
521 sf
661 sf
493 sf


Marshall St
Fremont St
Powell St
Powell St
259 sf
168 sf
396 sf
222 sf
1,299 sf
1,348 sf
988 sf

KEARNS & WEST

AUGUST 12, 2017 ECOBLOCK DESIGN MEETING SUMMARY

Meeting date and location:
Saturday, August 12, 2017
Emeryville Center for Community Life
9am-12pm

Staff: Maika Nicholson (Sherwood Design Engineers), Sandy Robertson (Stanford University), Nora De Cuir (Kearns & West), Monica Ayers (Kearns & West), Emma Tome (UC Berkeley Energy and Resources Group), Andréa Traber (Integral Group), Christine Thomson (SOM)

Attendees: 6 residents (see Appendix B: Sign-in sheet)

Notification Approach: All block residents and property owners received post card invitations. For residents who had previously provided email addresses, an initial email invitation was sent, followed by a personalized email re-iterating the invitation if they had not RSVP'd. Additionally, the block was canvased twice: once on a Saturday morning, with a following round of canvasing on a Wednesday evening.

Agenda: The meeting was designed for a flexible approach, dependent on meeting attendance. Based on the small group attendance, the project team chose an "office hours" approach, allowing attendees to talk one-on-one with project team members and with one another in a small group setting around a map of the block. The purpose of the meeting was to:

- Share options or alternatives for EcoBlock water, wastewater and electrical systems design
- Convey how resident input has been incorporated into the options, and where there are gaps
- Gather input on preferences for elements of the design(s) to aid in the selection of a preferred alternative
- Gather input on general preferences for management of block resources

After a brief re-introduction of the EcoBlock and explanation of the purpose of the charrette, attendees were invited to ask questions of energy and water team members. A brief PowerPoint presentation was available for attendees, outlining the scope of the Eco-Block project, including feedback from community meetings, the design process, and next steps. After the presentation, attendees were asked to provide written feedback, by filling out water and governance workbook handouts that were distributed during the charrette. Most discussions occurred around a large format aerial photograph of the block showing the existing condition.

The table that follows summarizes questions asked by attendees in a small group setting during the meeting, organized by category.

KEY QUESTIONS AND COMMENTS

Governance

- How much buy-in is needed to make changes to the block?
- The managerial aspect seems more challenging than physical design.
- Is this a statewide program? Is the City of Oakland aware and in favor of it?
- How will things work for owners versus renters?

Energy, Water and Transportation System Design

- Worry about leaks in properties before installing solar panels.
- We have problems with our sidewalks.
- Need for street improvements (flooding on sidewalks).
- Where would you find space for wastewater treatment center? How would you treat absorption of pharmaceutical drugs in wastewater?
- Problems with the kinds of trees that are planted (they drip).
- Trees are not drought resistant. Roots are very high.
- There is a need to slow down cars on the street.
- What are the short-term construction/cost impacts?
- Concerns over available parking (competing with business in the area).
- Where would we park electric vehicles?
- I am excited/inspired by idea of the project!
- I am in support of design options that are lasting.

Funding

- How is the project funded?
- Will more money be needed for Eco-Block implementation?

The following summarizes the results of workbooks that participants were asked to complete. Note that not all participants responded to every question.

GOVERNANCE

<u>How should we govern an EcoBlock?</u>

What role do you play on the block?

	Homeowner	Renter	Landlord (living on the block)	Landlord (living elsewhere
Number of Responses	2	1	1	0

How involved do you want to be in making decisions about energy and water systems on the block?

	I don't want to/let someone else handle it	Not very involved	Very involved	I am interested/willing to spend a few hours per month
Number of Responses	0	1	3	0

Additional notes:

- *"Very interested [to] [be] [involved] and willing to work."*

Would you be willing to pay a monthly or regular fee, bill, or equivalent increase in property taxes for operations and maintenance, if the cost were covered by savings on your utility bill?

	Yes	No	Maybe
Number of Responses	3	0	1

Please explain:

- *"Need details, but if cost are covered, yes."*

How might you prefer to pay for these EcoBlock ongoing costs on a regular basis?

	All at once or annually	Monthly	No preference
Number of Responses	1	0	3

What other features increase convenience?

- *"Ability to factor into taxes/rent."*

What kind of entity would you prefer be responsible for managing and making decisions about the EcoBlock systems? (Please mark your preferences on the scales and write any comments in the space below.)

	I would not be comfortable with this	I do not have a preference or a concern	I would prefer this	**Notes**
Community based organization	1	2	1	
Local Government Agency	4			
Energy or water utility			2	Maybe, but not City of Oakland
Private Third-Party				***Non-private*** third party

If a private third party managed the EcoBlock, what characteristics would you prefer that they have?

	Government certified	**Utility certified**	**Non-profit requiring community participation**	**For profit (large, well known company)**	**For-profit (smaller energy services company)**	**Other**
Number of Responses	**2**	**3**	**2**	**1**	**0**	

Please explain:

- *"Possible public/private joint venture."*

If a private third party managed the EcoBlock, would you feel comfortable if they owned the infrastructure outside of the house, in addition to maintaining it? (Could be subject to agreement with owners)

	Yes	**No**	**Maybe**
Number of Responses	**1**		**2**

Please explain:

- *"Would need more info."*
- *"Maybe, but probably not..."*

Which benefits of the EcoBlock are most important to you? **Please number the items below from 1-6, in the order of their priority to you. "1" is the highest priority.

Having energy and water security in case of disaster	**4**	**1**	**4**	**4**
Improvements to my street like sidewalk repair and landscaping	**3**	**4**	**1**	**1**
Knowing that my home is 'green'	**1**	**5**	**3**	**5**
Cost savings on utility bills	**2**	**6**	**5**	**6**
Opportunity for more transportation options like electric vehicles	**5**	**7**		**2**
Chance to rehabilitate an older home	**6**	**2**	**2**	**7**
Doing something groundbreaking	**7**	**3**	**6**	**3**
Other. Please explain				

What is your view of PG&E?

	Positive	Negative	No opinion
Number of Responses		**3**	**1**

Any comments to share on your experience with utilities?

- *"PGE- not friends to solar panel systems owners."*

What is your view of EBMUD?

	Positive	Negative	No opinion
Number of Responses	**2**		**2**

Any comments to share on your experience with utilities?

- *"EBMUD- okay, but…"*

How should the benefits and costs of an EcoBlock be shared? (Please mark your preferences on the scale below)

Tenant		Owner
	X	
	X	
	X	
	"shared"	

- *“I feel the homeowners should take on most of the financial responsibility, but not all, as tenants should share benefits, as well.”*
- *“Ownership and participation have to be shared.”*
- *“Benefits should be shared.”*

For Homeowners and Landlords

How willing are you to enter into an agreement that would “attach” to your property deed?

(An example of this type of arrangement that you might already have is an easement or an assessment).

	I would consider it, but need more information	Not interested in this at all	I am generally comfortable with this sort of agreement
Number of Responses	3	1	0

Please explain: [No response]

ENERGY

How should we manage our energy systems?

When the power goes out, what are you most concerned about keeping?

Refrigerator	1	4	5	1
Heater	2	5	1	7
Stove	3	7	4	3
Hot water	4	6	3	4
Lighting	5	2	2	2
Small appliances	6	1	6	6
Personal electronics	7	3	7	5

How would you prefer that information about energy use (such as how much energy buildings are using, and how much renewable energy is produced), be managed?

	Community managed data	Utility managed data	Third-party managed data	I’m concerned about data management and would prefer to:

Number of Responses	**1**	**1**		**Understand how my current solar panel PV is managed**

What is your preference for electric vehicle management? (Choose as many as apply)

	Shared electric vehicles, limited use by block	Shared electric vehicles, open to the public with potential to generate revenue for the block	Electric vehicle charging capabilities for each property
Number of Responses	**3**	**2**	**1**

How likely are you to purchase an electric vehicle for your next car? (Choose as many as apply)

	Very likely	Somewhat likely	Not likely	I would be more likely, if my home were set up for EV charging	I'm not interested in electric vehicles	I don't use personal vehicles for transportation	I already drive an electric vehicle
Number of Responses		**1**	**1**	**1**		**1**	

Are you willing to use an induction electric range?

	Yes	No	Maybe, I would need more information
Number of responses	**1**		**3**

Please explain: *"I do love my gas range."*

Are you willing to select direct current (DC) compatible appliances?

	Yes	No	Maybe, I would need more information
Number of Responses	**3**		**1**

Please explain: [No response]

Are you willing to select efficient electric space heating and water heating units for your home?

	Yes	No	Maybe, I would need more information
Number of Responses	**3**		**1**

Please explain: [No response]

Would you want to have electric storage at your house? (an example of this would be the Tesla Powerwall)

	Yes	No	Maybe, I would need more information
Number of Responses	**3**		**1**

Please explain: [No response]

Do you want to have solar panels on your house?

	Yes	No	Maybe, I would need more information
Number of Responses	**3**		**1**

Please explain:

- *"Already have PV system."*
- *"We already have solar panels."*

WATER AND WASTEWATER

How should we make our homes more water efficient?

	I am interested in water conserving retrofits in my home fixture upgrades	I am interested in native plants and efficient irrigation systems to reduce water use in my garden	I'd be interested in using recycled water or harvested rainwater to reduce potable water demand.
Number of Responses		**1**	**1**

- *"All good."*

How should we manage our wastewater?

	I'd prefer to remain connected to the City's sanitary sewer	I am interested in options for managing greywater at my individual home	I am interested in wastewater treatment and recycling, serving the entire block
Number of Responses			**3**

- *"More details needed [on wastewater treatment]"; "[City's sanitary sewer] broke, not good"*

How can we green our streets, and improve stormwater management?

	Individual or shared raingardens on private property	Sidewalk improvements and the addition of street trees	Green infrastructure within the parking aisle and sidewalk and landscaping improvements	A full green street redesign
Number of Responses	**1**	**1**	**1**	**2**

Appendix: Resident Interviews

Emma Tome, UC Berkeley Energy and Resources Group

Contents

Abstract

This research used in-depth, semi-structured interviews to learn about the experiences of residents and property owners historically, in relation to one another, and in relation to the proposed EcoBlock project. It discusses how the prospect of block-scale retrofits and resource sharing registered with renters and property owners, and explores how existing social dynamics could shape participation in and governance of such a project. It includes residents' reflections on participation in planning efforts to date, and if and how they might wish to engage further. It also situates the EcoBlock planning effort among other urban responses to climate change, and discusses several relevant precedents, including ecovillages, eco-districts, and block-by-block retrofit programs.

Acknowledgements

Thank you to the faculty who advised me: Isha Ray, for your sharp insights and grounding methodological counsel, and Karen Chapple for sharing your great expertise in equitable urban and regional development. Laura Enriquez' interview methods course, and Sandra Susan Smith's early involvement in the project, also greatly informed my approach. My graduate cohort and the ERG Water Group provided fantastic mentorship and feedback on an early version of this work. Sarah Knuth, Gene Rochlin, and Gwen Ottinger also provided me with thoughtful guidance at various phases of this effort.

Thank you to the EcoBlock leadership – Dan Kammen, Harrison Fraker, and Anthony Nahas – for entrusting me with this work and for your support throughout, and to the California Energy Commission for providing funding for this research. Thank you to Mark Wilson for your excellent editing and project management; to the whole EcoBlock project team and especially the Outreach Team – Nora De Cuir, Zach Barr, and Monica Ayers - for your dedicated and impressive work on a truly unique undertaking. Thank you to E.D. for opening your home to me and being such a thoughtful companion during my writing. My deepest thanks to the residents and property owners who participated in interviews and shared so generously of their time and insights. Your patience with, openness to, and commentary on this project over its very long course have been deeply informative and sincerely appreciated.

Executive Summary

While the main report focuses on the general potential for EcoBlocks to scale city- and statewide, this appendix describes residents' impressions of these potential technical and social changes. Rather than providing recommendations for outreach and engagement (for this, see Chapter 11), it discusses how the project registered with residents in the context of their personal experiences and values; their preexisting relationships with neighbors; and the broader history of the neighborhood. It differs from and complements the Case Study (Chapter 10) by providing additional historical context about the neighborhood, gleaned from research and interviews; reflections on the planning process from the perspective of residents and project team members, and a discussion of the projects' implications in terms of its equity and social justice goals. As is reflected in other areas of the report, residents posed a range of questions regarding the financial and governance models the project would require. Where resident questions fell outside the predetermined scope of the Phase 1 planning, they are also highlighted and, if possible, preliminarily addressed.

This appendix's primary purpose is to inform the EcoBlock project's ongoing planning efforts. It thus does not adopt the standard format of most research writing. First, this executive summary briefly synthesizes the core findings from the entire report. Then, in order to foreground resident perspectives on the EcoBlock project, interview methods and findings are presented, followed by a review of relevant literature.

Governing community-scale decarbonization

The communal elements of the EcoBlock proposal extend the scale of resource use and management just outside the home, to the city block—a spatially small, but legally, financially, and socially radical shift. This could mean great changes to life on the block, requiring new forms of collective resource governance, ownership, and use. Residents found the proposal compelling for both the environmental and social improvements it might bring to their block. It demonstrated promise to resolve global environmental and economic problems at the neighborhood scale. A successful EcoBlock project could, at once, strengthen social ties and intergenerational support, while also providing significant environmental benefits and demonstrate the feasibility of neighborhood-scale resource sharing.

The closest existing examples of the community-scale resource management required by an EcoBlock might be seen among eco-villages. Eco-villages are small-scale sustainable communities that employ a range of governance and ownership models, including nonprofit management, condominium associations, homeowners associations, limited liability partnerships, and community land trusts (Liftin 2014). However, eco-village governance differs from the EcoBlock in that these models usually derive from strong preexisting community relationships, including a shared sense of purpose, solidarity, reciprocity and trust. Strong relationships are not as essential to other governance arrangements, in which agreement to community norms and rules are a precondition for eco-village membership.

The EcoBlock thus diverges from eco-villages because its central purpose is not to socially transform city blocks and their inhabitants, but to provide a modular technical, financial, and legal model that allows widespread scaling. This aspiration implies that block-scale social cohesion might be a positive side effect of sustainable technology adoption, but not necessarily a prerequisite. Since the EcoBlock's central *technical* hypothesis is that the block scale will be a more efficient scale for energy and water retrofits, the ancillary *social* hypothesis might therefore be that the appropriate legal and financial structures will obviate the need for a block to be socially cohesive in order to become an EcoBlock.

Research summary

This research took the standpoint that any determination of the social feasibility of the project should be informed by resident perspectives more than an outsider's appraisal of preexisting social conditions in the neighborhood. This research thus focused on resident perceptions of the EcoBlock project; and their experiences, relationships, and life in the neighborhood. Interviews were structured around a few overlapping areas of interest: (1) opinions of the project and its various features; (2) life in the neighborhood, and personal understandings of and perspectives on neighborhood history; and (3) relationships in the neighborhood, and any perceived bearing they might have on the project's prospects. If the project is realized on this block, this research can also serve as a partial "snapshot" of the neighborhood prior to EcoBlock implementation, and aid in identifying social changes that might result from it.

This research took place in parallel with formal outreach efforts in summer 2017 (discussed in Chapter 11), and followed extensive informal outreach by project manager from 2014–2016. Most (28 of 31) interview participants had been introduced to the project before being contacted via mail to participate in an interview. Unlike the outreach efforts particular to the selected block's residents, this research was undertaken to produce generalizable knowledge about EcoBlock project feasibility, and so required Institutional Review Board ethics approval (Protocol ID: 2016-10-9271).

Project perceptions

The prospect of living in well-maintained and energy and water-efficient homes was broadly appealing to residents, especially those who were already sensitive to their personal environmental impacts. For residents who identified with behaving sustainably (such as buying organic food, recycling, bicycling, and taking public transit) and feeling frustrated by what remained out of their control (such as utility decisions about energy procurement, national politics, environmental policy, and wasteful industry practices), the project was seen as environmentally empowering. One even called the project a "guilt-eraser" for the way it could insulate the block from the negative environmental impacts of existing infrastructures and systems.

However, the project was not universally accepted among all residents interviewed. Technical features that drew the most opposition included all-electric cooking appliances, electric vehicles, and blackwater treatment and reuse. Exacerbated parking issues due to increased interest in the neighborhood or new charging infrastructure were also a point of concern.

Perceptions of potential social features also highly varied. For example, some households were concerned about long-term maintenance logistics and costs, while others were confident that they wanted to participate, even without detailed information about potential timelines and expenses. Residents speculated widely on whether and how the block residents would participate and manage new systems over the long term. The very notion of "community"—how it might be defined, and whether or not it would be important to the project's success—also varied among those interviewed.

Proposing to legally and financially unify many infrastructural elements of a block in a rapidly changing neighborhood faces several challenges. Residents saw gentrification for both its positive and negative dimensions. Several had complex personal conceptions of whether and how they could be seen as "gentrifiers", and offered personal reflections on how they negotiated their relationship to the wider neighborhood.

The EcoBlock planning process could expose and amplify any underlying dynamics in the neighborhood, not least through the formation of a Community Facilities District. The property value disparities common to gentrifying neighborhoods could make a Community Facilities District model challenging, since bases for taxation could differ dramatically among properties. It could also exclude those who may not culturally or socially relate to the project's approach and goals. Some of the residents who the project envisioned benefitting most—residents having trouble keeping up with household expenses and maintenance—were among those most skeptical.

Participation in the EcoBlock

Assembling a block community to participate in EcoBlock implementation would be the core focus, and challenge, of a Phase 2 project. Chapter 8 has identified preferred options for finance and governance of the EcoBlock project, but actually realizing these structures—drawing up legal agreements and reaching consensus on design elements—has not yet begun. As discussed in Chapters 10 and 11, participation in outreach activities was low. Residents' accounts reinforce findings in Chapter 11 that suggest that low participation was due to the outreach team's inability to inform residents in a timely manner, residents' busy schedules, and the overall vagueness of residents' roles in project design. Residents had received inconsistent messages from the project manager and outreach team about whether the block was the only EcoBlock contender, if and when construction would take place, and what, if any, their personal financial obligations would be.

Day-to-day maintenance logistics, short- and long-term costs borne by residents, and changes to routine relationships (to utilities, landlords, local government, and neighbors) are among the core issues residents would face upon implementation. Questions about rent control, resale restrictions, anti-displacement measures, and participation thresholds also arose in the context of interviews, and these are preliminarily addressed here. Indeed, the central "experiment" of a potential EcoBlock build-out is as much, if not more, about the potential for new forms of collective governance in the urban environment as the efficiency gains of block-scale resource sharing.

Since a few residents have expressed clear opposition to participating in the project, it is unclear if the block planned as part of Phase 1 will ultimately be the block where the EcoBlock plan is implemented. If the project moves forward without 100 percent participation, but with some of the block-scale elements, this would mean the Community Facilities District would be drawn to exclude certain residents. The project would remain vulnerable to resistance at the City Council level if block residents, or others in the neighborhood, are actively against seeing it implemented altogether.

Although the project prioritized developing financial and legal models for widespread EcoBlock deployment and scaling-up, this report finds that many of the key barriers to adoption may lie at the micro-scale of each neighborhood's particular history and social dynamics. Widely varied property values, incomes, tenure, and perspectives on the project will make finding an appealing agreement for the diverse range of block residents a demanding process.

Community-scale retrofit precedents

Research on the challenges to retrofitting renter-occupied homes corroborates resident accounts of the issues that arise when managing utilities and repairs with their landlords. In addition to the classic "split incentive" problem that discourages efficiency upgrades, tenants discussed challenges with replacing broken appliances and dealing with substantial repairs—basic habitability concerns beyond marginal costs and benefits to energy and water conservation. While these are certainly technical failures, the quality, timeliness, and permanence of a repair are conditioned by any given landlord. Tenants with challenging relationships with their landlords had two typical reactions to the project. It was viewed as an opportunity to address deferred maintenance, but it also raised fears over needing to engage more extensively with landlords, which some tenants avoided.

As discussed in Chapter 8, realizing communal elements of the EcoBlock would require novel applications of legal structures such as Community Facilities Districts, and the formation of new governing and managerial bodies, such as an EcoBlock Trust or LLC. Other urban sustainability projects, from neighborhood retrofits to eco-villages to large "blank-slate" developments, have proposed or realized applications of some of these legal mechanisms.

Previously implemented neighborhood-scale retrofit or sustainability projects in the United States include the LA EcoVillage, the Retrofit NYC Block by Block program, the Murray City Block-By-Block retrofit program, and the Kansas City Green Zones program. The LA EcoVillage, like other eco-villages, prioritizes close community relationships over implementing advanced technologies. The block-by-block and community-focused retrofit programs share relatively modest goals of engaging residents in individual-house upgrades, but doing so in the context of neighborhood initiatives. The relatively low uptake (14 percent in the case of the NYC pilot) underlines the challenges of building trust, especially among residents who are skeptical of free programs.

The Philadelphia Coolest Block Contest is a particularly useful point of comparison for the EcoBlock because the project focused on gaining participation from all residents on a single residential block. It employed a municipal-private sector-nonprofit partnership and held a city-wide contest to select a block for a cool-roof coating pilot project. A range of intermediary actors, especially neighborhood-level advocates, were necessary for successfully realizing the project. However, this case was a one-time, short-term intervention, while the EcoBlock project would require at least some degree of ongoing maintenance and neighborhood decision-making, especially if it included block-scale features.

While much larger in scale, the Sonoma Mountain Village (SOMO) and Treasure Island are two new-build eco-city development projects in the greater Bay Area that provide useful points of reference for finance and governance models. While they are much larger than the EcoBlock, their contrasting governance and finance structures (private developer versus public-private-partnership) illustrate the potential trade-offs between technological innovation and public engagement (Joss 2011b). Treasure Island, which arguably has been more attentive to social benefit concerns than SOMO, still faces public criticism for its lack of transparency, and for multiple environmental contamination issues. EcoBlock implementers could learn from the legal structures, public engagement, and implementation strategies that Treasure Island employed—as well as the challenges it has faced.

The EcoDistricts organization, founded in 2012, uses an approach to scaling not focused on specific technology so much as codifying principles and engagement methods to support grassroots efforts. It grew out of the Rocky Mountain Institute's Living City Block (LCB) project, which has itself been discontinued. Several LCB projects were attempted in Denver, San Francisco, Washington, D.C., and elsewhere, but none were realized. News media has highlighted the challenges faced by these projects, including attaining adequate financing and levels of community buy-in, which parallel those the EcoBlock now faces for a Phase 2 implementation. The EcoDistricts organization, rather than itself leading project development, has developed an EcoDistrict Protocol, training program, and incubator for those interested in starting EcoDistrict efforts in their own communities.

EcoBlocks and housing affordability

Since the EcoBlock prioritized both scalable advanced technology deployment and equitable sustainable development in the urban environment, the report also discusses California policies that jointly address climate change and environmental justice concerns. The Bay Area faces pronounced crises of housing availability and affordability. These broader contexts have bearing on the EcoBlock project insofar as it aspires to provide widespread urban revitalization without the negative impacts of gentrification.

Many residents moved to and remain in the neighborhood because it is affordable yet relatively safe, aesthetically pleasing, and close to community institutions that they care about. Renters were concerned about their landlords raising rents in the wake of an EcoBlock project being developed. According to the Oakland Rent Adjustment Program, there do appear to be avenues a landlord could take to raise rents or even temporarily evict their tenants for EcoBlock construction. Legal arrangements might need to be made to ensure tenants could afford to stay in their homes if they wished to.

Apart from explicitly sustainability-oriented projects, affordable housing and community-based revitalization initiatives focused on maintaining housing affordability could also be useful points of reference for creating models to govern and maintain EcoBlocks. The Dudley Street Neighborhood Initiative in Boston uses a community land trust model (Agyeman 2013), and limited-equity housing cooperatives in D.C. create an “urban commons” (Huron 2015). Locally, the Bay Area is home to several urban land trusts, including the Oakland Community Land Trust, San Francisco Community Land Trust, the Berkeley Community Land Trust, and the Sogorea Te′ indigenous women’s land trust.

The rest of the report is structured in two parts. First, research objectives, methods, and key findings are discussed, including block history and selection, project perceptions, neighborhood relationships, and community participation in the EcoBlock. Then, literature on household- and community-scale retrofits, eco-city governance, gentrification, and housing affordability is presented to further contextualize these findings.

Research Objectives

In the case of a novel and as-yet untested experiment such as the EcoBlock, it is important to approach social research from an exploratory standpoint that does not predetermine residents' understandings of the trade-offs, financial and otherwise, involved in potential participation. Accordingly, this research used in-depth interviews to develop a qualitative report driven by the insights and experiences of residents. This approach is less common but growing into greater use in social studies of energy and resources (Ambrose, Goodchild, and Flaherty 2017).

Still, this approach has several limitations. First, these findings speak more to this specific project than the social feasibility of EcoBlock-type projects in general. For example, a survey that recruited participants from a variety of different neighborhoods in Oakland may have yielded a broader sense of perspectives on EcoBlock implementation and explained factors that contribute to varying levels of acceptance. However, since the block was selected prior to this research, it was most appropriate to engage the residents who were already familiar with it.

Second, approaching residents to participate in research interviews could potentially complicate an outreach or community engagement process. Asking residents about their perceived benefits *and* concerns might invite uncertainty about participating. Still, given that project outreach was underway before this research approach was developed, interviews were an effective way to approach residents not as an advocate for the project, but to elicit their opinions about it.

This also allowed many of the nuances that might be less visible to a general community engagement process to emerge, particularly around motivations to participate – or not – in neighborhood meetings, and around issues such as gentrification, which did not surface in group conversations. Typically, interviews associated with project implementation might only be undertaken with those who have decided to participate, so this research includes perspectives from project supporters and skeptics alike.

Like other interview-based neighborhood studies, this inductive analysis does not attempt to *prove* that a percent of residents felt one way or another, or that certain demographic or attitudinal variables are positively or negatively correlated (Freeman 2006). Rather, it is primarily interpretive and descriptive, and aims to provide a sense of both the general project perceptions among those interviewed, as well as those of exceptionally strong support or opposition.

Methods

I conducted 24 resident interviews from June to November 2017, after the research protocol was developed and reviewed during the 2016–17 academic year. These interviews covered three topic areas: perceptions of the EcoBlock project plan, personal history and experiences in the neighborhood, and neighborhood relationships. After each interview concluded, I distributed a paper questionnaire that addressed energy, water, and transportation use habits, utility bills, and demographics, which respondents could fill out in person or return by mail. I typically sat with residents as they filled out household questionnaires, so I was available to help clarify questions and identify their appliance types/ages. When residents did not have time to complete questionnaires in person, I would leave a stamped, self-addressed envelope behind. These meetings lasted 1–2.5 hours, and respondents were given $50.00 for their participation. With permission, I audio-recorded interviews in all but two cases.

Recruitment took place through a combination of in-person introduction meetings (the Meet-and-Greets described in Chapter 11) and mailed letters. I hand-delivered postcards to every doorstep on the block to notify residents of two neighborhood meetings in early June 2016. At these meetings, the project manager introduced me to the residents. I explained my research project, its distinction from the planning effort, and my neutrality with respect to project outcomes. I followed these meetings with mailed interview recruitment letters, sent to every home address on the block (accessed from the Alameda County Parcel Assessor's office database). I sent a second round of identical letters in October 2017. At this time, I sent similar letters to absentee landlords via offsite addresses listed on the parcel assessor's database. I did not receive any replies to these interview requests.

Table 1 details response rates, and Table 2 provides detailed counts of residents (31) and households (23) by housing type (there are more residents than households, as some partnered heads of household elected to be interviewed together). Residents from 13 of the 26 properties on the block were interviewed. These properties included 7 single-family homes; units from 6 multifamily apartments, condos, and duplexes; and a parcel used as a garden. The majority of residents had spoken with the project manager as early as 2014; for just three interviewees, the letter they received about participating in an interview was the first time they had heard of the EcoBlock project.

Table 1: Response Rates

	Residents	Absentee Property Owners
Letters mailed	60	10
Responses received	27*	1
Response rate	43%	10%

	Households
Questionnaires delivered	22
Questionnaires returned	19
	86%

Table 2: Household and residents interviewed, by housing type

	Single-family home	Multifamily					
		Apartment	Condo	Duplex	In-Law	Other	Total
Households	7	5	4	3	3	1	23
Residents	10	6	6	4	4	2	32

I transcribed audio-recorded interviews in their entirety, some on my own, and some with the help of a transcription service. I used MaxQDA software to search and auto-code key terms, then reviewed auto-coded segments, weighting quotes by relevance. Before and after auto-coding I also reviewed transcripts individually and in their entirety, adding additional codes across themes.

Since just 32 residents were interviewed (of an estimated block census of 100+), descriptive details are shared in connection with resident perspectives and quotes only to the extent that they provide important context (distinguishing between an owner or renter, for example) and cannot be traced to a specific person.

In the following section, interview findings are presented across several core themes: environmental values and technologies, utility expenses, experimentation, community, existing relationships, governance, gentrification, and participation in project planning.

Findings

Block selection

While Berkeley was initially under consideration, project leadership eventually decided to seek out a block in Oakland because it would provide a population more "representative" of the general public and of aging "first ring suburb" housing stock in a "lower-to-middle income neighborhood." The other principal investigator discussed the importance of the EcoBlock project taking place in a community that would not otherwise have access to leading sustainability technologies, from "both a theoretical and policy perspective." The project manager described the merits of the block in terms of it being socio-demographically "representative" of a more "real-world" place.

Thus, representativeness was important in at least three ways. One, the population on the block was seen as being demographically representative of Oakland, and Oakland as representative of other cities in California. The project was also to be representative of potential EcoBlocks elsewhere. So how was this particular block chosen? What is its history, and how does it inform both life on the block and whether an EcoBlock project might be successful there?

Neighborhood history

The present-day Golden Gate neighborhood was home to the Ohlone people before they were dispossessed of their ancestral lands by the Spanish settlers. Peralta held land claims throughout the present-day East Bay until they too were annulled under the treaty of Guadalupe-Hidalgo at the end of the U.S.–Mexico war. Among the settlers that came to California from the mid- to late- 1800s, Charles Klinker was a well-known, ambitious developer and entrepreneur, building over 70 homes, a baseball field, a great hall (named for himself), and even attempting to rename the neighborhood "Klinkerville" (Phillips 2012).

The EcoBlock project was inspired by the heyday of the "streetcar suburb" in the Bay Area. As discussed in the Case Study (Chapter 10), the Key System was fundamental to the early twentieth century economic growth in the Bay Area, as it allowed then-suburban residents to easily reach downtown areas and the harbor for work in industry and shipping. But work opportunities all across the Bay Area, and in the Key System itself, were defined by segregationist hiring policies. The Alameda County NAACP and Shipyard Workers Committee against Discrimination successfully sued the Key System and the operator's union for discrimination in hiring and membership, although the Key System was very slow to implement any changes resulting from this ruling (Self 2003, 47).

Access to housing, and particularly home ownership, in Oakland was also racially segregated. By the mid 1930s, the Home Owners Loan Corporation (HOLC) "redlined" many parts of Oakland, including the neighborhood where the EcoBlock is located. These ratings were based on community demographics, and are widely understood to have exacerbated racial segregation and disinvestment in predominantly Black neighborhoods (Rothstein 2017). Redlining marked areas as "risky" to investors and home loan lenders, making it extremely difficult to access loans for home purchase or repairs. African-Americans were shut out of the Federal Housing Administration and Veterans Administration loan programs. They only supported new home purchasing, but nearly all postwar developments were restricted to whites.

The end of the war and decline of the industrial economy in urban centers across the United States was central to the postwar challenges cities, including Oakland, faced. Redevelopment programs were enacted during the post-World War II "white flight" climate, when central cities became increasingly devalued and lost their tax base (Chapple 2014). California's 1945 Community Redevelopment Act gave birth to the Oakland Redevelopment Agency (ORA), and over 400 others like it statewide (Blount, Ip, Nakano, and Ng 2014). In 1952, California was the first state to establish tax increment financing (TIF), which allowed redevelopment agencies to access much-needed upfront capital, backed by taxing the long-term property value increases reinvestment and redevelopment would yield (Lefcoe and Swenson 2014).

The ORA had the power of eminent domain—it could identify areas of the city as "blighted" and in need of redevelopment. Urban renewal programs across American cities "constituted a massive redistribution of property and people in the name of saving downtown (Self 2003, 149)." Patterns of investment and neighborhood revitalization remained racially unequal, as these programs dispossessed many African-Americans of their homes. In the face of the threat of displacement, African-Americans had to at once fight for their right to self-determine the future of their neighborhoods, and against the prevailing racist and paternalistic assumption that Black migration to northern cities from the south was the cause of urban decline (Self 2003, 144). Urban renewal financed the construction of several highways—such as Interstates 980 and 880—that cut through some of the most vibrant African-American neighborhoods in the city, and plunged them further into decline.

In 1964, Lyndon B. Johnson declared a "War on Poverty," and Oakland was among the few cities targeted by the federal Area Redevelopment Act (Rhomberg 2004). In 1960, Oakland's unemployment rate was at 8 percent, and in the flatlands it was as high as 13. The Oakland Interagency Project (OIP), a controversial pilot social services program funded by the Ford Foundation, was already active in the Castlemont neighborhood. Although it had little demonstrated success, OIP leadership was drawn into citywide anti-poverty planning efforts. The citizen's arm—the Oakland Economic Development Council (OEDC)—was placed in charge of policymaking, but those appointed to the council "reproduced the elite bias of the OIP, since none of the appointees actually lived in the target areas or met federal poverty guidelines (Rhomberg 2004, 138)." The Black leadership in the OEDC often disagreed strategically with the Target Area Advisory Committees (TAACS) formed by residents and local leadership in the target neighborhoods (North, East, and West Oakland). The OEDC favored technical assistance, information referral, and education, while TAACs wanted more direct services like legal aid, jobs, and childcare (Ibid.). Eventually, TAACs won more local control over the OEDC, but frustrations over ineffective social programs continued to build.

Chris Rhomberg argues that African-Americans sought three strategies for local development: bureaucratic assimilation (in the ORA), bureaucratic opposition (in the OEDC), and independent party organization, "embodied in the Black Panther Party for Self-Defense (Rhomberg 2004, 146)." In 1966, the Black Panther Party was formed by Bobby Seale and Huey Newton, two employees at the North Oakland Neighborhood Anti-Poverty Center, which had been established by the North Oakland TAAC. Two households interviewed mentioned the Black Panthers' history in the neighborhood.

Closer to the EcoBlock neighborhood, the former Klinker Hall become home to Your Black Muslim Bakery in the late 1960s. The bakery espoused values of African-American empowerment and economic independence, earning the support of Mayor Dellums and Representative Barbara Lee. The bakery also received a city advance on a $1.2 million federal redevelopment loan for a healthcare job training program. Over time, it became clear that the bakery was also host to a variety of criminal activities (Mowry 2012). Chauncey Bailey, editor of the Oakland Post, was killed in front of the bakery in 2006, while working on an exposé about the bakery and its leader, Yusuf Bey (MacFarquhar 2007). Residents living there at the time vividly recall the police raid on the bakery, and observed a marked shift in the neighborhood thereafter.

Today's Golden Gate neighborhood, by long-term residents' accounts, is dramatically different from the "rough" neighborhood they moved to in the late '70s and '80s. Even residents who had lived in the neighborhood for only the last six or seven years thought that the neighborhood continued to feel "safer" over time. More recent arrivals to the neighborhood cited its relative affordability and aesthetic appeal as the main drivers for relocating. For one, "if money were no object, I'd have bought in North Berkeley, but I like it here." Some had had personal experiences with break-ins or mugging on the block, but remained in the neighborhood because they liked their homes and found them relatively affordable and safe.

Gentrification – defined by Ruth Glass as the replacement of working class populations with higher income residents through the upgrading of the built environment – was a particularly salient theme in residents' discussion of the neighborhood (Glass 1964). Formal criteria[1] indicate that the census tract containing the project planning area is undergoing "advanced gentrification" (Zuk and Chapple 2017), and resident accounts reflected the associated material and social changes. An apartment building formerly occupied exclusively by Section 8 housing voucher recipients was slowly re-tenanted by the new owner. A former factory was converted to apartments that were later sold as condos, and several residents also noted a spike in short-term rental (AirBnB) conversions. Real estate agents also rebranded the Golden Gate as "NOBE" (North Oakland-Berkeley-Emeryville, drawing the ire of locals who resented the new attention, investment, and change (Winstead 2014). In late 2017, Movement Generation, a local social and environmental justice advocacy group, released a mini-series political comedy, "The North Pole," which addresses the threat of gentrification and displacement in North Oakland (2013).

Many residents thought the gentrification of the immediate area was linked to the arrival of a nearby spiritual community. After its establishment in the early 1970s, the spiritual community's nonprofit organization, and many people affiliated with the spiritual community, purchased several properties in the neighborhood. This community attracted many relatively affluent residents who otherwise would not have chosen to live there:

> *When the [spiritual community] came in, white people started moving into this area to be part of the community. And there was a lot of hostility towards us because we were white and this is traditionally a black neighborhood, older black neighborhood. And the church down the street… has lost a lot of their black population also due to gentrification. So the whole gentrification piece is certainly part of what's going on and I benefit from it and I lose from it both.*

Residents expressed a wide range of personal perspectives on gentrification, often describing it in terms of its both positive and negative features. Positive features included feeling safer in the neighborhood, having more access to cafés and shops, seeing more families and dogs, and seeing the quality of building maintenance improve. Negative features included loss of the

[1] The Urban Displacement Project compares census-tract scale data to regional medians over time to identify areas at risk of or undergoing gentrification or exclusion. Indicators include: household income, education level, percent renters, and percent nonwhite residents. Also see Figure 4 on p. 19.

neighborhood culture, older residents, and older neighborhood businesses, along with rising rents and cost of living.

The project manager was introduced to the block through a connection to this spiritual community. Just under half of the residents interviewed participated in activities there regularly, and knew other members well. Many had bought property in the neighborhood shortly after the spiritual community was established in the early 1970s. Others had been renting on the block for a decade or more. They cited the spiritual community as the main, or even the only, reason why they moved to the neighborhood.

Neighborhood relationships

Most residents reported knowing their neighbors on either side, across the street, or those with whom they shared a building. Others did not have as deep or sustained relationships, but they were still broadly cordial and "neighborly." Informal social connections typically included neighbors on the opposite side of the street, rather than across the back side of the property line, so some were surprised that the "block" design of the project did not reflect this.

Most residents asked neighbors for small favors, or to look after their home while they were away, and would feel comfortable calling on them in an emergency. However, almost all residents' core social, emotional, and financial support networks were in their friendships and family connections outside of the neighborhood. As expected, those who had moved to the neighborhood more recently and worked demanding jobs knew the fewest, with one confessing to "not knowing everyone in my building."

The spiritual community was a focal point for about half of the residents interviewed. Residents with a shared spiritual practice had more familiarity with one another than with others on the block, and one apartment building was occupied entirely by members. One resident discussed the political influence the spiritual community had in the neighborhood, recalling that they had mobilized to block the installation of a cell tower nearby because of concerns over electromagnetic fields (EMFs), that they had been able to increase police responsiveness to calls from the neighborhood, and that they had pushed for enforcement of a fireworks ban.

Dog owners were comparatively familiar with the other dog owners on the block. Helping with pet care was one of the ways residents who had few other supportive social bonds contributed to community life. However, dog waste was seen as a marker of potential disrespect. One resident recalled feeling especially guilty when she realized she had forgotten bags and her dog relieved itself in front of an older African-American neighbor's house. She described going back, making sure that she cleaned everything up, along with other waste that had been left behind. She described feeling frustrated that neighbors might be skeptical over whether she was a responsible dog owner.

Parking is another subtle but common way that tensions between residents emerged. It has become increasingly scarce in the neighborhood, with additional infill housing development, and more nearby business traffic. Several residents discussed norms that had developed over parking. Although parking on public streets is open, many residents see the space directly in front of their house as their own. Failure to recognize and adhere to such norms, irrespective of awareness or intent, can be felt as tacit disrespect for the history and culture of the neighborhood.

Some residents expected the EcoBlock retrofit to attract attention to the neighborhood. One saw the prospect of media attention in a positive light. Others worried about increased traffic, exacerbated parking issues, or even heightened crime if the quality of the neighborhood increased dramatically relative to neighboring blocks. Similarly, a few cited some measure of concern over adjacent blocks becoming jealous; or disappointment that their neighbors across the street would not be included.

The electric car charging infrastructure drew concern from residents insofar as it could further reduce parking availability and draw in more outsiders—and, in the broader context of parking issues, dramatically change established norms around parking. Residents asked who would have access to charging stations—if it would be restricted to block residents, or open to others from the surrounding neighborhood.

Gentrification and residents' sense of belonging occasionally came up in the context of discussing relationships. Quastel (2013) writes that "gentrifiers face systematic moral predicaments as the roles they perform in competitive housing markets undermine their values." While newcomers might value diversity and equity, as a population that can afford higher rents and housing prices, gentrifiers can potentially displace or exclude economically vulnerable and socially marginalized groups. Some recent arrivals to the neighborhood had internalized a sense of its history and their place in it, highlighting the importance of respect:

> *100 years ago [the neighborhood] was Portuguese, Italians that worked in the harbor. Then there were African Americans. This belonged to an African American family. Unfortunately, this is a typical story that happened to them. I think that the household or family passed away. The – his son was trying to renew the house to sell it, but he defaulted on his payments. Someone else bought the house and fixed it up and sold it to us. And this is – it's important to know this. And I'm very respectful of what has happened here before me. And I feel very lucky to be here, to live in this – what I believe is a nice place.*

This resident went on to discuss how participating in the project would be a way of "doing something for society by even paying a little bit more." In this light, participating in the EcoBlock, as a research demonstration and community-building project, was an important way this resident might be able to give back or show respect for the community. Another resident made concerted efforts to get to know his neighbors better so that he, as someone "part of the gentrification" would not have a negative or exclusionary presence.

On the other hand, another newer arrival to the neighborhood was wary of speaking up at EcoBlock meetings because of the way they thought they were seen by others:

> *I'm pretty used to being written off pretty quickly too, so I'm pretty intentional about when I choose to say something in a larger crowd of people I don't know, you know? So like it'd be really easy for any one of those people to be just like, "you're new, you don't own property, you don't get it, you know, and look at you, also." …That's another reason why I didn't say anything. I don't know if it's really my place, I fully acknowledge those sentiments, I don't*

know, but I feel like we try to be thoughtful about the impact that we have on our surroundings.

Another remarked that almost all the neighbors they saw at the meetings "ha[ve] been white and for the most part older except for us," and that "it does sort of scare me the diversity of this block might get lost." The majority of interviewees were white or Asian-American, although resident accounts indicated that there were at least two other African-American-headed households on the block who did not participate in interviews (for a comparison of interview participant and census block demographics, see the figures on the following page).

On the other hand, a long-term owner had witnessed the loss of African-American households in the neighborhood, but didn't see this in a negative light, since "they sold the properties for big bucks and have been very happy." These accounts echo the complex debates over the multiple impacts of gentrification, drawing attention to questions of who has a "right to the city," particularly as local amenities and quality of life improve (Lees, Slater, and Wyly 2008).

Race was rarely discussed explicitly, but formed an important subtext to how the project was received in the neighborhood. One resident was bothered by a "neighborhood watch" email list that seemed to disproportionately scrutinize their African-American neighbors. Many residents thought they would not join the project: "I don't really think they would be interested—they're just trying to get by." Another resident, who expressed pointed fears about resource scarcity in a shared system, wanted to exclude this household entirely, saying that "we couldn't have them on the grid."

As the topic of this household continued to arise, one resident summed up the range of speculation, and this home's status as an "outlier" in the changing neighborhood:

Some of the conversations have been really negative about them at times from some people…You think they're stealing cars, but oh, no, I know. You haven't seen it. Maybe they're really running a business out there, those aren't stolen cars, but people are paying them to work on them. That sort of difference of – so what I'm saying is with any community, there are differences of opinions and viewpoints.

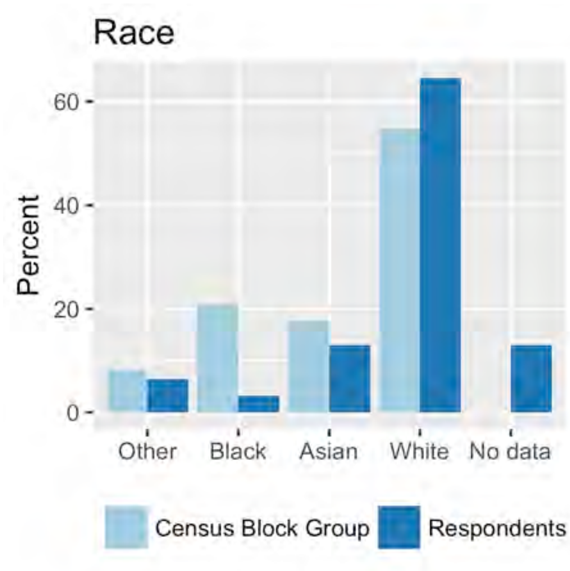
If this household or others didn't participate in the EcoBlock, the project could risk transforming social distance into overt segregation, and even introduce a sense of political and cultural displacement and community loss. As Derek Hyra writes, "maintaining political equity and power balances between longstanding and new residents in transitioning neighborhoods might be important to ensuring that long-term residents benefit and thrive as their neighborhood revitalizes around them (Hyra 2015, 15–16)."

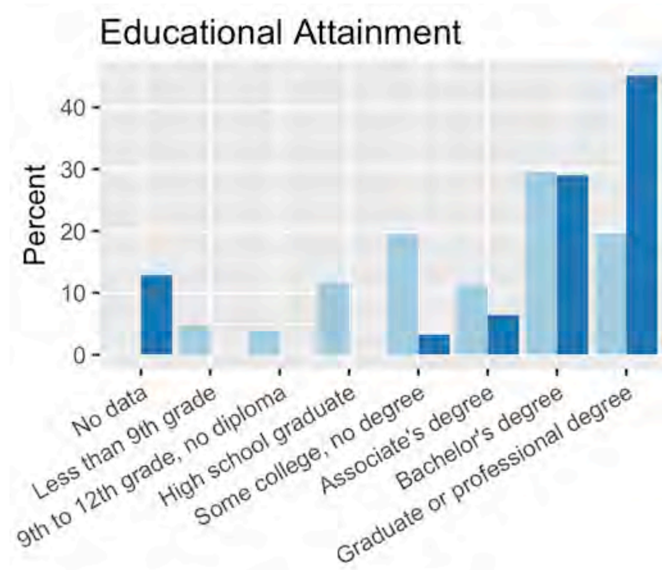
One resident called the EcoBlock a "white man's project," since there weren't any "Black people behind the scenes." While the block was selected for its diversity and "representativeness" of a more "real-world" neighborhood, this account suggests that racial diversity and representation on the project team also influenced how it was received in the neighborhood.

Figures

Figures 1-3: Census block and respondent demographics

Source: Questionnaires and American Community Survey, 2016.





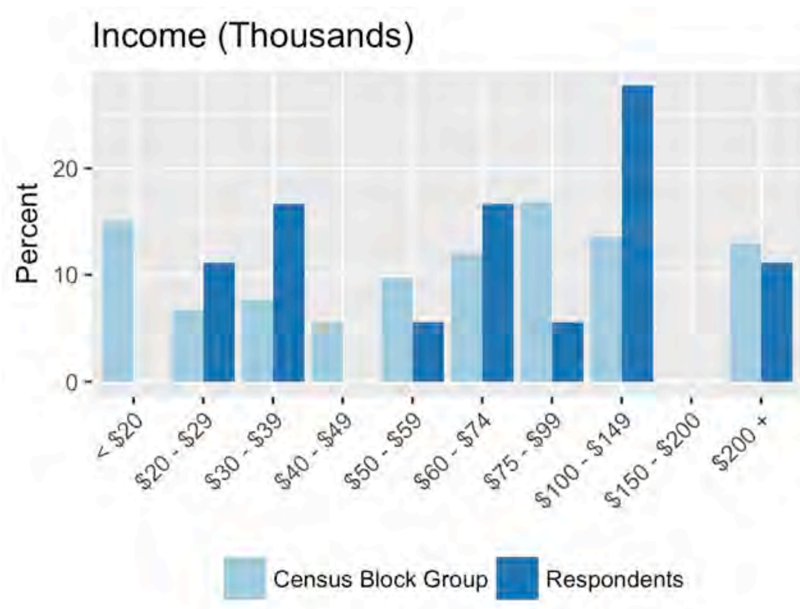


Figure 4: *Urban Displacement Project Census Tract Typology. EcoBlock area outlined in black.*

Source: www.urbandisplacement.org, 2017.

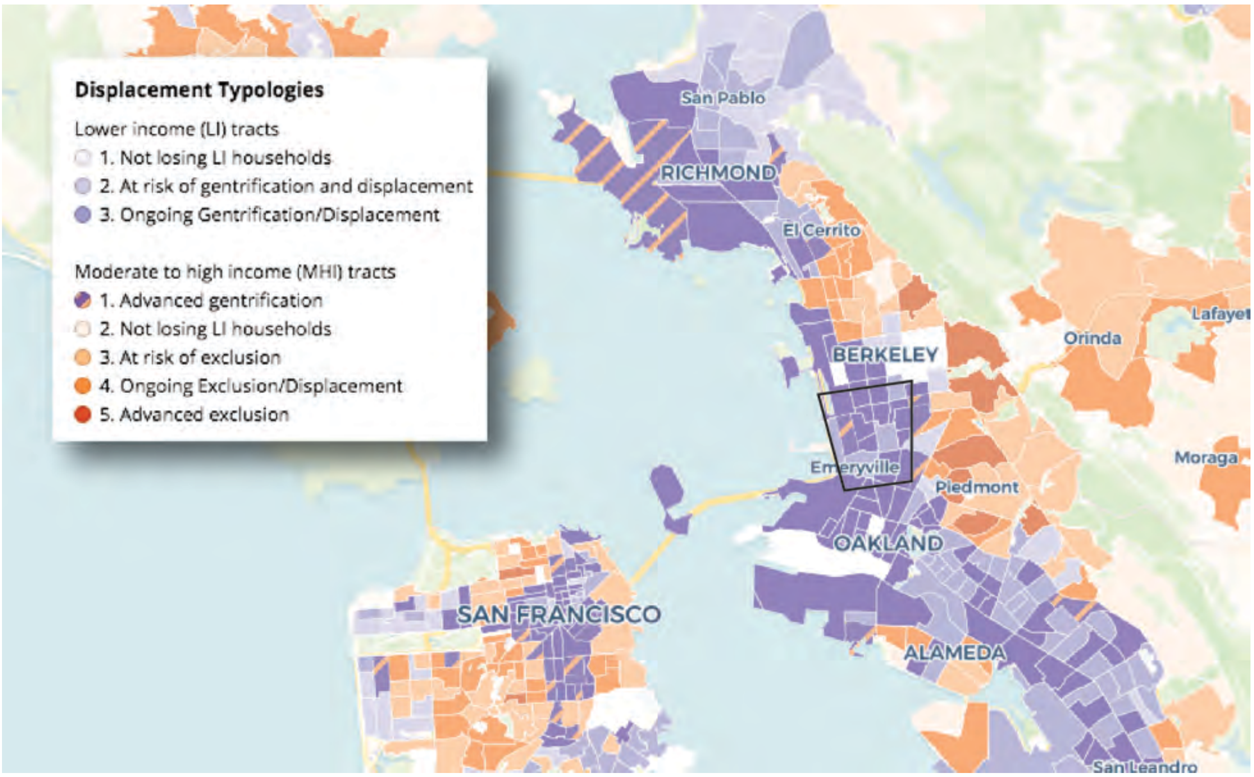


Figure 5: Property Values (US Dollars).

Source: [Alameda County Parcel Assessor's Database, 2016](#).

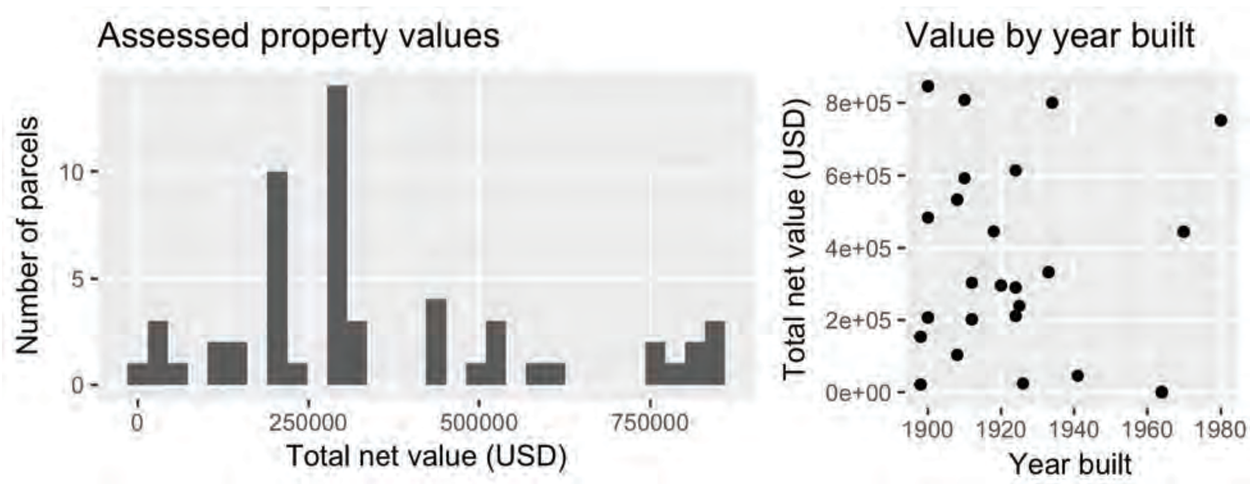
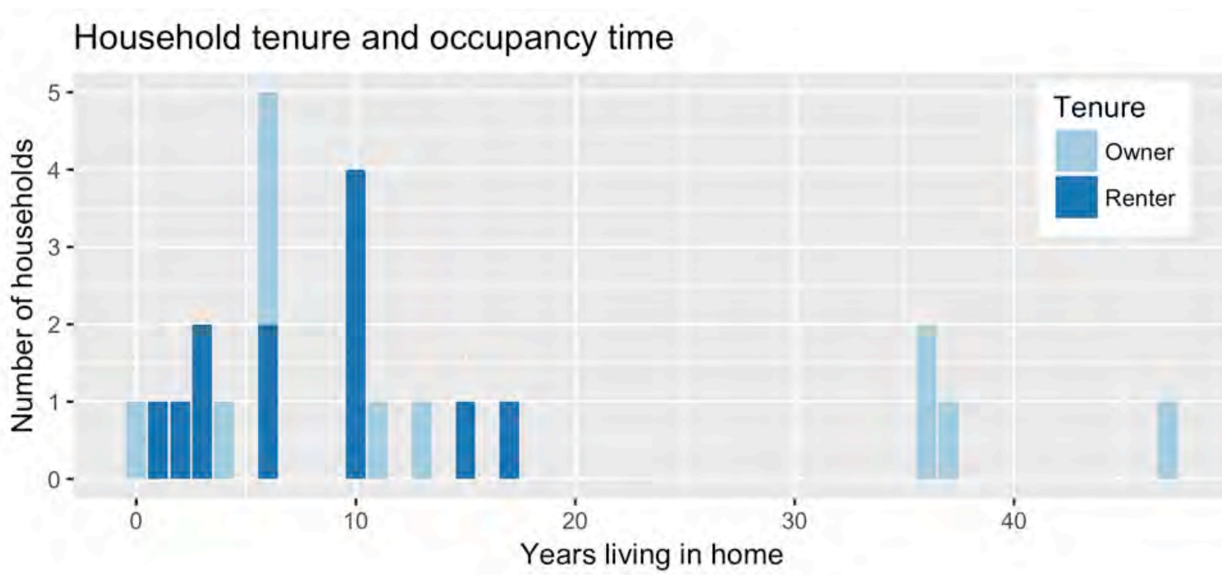


Figure 6: Years in home by Owner (11) and Renter (12) status.



Project perceptions

When asked about their initial impressions of the project, most residents thought that the idea was good and exciting, and were personally very interested in learning more and participating. The project was especially compelling because it promised to, at little cost to residents, improve the quality, efficiency, and value of their home. It could also address some longstanding neighborhood-level maintenance issues over which even homeowners had little to no control.

For those who wanted to see improvements to street and sidewalk condition, the EcoBlock could mean a better-maintained neighborhood. Residents also discussed environmental benefits in terms of comfort, livability, and aesthetics. Some did see potential environmental benefits and other priorities at odds; for example, in having a strong aesthetic preference for older, but less energy-efficient windows.

In general, interviewees were highly educated relative to the population of the surrounding census tract (see Figure 2), and the research merits of the project were most strongly voiced by those with an academic background in environmental science, research, planning, law, and related disciplines. Some even directly cited the merits of "testing the case" of an environmentally sustainable urban city block, and were eager to participate in the project for its potential research benefits.

Water

Although more residents reported being worried about wasting water than energy, fewer reported that their water bill influenced their consumption. Water costs are aggregated at the property or building-level, and paid for by property owners or drawn from homeowner's association dues, so residents may be less individually sensitive to price fluctuations. A few residents attested to their water-saving behaviors, such as saving warm-up water from showers for toilet flushing or garden use. Eight residents brought up the recent drought. They discussed losing plants from their garden, exchanging plants for more drought-resistant varieties, and facing fluctuating water bills.

Water-related issues also presented more day-to-day concerns than energy or transportation. One of the large buildings had been dealing with a persistently leaking roof after multiple repair attempts. Two residents had experienced indoor sewage backups during winter storms. The street and sidewalk condition was a point of frequent conversation. Large city tree roots led to cracks in the sidewalk. In Oakland residents are responsible for repairs to their own sidewalks, unless the damage is caused by a City tree.

Some residents were firmly opposed to potential black water reclamation and treatment for physical and spiritual health reasons. They worried that medications and other insoluble wastes would make their way into any food grown onsite, and that the water would no longer be "alive."

Energy

Eighteen of nineteen households reported using gas for cooking, and six had replaced their range and oven since living in their home. Three households expressed a strong sense of attachment to gas cooking. One discussed their vintage stove being a major selling point for their home, another discussed having gone to great lengths to find an affordable restaurant-grade gas stove for home cooking, and one resident was firmly opposed to the project altogether if it would mean losing access to gas cooking. Others did not directly discuss loss of gas cooking as a project drawback, or saw it as a fair trade-off to make in exchange for new appliances and energy savings.

Two households had home solar with net energy metering. Two households were on CARE (California Alternative Rates for Energy). Two had enrolled in PG&E's Solar Choice program, and four were on time-of-use rates. Six of nineteen homes reported having ENERGYSTAR-rated refrigerators, three did not, and ten were unsure.

Four households reported having central forced-air heating, and one had radiant floor heating. Alternative heating sources included gas wall units, space heaters, or a combination of the two. One resident reported using their gas oven as an additional heating source. Eleven households reported issues with indoor thermal comfort (all were heated by gas wall units, space heaters, or had no heating), and more tenants than owners reported dissatisfaction with thermal comfort.

One resident, a long-term homeowner, reported having experienced utility disconnection due to bill nonpayment, or having had to give up some other necessity (such as food or medicine) to pay utility bills. The same resident also expressed serious concern over being "forced" by a communal governance structure. If, for example, the neighborhood voted for more expensive upgrades, they did not want to be outnumbered, and unable to afford the changes. This resident, whom the project had anticipated benefitting most, was among the most apprehensive and concerned.

Cost of living

Those who had owned their homes for decades or more had seen their values appreciate significantly—for some, by over an order of magnitude. Some more recent homebuyers who paid higher premiums for their housing could still only just met their basic living expenses, and worried that the high taxes they paid weren't reflected in the quality of local schools.

For tenants who had had negative experiences with landlords over property maintenance, the EcoBlock project could mean better quality housing. Yet housing affordability was central to many residents' decisions to move to and stay in the neighborhood, so some tenants were concerned that their landlord might try to justify a rent increase after upgrades were complete. The implications of the EcoBlock project development on rents is discussed in more detail in a later section (on housing equity and financing the EcoBlock project).

Permitting and code compliance

The installation process, and that of the project approvals in general, also raised concern among tenants who had challenging relationships with their landlords or property managers. At least one resident expressed uncertainty over their property's code compliance. For example, one was skeptical that their landlord had actually gained proper approvals before subdividing a unit to rent to an additional tenant.

Another resident recalled a neighbor's complaint leading to a number of homeowners needing to personally pay for sidewalk repairs. Subjecting the block's properties to close scrutiny could thus present legal, financial, and interpersonal challenges. While remote video inspections (as discussed in Chapter 7) might be a feasible work-around, property owners and residents would likely want assurances that they would not be at risk for costly mandated repairs should aspects of their homes be found out of code-compliance.

Personal values and the EcoBlock project

Steg et al. summarize four types of values that are relevant for individual's evaluations of sustainable energy use: hedonic values, or pleasure and comfort; egoistic values, or personal gain financially or in terms of status; altruistic values, or a focus on the well-being of others and society; and biospheric values, or a focus on the consequences for the environment (Steg, Perlaviciute, and van der Werff 2015).

While these values emerged in the context of resident interviews, they did not influence residents' perceptions of the project in uniform ways. For example, some residents' "biospheric values" led them to appreciate the project's innovative potential; others with strong environmental convictions were concerned that the block's potential impact would be dwarfed by larger-scale measures. Hedonic values could underlie both the excitement of participating in a sustainable neighborhood project, and resistance to giving up certain amenities like gas cooking.

Egoistic values, expressed through discussions of the potential for personal gain, were also complex and connected to perceptions of personal risk. While being a tenant could mean having "voyeuristic" attitude to the project—not much to gain or lose but the pleasure of observing things unfold and enjoying the material benefits for a short time—it could also provoke questions about whether one would be able to stay in the neighborhood, and if they might be at risk if project were implemented. Homeowners with steady and high incomes were not as deeply concerned with the uncertainties and risks that the project implied; homeowners with lower incomes, and arguably more to gain, were less eager to shoulder the risks inherent to significant changes to their homes.

Altruistic concern for others could mean taking a leadership role in seeing the project realized in the neighborhood—or it could mean distancing oneself from being a vocal supporter of the project out of respect for neighbors whose opinions differ. Altruism might also be more readily attributed to the everyday social and material support that neighbors can provide, rather than the collective benefits of resource sharing as an EcoBlock.

Steg et al. further find that personal values influence the “acceptability” of an energy system or policy change. If the changes positively affect conditions related to their important values, they will be more acceptable. Trust in the parties involved in an energy system or policy change is even more influential. Trust is based on perceived competence and integrity, and it can affect evaluations and perceptions, especially when people have little personal knowledge of the proposed changes (Steg et Al. 2015).

For the EcoBlock project, trusting relationships are important across at least two dimensions: among residents, and between residents and project planning members. This research did not systematically measure residents’ individual trust of one another, or of the project as a whole. However, trust did emerge as a theme in discussions of community participation in the project (trust among residents), and participation in planning activities (trust between residents and project planning members). The following section discusses key findings from discussions with residents about whether and how they and their neighbors would participate in both the planning processes and the ultimate project.

Community participation

Alongside their personal interest or disinterest in participating, many residents speculated on whether others on the block would participate, revealing personal theories about the EcoBlock’s social feasibility in the neighborhood (and often in American society at large). Residents’ collective understandings of the social feasibility of the project in their neighborhood, alongside the previous section’s findings about relationships and personal histories in the neighborhood, provide a more complete description of the project’s reception and potential future.

To structure and compare residents’ ways of seeing the project, I use Bardhan and Ray’s (2006) typology of methods for studying common pool resources. They outline three core dichotomies in researchers’ understandings: the individual as autonomous versus embedded, a focus on process versus outcomes, and the pursuit of parsimony versus complexity. In practice, community resource management rarely falls at one end of each dichotomy. Treated as continuums, they provide a useful framework for parsing the variety of perspectives on the nature of community resource management. Although residents’ observations do not derive from formal research, this framework is still useful for explicating the variety of perspectives residents held about the potential for the neighborhood to successfully manage shared electricity and water systems.

Autonomy and embeddedness

The dichotomy of autonomy and embeddedness could be phrased in terms of the question: At the neighborhood level, will project participation be driven by private costs/benefits or the strengths of social relationships? Midway between the two might be social acceptance or compatibility of the project with existing norms and values in the neighborhood.

Some residents saw themselves and their neighbors as autonomous and independent decision-makers—that is, they would each undertake a private cost-benefit analysis to decide whether they would participate:

We will need to see all of the amount and why it is the way it is and I think it's, like I say, transparency, you know? … It's to do your due diligence and sit down and read it and analyze and if you have questions, ask you guys and no problem. I'm sure there's gonna be meetings and stuff but that's what I will need. I'll need the data to see what's the energy, what are we getting, what are we getting on a sunny day, how much energy do we get, how are we disseminating it, like, you know, all of that stuff. It's very important to me.

The project's goal was to reduce utility expenses, or on balance, have them remain the same. During early project outreach in 2014 and 2015, residents were informed that any retrofits would come free of charge. Residents' skepticism concerning this claim registered in their thinking about the project. What might be the non-economic costs—such as construction noise and disruption to their ability to work at home in the daytime?

Residents were asked about their willingness to pay more for their utilities to participate in an EcoBlock project. Most residents were not open to paying more than they currently do for utilities. About half were willing to pay relatively more for utilities "up to a point," the highest amount more being "20 to 30 percent." Notably, this resident discussed the premium he would be willing to pay as a way of "giving back to society." Even those who presented their thinking as driven by short- and long-term costs and benefits acknowledged some of the social dimensions of the project. However, the social dimensions were seen as an ancillary benefit, or yielding in a "snowball" effect in terms of adoption: "If you get 50 percent to sign on you'll get at least 70 percent." In this sense, social dynamics might further *enable* the project but inducing more individuals to think about participating, or be *benefitted by* the project in the broadest terms.

Many residents saw the EcoBlock as potentially helping the block "come together as a community." In simply giving people "a reason to talk," the EcoBlock could unite residents in a rapidly changing neighborhood, bridging supportive connections across socioeconomic differences. For some, the EcoBlock project was compelling because a stronger community itself was desired: for this reason, one resident even called the project the "sexiest thing ever."

Desire for a more community-minded neighborhood was tempered by wariness about loss of privacy, loss of physical and even emotional boundaries with neighbors, and exposure to invasion from strangers. The proverb "good fences make good neighbors" was used several times in interviews.[2] Many residents pointed out that American cultural values of individuality and private property were at odds with some of the project's communal aspirations.

It's weird to think that like just because we live in the same neighborhood that we would share anything in common. Or get along or want to do something so massive that could be time consuming, that could be expensive, that could take time and energy. But then I read in the newspaper in other countries they're doing amazing projects and doing amazing research and how we can change the world and make it better. In my mind it doesn't encompass America at all, right? I mean the fact that we could do that—that's really

[2] The phrase gained popularity after Robert Frost's 1914 poem, "Mending Wall," in which two neighbors engage in a ritual yearly maintenance of the wall that divides their properties. The poem does not clearly endorse the sentiment that "good fences make good neighbors" but rather contrasts it with the narrator's private skepticism and frustration over maintaining the wall.

cool…that's super inspirational... It's just weird to think about it happening on a neighborhood scale.

Thus, even among those who interpreted the feasibility of the project in terms of embeddedness, a tension arose between a desire to build a supportive community, and an uncertainty over whether it would be possible. If the project were realized, would it strengthen social ties? Or would it threaten otherwise "neighborly" relationships by introducing collective material and financial responsibilities?

More residents thought of themselves and their neighbors as primarily "embedded," that is, they saw good relationships as a prerequisite for the project. As one resident put it, "before you even worry about what sort of utopia you're trying to build it's just important to get everybody to know each other." Residents felt that the focus group meetings were just a starting point, and that the block would need to come together to discuss the project, even, or especially, without any people from the planning team present, to better understand their neighbor's impressions. Several people who were personally enthusiastic about the project were wary about pushing their views on others.

Parsimony and Complexity: Law or legwork?

Rather than thinking about parsimony and complexity in terms of explanatory arguments, I interpret these concepts in terms of how the project might be operationalized. Are strong and ongoing social connections and a set of "shared values" necessary and/or sufficient for realizing a successful project? Or could the right legal structures, deed restrictions, and monitoring and control technologies ensure that the EcoBlock would function well, and account for the full range of concerns regardless of differing values, perspectives, and relationships?

When asked to provide their thoughts about potential maintenance and governance arrangements, some residents were unable to comment, or hadn't given the questions much prior thought. Others commented extensively on potential challenges, citing disenchanting experiences in homeowners' association politics, community garden management, and with inefficiencies or suspected corruption in local neighborhood associations. Still others remained optimistic that the project could bring the neighborhood together.

In terms of new utility arrangements (such as shared electricity metering and non-potable greywater use), "parsimonious" arrangements were very plausible and generally trusted by residents. Most felt comfortable with a shared utility metering system, as long as there were assurances that all residents would continue to pay their fair share, and that no bad actors would manipulate the system. Real-time feedback works well in such a system, incentivizing and reinforcing positive behavior.

One resident saw the question of community buy-in as not altogether complicated, since it would presumably be voluntary at the outset:

You need buy in in the first place that's completely voluntary, and then after that it's a condition upon moving in. So anybody who moves in there has to know about it and be voluntary…it becomes self-selecting. Once the area is established, then anybody who comes into that has the option to go elsewhere. They have the option. You're not displacing anyone and you are self-selecting the people who would move into it.

To date, two property owners and one tenant have expressed clear opposition to the project. This means that realizing the project in this block would require winning over these residents or redrawing the boundaries of the block's shared systems to exclude them. Although the Community Facilities District (CFD) was identified as the best financing mechanism because it allows for interest-free investment and access to larger bonds, the success of this legal form is indeed underpinned by managing the complexity of local social relationships, and property owners' financial priorities.

CFDs, also known as Mello-Roos districts, tend to work well when the properties within them are relatively homogeneous and stable. In the EcoBlock planning area, property values and taxes are highly varied. (see Figure 5).

Residence times (see Figure 6) for those interviewed (still only about half of the households on the block) suggest that the neighborhood has seen significant turnover in the last 20 years. More homogeneous areas—more uniformly low-income or affluent—might have an easier time crafting agreements that meet the needs of all parties, so gentrifying neighborhoods might be relatively less suitable candidates for EcoBlock development.

Proper legal models could provide the necessary assurances to meeting resident needs, but *establishing* these models in the first place could prove quite challenging, and require residents to give of their time and effort, as well as communicating and negotiating over individual and collective needs.

Twice, other residents' opposition to the project was discussed in terms of NIMBYism. They were frustrated that neighbors who didn't want to expend extra effort to be the first participants in the project would effectively sabotage a good idea that the majority of the rest of the block would be in favor of. On the other hand, one resident expressed concern over "the lengths people will go to get other people to participate." If a majority of residents wanted to participate, would they attempt to socially or financially convince remaining holdouts on the block to join in?

In this matrix of economic and social relationships, tenants occupy a particularly complex position. Although they would benefit from any additional comfort or utility savings the project yielded, they would not own any of the new assets nor be responsible for financing upgrades. However, if their landlord finances the upgrades through property tax increases, they could pass on additional costs to their tenants through rent increases.

Tenants do retain some protections under Oakland Rent control law, which only permits "just cause" evictions. These laws compensate for the fundamental power asymmetry between tenants and landlords. The CFD legal model thus introduces a potential inversion of typical landlord-tenant power relations, since tenants, as equal voting members on the block, could vote for property tax assessments that their landlord might be opposed to. But tenant's perceptions of the projects' benefits could be contingent on any agreement they established with their landlord. It is unclear whether this agreement would be developed independently for each rental property, or a standard agreement would be in place for all participating EcoBlock residences.

Process versus Outcomes: Resident perspectives on participation

Since interviews occurred in parallel with outreach efforts, residents' perceptions of the planning processes were also discussed. Block residents were approached about the project as early as spring 2014. The project manager led these informal outreach efforts, starting with people who were connected to the spiritual community, and then branching out: "I was a little bit fearless. I just walked up, knocked on doors, and got to know more and more people." The project manager held several living-room and backyard meetings with residents throughout 2015.

However, residents expressed conflicting understandings of whether the block was indeed the only contender for becoming an EcoBlock. Some were thrilled that they had been so lucky to be selected. Others weren't "getting [their] hopes up" because they thought multiple blocks were under consideration, and were surprised upon learning that theirs was the only block that was being planned during Phase 1. For others, the apparently arbitrary way the block had been chosen was itself a cause of skepticism.

Because a Phase 2 project was not guaranteed, residents could not be assured that their time and energy spent participating in focus groups and the design charrette would yield any concrete outcomes. Although areas of primary concern from the resident perspective were long-term costs and maintenance responsibilities, these were not a focus of Phase I legal and financial analyses, which focused on EcoBlocks' broader scaling potential. As one resident put it: "It's hard to get people to commit to volunteer service. Especially when the goal is not defined enough. So I think this was a catch-22 with this project."

Still, the notion that the project might improve relationships among neighbors rang true even in the context of planning. For some residents, the EcoBlock outreach meetings were the first time they had met or spoken with some of their neighbors. One remarked, "my favorite part of all of this is recognizing my neighbors when I walk down the street."

Community associations

Local leaders from the Golden Gate and Santa Fe Neighborhood associations were initially engaged in the project, and contributed some of their extensive knowledge of the neighborhood. But since they did not live in the EcoBlock area or know the residents there, the associations were not a necessarily a meaningful representative body for residents in the selected block area. Some residents had attended a Golden Gate Neighborhood Association meeting or two, but none were currently actively involved in the Association's activities.

One resident was fairly active in the neighborhood as the "community liaison" for the spiritual community. Other community affiliations included the startup community, local activism, and healing work. For some residents, the EcoBlock meetings felt like yet another commitment, when they were already "trying to save the world in other ways."

Lack of time and hesitancy

Some residents expressed desire to have attended EcoBlock meetings, but ultimately got too busy or forgot that they were occurring. For those who did attend, they felt that the meetings were a positive first step, but that many more conversations would be required to deliberate over exactly how the project would be implemented. One resident even suggested that the block have meetings on their own to “understand how everyone feels” about the project. Others expressed having grown somewhat frustrated or skeptical about the project over time; one remarking that “people’s enthusiasm has been diminished by the slow pace of the progress.” Others remained optimistic and interested, happy to participate in meetings when time allowed, but taking a “wait-and-see” approach to whether they would personally sign on.

Alongside enthusiasm about being in a more community-minded neighborhood, residents still felt some reluctance about discussing the project with their neighbors. Some saw it as “invasive” to bring it up with a neighbor who might not share their perspective. Perceived social difference was a source of apprehension for sharing personal viewpoints or attempting to rally support for the project: “We are coming from different sociodemographic backgrounds, everything.” As one resident put it: “We don’t really know how we all get along yet.” One resident commented on their neighbors even being unfit to participate: “they are just not educated enough; they haven’t thought about these things. I would worry about stealing.”

Mistrust and opposition

Sharing utility data via Utility API, a third-party service for accessing consumption data, was sensitive for residents with privacy concerns. It was collected for planning purposes by the technical and outreach teams to estimate the sizing and needs of the block’s utility systems. In one instance, a resident declined to share their utility bill data because they had grown skeptical of the project. Because this data was used for planning purposes, providing it could amount to tacit endorsement of the project. Project leadership decided to offer cash payments of $20.00 for residents who provided this data. This exchange was not reviewed by the Institutional Review Board.

One of the strongest opponents of the project also had extensive experience in environmental education and planning, as well as building retrofits and construction. An early supporter, he first voiced his opposition to the project in 2015, before formal planning efforts were undertaken. This resident’s opposition was based primarily on how the community was being engaged, and what he saw as an unrealistic approach to managing the expenses of permitting and construction, and the demands of ongoing maintenance. He was firmly uncomfortable with being a “guinea pig” for the project.

Participation thresholds

Some saw the question of gaining an adequate level of participation as a matter of education, in terms of providing information about the project and its benefits. Many were very interested in and supportive of the project efforts, even without upfront details about potential changes to utility costs, property taxes, and construction/modification timelines. Especially for those with little free time, they expressed more interest in seeing a clear plan and explanation of the trade-offs than the prospect of being continuously engaged in planning:

> *I don't mind discussing this with whoever is, like, designing the models and just have a conversation with a person in other words where he exposes or she exposes you know "This is where we are, this is what we think is how it's gonna work and these are kind of the benefits, possible downsides and this is how you're going to implement and try to reduce the downside of all this." I mean that, I can participate in that but in terms of participating before and in terms of the planification and I don't have time.*

On the other hand, some residents found community participation to be lacking, and wanted to know how they could personally get more involved:

> *We'd like to keep this project alive, we'd like to keep this thing warm, and not knowing exactly where it's going to go. And by doing that, we're suggesting that a better sort of closer collaboration actually should happen.*

Others felt the project lacked "transparency" and that focus groups did not provide firm enough answers about costs, changes, and governance structures; they needed more information to decide how they felt about the project.

Alternative approaches to participation and engagement

Residents also suggested several means of engaging with one another around the project, including a neighborhood email list, newsletter, and personalized postcards. Some also expressed personal interest in taking on a leadership role in mediating between the research and planning team and the neighborhood. Subject-matter expertise could be helpful to realizing the project, because those more familiar with the proposed technologies could act as intermediaries between the planning team and neighborhood. Some even saw the work of participation in planning, and establishing and engaging in governance systems for ongoing maintenance, as itself a worthy form of public service.

Residents' relevant professional experience and skills could make them key collaborators in EcoBlock design and development processes. If they are substantively included in project planning and are fairly compensated for their time and effort, this form of engagement could bring great returns in terms of building active relationships with core residents who could also help with communication between other residents and the research team. For example, one resident suggested that the team could provide "trainings" for residents interested in introducing their neighbors to the project.

Residents and project team members alike recognized the social and political limitations of engaging a community that is not already self-organized (Taylor Aiken et al. 2017). The project faced several open questions implicit to, but not directly addressed by, the formal scope of work: How could residents be productively engaged in planning processes without leading to "meeting fatigue"? How would incompatible resident preferences over shared elements of the project be incorporated in the project plan? How important is ongoing engagement in project planning to acceptance of the final product? The following section turns to discuss some project team member perspectives on resident participation in the project.

Project team perspectives on community participation

Many EcoBlock team members found that the "community process for this phase of the Oakland EcoBlock project should have taken place earlier and that it should have been more robust (Chapter 10, 310)." Chapter 11 discusses the challenges of engaging residents in the feasibility study, and the low level of "community engagement" throughout. For example, the planning team members outnumbered residents in attendance at the design charrette, which was intended to be a culminating "all-hands" planning exercise following the focus group activities.

This section draws on additional interviews conducted with members of the project team, focused specifically on detailing their expectations and experiences of community engagement processes throughout the project. Taken alongside resident accounts, this provides a more complete account of how outreach processes played out over the course of the project, and presents some alternative research approaches suggested by the project team.

Informal and formal outreach

Many residents were engaged through the project manager's informal outreach throughout 2014 and 2015—the project manager, more than any other on the team, was the "face of the project" in residents' minds. This was reflected inside the planning team as well. For example, one described the project manager as "really, really adamant about getting people on board with the project and was pretty much a salesman trying to sell the project to the block members."

In a presentation about the EcoBlock proposal delivered to the Lawrence Berkeley National Laboratory in early 2015, the project manager described how residents were enthusiastic about the project, but that "they're also afraid (Berkeley Lab Energy Technologies Area 2015)." Yet when this presentation was delivered, the "legwork" on the block was presented as nearly complete, and the appeal of the project presented in terms of its potential to address any number of behavioral research questions researchers at the lab might have.

Many project team members accordingly expressed not having understood the lack of full community buy-in early on. The physical block did not itself readily constitute a social community. Residents' communication preferences varied widely, as did their relative levels of interest and ability to participate in planning exercises. Over time, it became clear that some residents were growing impatient, confused, or frustrated by the slow pace of progress.

Social sciences team

The Outreach team understood their scope of work as defining an outreach strategy for disseminating information about EcoBlocks to relevant stakeholders, and designing—but not necessarily implementing—stakeholder engagement processes. This differed from the ultimate role they performed, consisting of several focus groups and a design charrette for block residents. The project team was conscious of the issues that the EcoBlock project could present, and wanted direct resident feedback on potential design options. Meeting with the block also meant the project would be seen as more legitimate. However, these efforts were undertaken with only a very rapid, late-stage strategy development, rather than being woven throughout each team's conception of their work and goals over the full arc of Phase 1 planning.

Thus, governance was not only an open question in terms of the project's future, but also an in terms of the organization of the early phases of the project itself. What kind of information would be asked of residents, and when? Governance is often caught in a dilemma "between lacking enough information in the present and waiting for perfect knowledge (Collinridge 1980, as cited in Dietz and Stern 2008)." This arises in the context of selecting preferred technologies based on cost, but it also arose in the context of needing to understand the goals and structure of outreach processes before undertaking them. The project team itself took varying approaches to discussing the project with residents, varying between "painting a big picture of what the block could be" and "asking the residents to tell us what it could be."

The Chapter 10 Case Study Report illustrates project team members' varying perspectives on what should constitute community engagement; from listening to concerns to eliciting decisions about the technical design of the project, under an overarching desire to "make sure all community concerns are addressed." But beyond expressing this general concern for community satisfaction with the project, the bulk of the team's efforts remained abstracted from the block itself.

Still, several different kinds of "inputs" were requested of residents throughout the planning process, and even more would be required of them were the project to be built. These ranged from the questionnaires they completed as part of our meetings, to the utility application programming interface (API) data requests discussed in Chapter 11, to their personal opinions and preferences during the focus group meetings and design charrette. For each kind of information, there are a variety of barriers to attaining accurate, timely, and representative input. Without a thoughtfully designed approach to the community, residents could tire of multiple contact attempts and requests for information.

The role of participation

Eliciting community perspectives is widely understood to be a best practice, if not essential, to an effort like the EcoBlock. Engaging the public in transparent assessment and decision-making is a best practice in government-led sustainable development (Dietz and Stern 2008). Participatory processes create a "soft space" where perspectives of participants and experts can be mediated (Haughton, Allmendinger, Counsell, and Vigar, 2010). But the EcoBlock, in proposing changes in residents' homes, over which they will have ultimate authority, arguably cannot approach community engagement using standard "best practices" for projects such as parks and public amenities, where ultimate decision-making power does not rest in the hands of residents and property owners.

Even when participatory processes are in place, they may not yield equitable or just outcomes. Participatory processes for urban climate planning are critiqued as a governmental strategy for cultivating widespread endorsement of a predetermined solution (2006). Maskovsky (2006) further argues that "failures of neighborhood participation lie not in the success or failure of particular redevelopment plans… but in the fact that it is remarkably ineffective in actually representing disenfranchised urban residents and achieving real social equity on their behalf (p. 93).” He argues that an insistence on multicultural participation in community in fact *reproduces* racial inequalities and class divisions, and that planning processes cannot “escape the ideological and material realities of racial inequalities and class divisions.”

Social research and outreach

As Chapter 11 discusses, community participation in planning efforts can range from simple information provision to opinion solicitation to active decision-making, so developing an engagement approach based on an assessment of stakeholder and project needs is essential. If the goals and means of a project are not clear, this can lead to high costs and communication problems (van Doren, Driessen, Runhaar, and Giezen 2018). As a result of this need to engage the block quickly and on short notice, the Outreach team was unable to use many of their best practices, or establish a desired level of clarity and transparency with residents. This was due in part to several internal logistical delays. The research undertaken for this appendix required Institutional Review Board ethics approval, since it aims to produce “generalizable knowledge” about the neighborhood and resident perceptions of the project. Initially, outreach team members were considered research personnel, before separating their outreach efforts from this interview research.

The outreach team’s initial inclusion as research personnel acknowledged that the EcoBlock project could be, as described by one resident, a “giant human subjects experiment.” Because its goals were to develop a generalizable and scalable model, all of the information collected from and engagement with residents arguably could have undergone ethical review. As discussed previously, informal outreach efforts were already well underway even before a Phase 1 grant was submitted or outreach team assembled.

When the Phase 1 grant was submitted to the California Energy Commission, no social science faculty were included on the project team, which was comprised of researchers and professionals in engineering, architecture, law, local government, and community outreach. The presence of a lead investigator for the social sciences team, with the authority to delineate research and outreach activities from the outset, may have resulted in a more structured and integrated community engagement process, but this would not necessarily have affected residents’ perceptions of or willingness to participate in the project.

Alternative approaches to research and outreach

In informal discussions and interviews with planning team members, the “academic–practitioner” divide was a frequent point of conversation. On one hand, these tensions were understood to be intrinsic to the project and indeed an important dimension of its innovative nature. However, advancing research goals—of both a technical or social nature—might be in tension with developing a single real-world project. This tension presented quite clearly in terms of both constricted timelines for community engagement and the multiple ways in which residents were contacted and engaged.

One alternative approach to outreach, suggested by one of the principal investigators, would be to gather utility bill information, develop preferred scenarios, then present more specific options to homeowners. Such an approach could involve a detailed general project description, consent for water and utility bill release, and participation in a structured transportation survey or transit modeling. Care would need to be taken to ensure that the research goals were clear, along with the possibility of ultimate project development, and what this might entail for residents.

A more participatory community-based research effort may have facilitated a more equitable dialogue among the research team and residents. A participatory approach establishes mutually agreed-upon scopes of work with community partners at the initial project stages, and engages them directly in research question development and data collection. In this particular case, given the already lengthy Institutional Review Board approval process for an interview-based study, developing and implementing a more participatory research design would have been untenable given the pre-existing project structure and timeline. Such an approach could be effective in future projects.

Literature Review

In this section, I place findings from interviews in the context of existing projects, programs, and policies around retrofitting and governance of sustainable urban communities. First, I review relevant themes from the broader literature about efficiency retrofits at the household and community scale. Then, I review other block-scale retrofit programs that provide instructive cases of prior attempts to retrofit at the community scale, and discuss barriers to participation and equitable benefit that also emerged in the context of the EcoBlock project. I discuss new-build eco-city, and eco-town projects that provide points of reference for potential eco-block governance models. I discuss California's policy contexts around sustainable and equitable local and regional development, and its implications in terms of environmental justice and access to affordable housing, two foundational goals of the EcoBlock project.

Household retrofits

Landlord-tenant related challenges may arise in terms of "split incentives," or the inherent difference between who benefits from and who makes decisions and pays for efficiency measures (Gillingham, Harding, and Rapson 2012). This problem is particularly pronounced for low-income renters, who are likely to pay a disproportionate share of their income for energy related expenses, yet live in some of the least efficient housing (Hernández 2016). On-bill financing models and improved efficiency incentives for landlords are some promising policy interventions at the single-building scale (Bird and Hernández 2012).

Even zero-cost energy efficiency programs face large non-monetary costs related to adoption, so take-up rates often remain low (Fowlie, Greenstone, and Wolfram 2015). Federal programs intended to benefit low-income populations may thus fail to serve those with the highest energy burdens, as prior participation in a social program tends to be the greatest predictor of weatherization program participation (Higgins and Lutzenhiser 1995).

A wealth of behavioral research studies the potential implications of adopting more efficient technologies, including "rebound" behavior that offsets the initial estimates of savings as residents can more cost-effectively attain higher comfort levels (Abrahamse, Steg, Vlek, and Rothengatter 2005). While such behavioral research would be central to an established EcoBlock project, a variety of other social questions pertain to realizing these retrofits at all.

Knowledge, motivation, and contextual factors influence sustainable behaviors, but interventions can change the actual costs and benefits of different choices, or people's perceptions of them (Steg, Perlaviciute, and van der Werff 2015). For example, psychological factors influencing community acceptance of renewable energy projects could include place-attachment, place-identity, trust, and individual values, alongside contextual factors, including perceptions of personal cost and benefit and distributional fairness (Perlaviciute and Steg 2014).

These questions are often described in terms of the "ABC": attitudes (what people think and feel), behaviors (habitual actions, shaped by personal preferences and external conditions), and choices (active decisions resulting from a combination of attitudes and preconditioned behaviors) (Shove 2010). However, the ABC approach itself is criticized for being overly deterministic, mechanistic, and not accounting for the rich contextual factors at play in resource decision-making (Shove 2010).

Indeed, some research critically evaluates not only the relationships between landlords and tenants, or buildings and their occupants, but also the professionals designing energy efficiency initiatives and the "imagined publics" for these initiatives (Cherry, Hopfe, MacGillivray, and Pidgeon 2017). "Imagined publics" are formed by the collection of assumptions experts work from when designing new technologies; these might include resistance to lifestyle change, and fear of new technology due to a lack of understanding. These assumptions can produce a "technological optimism and cultural pessimism" among designers, and yield interventions that "design around culture," but fail to meet public needs around comfort, security, and control. In this way, a "glossy vision" of a technological future could alienate, rather than engage, potential participants (Ballo 2015).

The rational actors imagined as recipients in a building-scale energy intervention and subjects of behavioral studies of energy and water use and conservation thus might differ markedly from the social actors imagined in the context of community-scale interventions. In other words, even if people apparently share the same values, they can be expressed in community in quite disparate ways. Behavioral studies test the efficacy of certain interventions, such as competition and comparison, for improving individual households' energy performance. But potential building-scale challenges are compounded by parallel, but relatively understudied, questions concerning community water and energy systems management. Retrofitting at the community-scale, while it promises heightened local social reinforcement, also introduces challenges related to collective ownership and resource governance.

Community-scale retrofits

In the United States, the 2008 American Recovery and Reinvestment Act (ARRA) saw a twenty-fold increase in federal weatherization funding, from $230 million to $5 billion (Reames 2016). Several community-scale retrofit pilot programs were launched, guided by the hope that a more social approach to retrofitting could mitigate the challenges presented by traditional programs. While these programs differ from the EcoBlock since they focus on building-scale improvements and not collective neighborhood systems, several lessons may be gleaned from their implementation.

Block-by-block retrofits

In Murray City, Ohio, a block-by-block retrofit project led by the Corporation for Ohio Appalachian Development weatherized 75 percent of homes in the city. The project benefitted from the gradual trust and buy-in they built in doing whole-home retrofits, alongside strong endorsement from the city's longtime leadership; and its ability to leverage utility and private funding sources along with federal funding (Gerdes 2013). Still, even when the benefits were clear and their neighbors had signed on, some residents simply remained skeptical that the program would be as advertised.

The Retrofit Bedford-Stuyvesant Block by Block pilot in New York featured a similar model. It sought to retrofit an older brownstone neighborhood, focusing on both local energy savings and workforce development. The pilot project aimed to support the city's green jobs initiatives and encourage strong uptake of the state's new PACE (Property Assessed Clean Energy) programs. The pilot used mailings and phone calls to invite block residents on the selected street to meetings. However, program uptake was much lower—only 14 percent of the 105 residential buildings contacted eventually participated in the program (Rourk 2010).

Although these programs had similar designs, they experienced markedly different levels of uptake. Murray City was a much smaller city, with a population of just about 500, and 74 percent of the 200 homes were successfully retrofitted. In such a small community, it may arguably have been easier to ensure widespread awareness of the program. In the Retrofit Bedford-Styuvesant project, outreach made a special effort to include community institutions like the local church, and found that word of mouth outreach among neighbors was more effective than that of governmental representatives. The project report emphasized the importance of having "crystal clear" and multi-tiered offerings for different levels of efficiency upgrades, especially since many lower-income households are debt-averse and need clear information about payback periods (Rourk 2010).

Green Impact Zone

Another ARRA-funded Weatherization Assistance Program, the Kansas City Green Impact Zone (GIZ), attempted to resolve classic uptake challenges faced by standard self-referral implementation programs (Reames 2016). The GIZ program directly targeted five low-income, predominantly African-American neighborhoods to participate. It was designed with attention to the unique community-scale barriers to adoption in urban environments and that can result in inequitable program uptake and implementation.

The program was structured around community capacity building, and began with the city hiring eight staff members, including five community ombudsmen—one for each neighborhood (Reames 2016). However, the program only reached 50 percent of its overall weatherization goals, owing to barriers defined as "social (public priorities and public distrust), market (information gap and split incentive), and regulatory (pre-weatherization repairs and previous weatherization ineligibility) (Reames 2016, 7)." Even in the absence of financial barriers, since all upgrades were offered for free, pronounced social challenges emerged in terms of lack of knowledge and mistrust of programs.

The GIZ program worked to address these challenges to community participation in free retrofit programs. The program intentionally hired an all African-American staff to reflect the racial makeup in the neighborhood, and engaged in extensive door-to-door and community-based social marketing campaigns that relied on testimonials from residents. Still, residents remained skeptical of, and reluctant to, participate in the program simply because it didn't match up with their everyday priorities.

Coolest block contest

In Philadelphia, Dow Chemical partnered with the Mayor's Office of Sustainability to launch the "Coolest Block in Philly" contest. The winning block would receive a free white-roof coating, which would reduce the costs of summertime cooling and improve indoor comfort in some of the city's aging building stock (Edwards and Bulkeley 2017). The contest was judged in terms of each block's application; high level of participation was one of the most important criteria. The winning block was home to an architect and engineer couple who passionately advocated for the project to their neighbors, reinterpreting the coatings' benefits in a way that felt relatable to each of their neighbors.

A contest-based model might relieve the project team of the responsibility of advocating for the project to garner high levels of participation. However, a contest-based model raises equity concerns—that those benefitting most from neighborhood sustainability investments might only be those "already able (Edwards and Bulkeley 2017)." In the case of the Coolest Block, the winning block had active leadership and expertise from its residents, and the program benefited the most competitive block, not necessarily the one in greatest need.

Eco-villages

Eco-villages are grassroots initiatives, rather than government-sponsored projects (Dawson 2006), and may not engage the professional services of architects or designers (Loezer 2011). They often start with, and focus on, local food production. Many eco-villages have a shared spiritual practice, and even secular ones have core shared values. Eco-villages entail, and require, local transformations of "economy, ecology, community and consciousness," and participation has been described as "taking part in a lifelong personal development workshop (Liftin 2014)."

Ecovillages employ a range of governance and ownership models, including nonprofit management, condominium associations, homeowners associations, limited liability partnerships, and community land trusts (Liftin 2014). However, eco-village governance differs from the EcoBlock in that these models either derive from strong preexisting community relationships—including a shared sense of purpose, solidarity, reciprocity, and trust—or agreement to community norms and rules that are a precondition for eco-village membership.

Even when community-scale sustainability projects centrally prioritize equity in terms of participation and representation, diversity issues still arise. LA Ecovillage was established in the wake of the 1992 Rodney King riots. Its founder had intended to build an eco-village on a brownfield on the outskirts of the city, but saw a stronger need to focus her efforts on revitalizing the built environment and social fabric in the inner city around sustainable principles. Despite its explicit and central attention to social equity, the LA Ecovillage has still faced challenges with diversity and inclusion, and has ongoing and active racial justice conversations among its membership (Arkin 2012).

EcoDistricts

The EcoDistricts organization was established in 2012, as an outgrowth of the Living City Block (LCB) initiative developed by the Rocky Mountain Institute. LCB had proposed, but did not implement, several community-scale energy and water retrofit projects in cities across the United States. Given the challenges faced by these projects, the EcoDistrict organization adopted a new approach. Rather than focus on particular technologies, their protocol instead focuses on equitable engagement and community benefit. Their protocol and its “imperatives” aim to provide a scalable model that grassroots organizations can implement. Several EcoDistrict case studies could be useful points of reference for the EcoBlock in its Phase 2 implementation. The organization also maintains an official registry of certified EcoDistricts and runs a professional accreditation program. More study is necessary to understand how this approach bears out in practice.

Eco-cities

The governance of an EcoBlock project will be highly contingent on its policy contexts. This includes not only local zoning and permitting requirements (discussed in Chapter 7), but multi-scalar utility, city, and state policies (discussed in Chapter 8). Within these multiple policy contexts, the project would require its own novel and multi-scalar legal and financial arrangements to structure the project development and long-term management. The cases of Sonoma Mountain Village (SOMO) and Treasure Island (TI), two larger-scale new build projects in the greater Bay Area, illustrate some of governance and finance structures that small-scale eco-district initiatives have developed, and the challenges they faced. Eco-Towns, a national initiative in the UK, provides a precedent and point of comparison for what EcoBlock development could entail if it attempted to expand outside of Oakland and the Bay Area.

Eco-city approaches might be highly varied—from retrofit to infill (expansion of brownfield sites within the city) to entirely new cities—but they share a focus on seeking positive outcomes in terms of greenhouse gas reductions, urban economic growth, and technological innovation. Eco-city projects often follow a “clean slate” approach, appealing because obdurate existing systems needn’t be modified, repaired, or incorporated (Selin and Sadowski 2016). Despite multi-scalar support and a clear sense of urgency, even new-build eco-city projects take time and extensive resources to realize. In the case of SOMO and TI, both took six years to develop custom governance mechanisms that allowed them to move into physical implementation (Joss 2011b). Attempts at creating a national eco-towns development initiative in the UK were stymied by local opposition and eventually changes in political leadership.

Project development and governance

Joss (2011) compares SOMO and TI, which are both infill eco-city developments. SOMO is less relevant to the EcoBlock case, since it was led primarily by a regional building company (Codding Enterprises [CE]) operating as owner, master planner, and sustainability innovator (Joss 2011). However, SOMO is a pilot of this business model and eco-city development on 200 acres of a former technology campus. The City of Rohnert Park is not an underwriter, and primarily regulates. CE, rather than the city, led local engagement efforts to build local support for the project. CE entered into a community benefit agreement with the Accountable

Development Coalition (ADC), a group of housing, labor, and environmental advocacy nongovernmental organizations, and held its own consultations with residents.[3]

Treasure Island, however, used a Public-Private-Partnership (PPP) model somewhat analogous to the preferred model identified for the EcoBlock. The Treasure Island Development Authority (TIDA) is a public agency established in 1997 to oversee the island's redevelopment from military use. In 2003, it entered an exclusive redevelopment contract with Treasure Island Community Development (TICD), a group of major homebuilders and private investors. The public sector is closely involved in defining the strategy and underwriting the investment. If EcoBlock development were to use a PPP model with a Community Facilities District, its governance might look more like TI, albeit at a much smaller scale.

How does the PPP model work in the context of the TI eco city? TICD (the private developer/investor group) pays for public benefit measures, such as the development of public spaces and affordable housing, on the city's behalf, but TIDA (the public redevelopment agency) retains ownership of them. Although the project anticipated using Tax Increment Financing (TIF) to repay investors, TIF was abolished in California in 2011 (Lefcoe and Swenson 2014). TIDA now appears to be pursuing a Community Facilities District financing model (TIDA 2017).

For TI, the PPP legal documentation defines project elements and specifies objectives and targets, describes the responsibilities of the various parties in great detail, and forms the structure of the partnership. An EcoBlock PPP would likely take a similar form. In practice, the private and public-sector actors work as a joint project team. Even though all project documentation is available to the public, it is not easily accessible "due to the technical complexity and jargon involved (Joss 2011, 344)." Although TIDA convenes a citizen's advisory board and seeks public input, the TI redevelopment has been criticized for its lack of transparency.

The EcoBlock faced similar criticisms from residents during the early stages of planning. Although the plans were still under development, residents expressed a strong desire for a more concrete sense of the long-term financial implications and short-term construction burdens. The more legally, technically, and financially complex and detailed a project, the more likely it may "stand in tension with demands for transparency and public accountability within the planning and wider political processes (Joss 2011)." For example, this Phase 1 report might not be readily legible to anyone seeking general and personally relevant information about the project.

Moreover, for an EcoBlock project, it remains unclear which body would manage communication with residents, arrange for meetings, disseminate information, and notify residents of pending decisions. Several of the bodies proposed in Chapter 8 might be suitable, including a limited liability corporation, nonprofit trust, or homeowners' association; but the

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[3] As of May 2018, over 1,000 businesses are leasing space at SOMO, but the development is still seeking partners for home construction (van Doren et al. 2018).

channels through which this body would be established are not yet clear. TIDA is a body of the State of California (established pursuant to the Base Realignment and Closure Act), although it is managed by the Office of the Mayor. It convenes the Treasure Island Citizens Advisory Board, and holds numerous public meetings. All plans and meeting minutes are publicly available. The City of Oakland, like the cities of Rohnert Park (of SOMO) and San Francisco (of TI), does not indicate that it will take ownership of the EcoBlock project in financial or organizational terms, but there is no intermediary body that would manage project development.

The EcoBlock project, as part of the California Energy Commission's "Advanced Energy Communities" challenge, was focused on both novel technology deployment and equitable urban greening. The SOMO and TI cases illustrate some of the trade-offs between advanced technology deployment and "social sustainability features." Since SOMO is led by a single owner-planner-developer, it has been able to focus on cutting edge sustainability technology, earning Leadership in Energy and Environmental Design (LEED) Platinum certification as compared to TI's Gold, and even undertaking its own steel framing and biofuels production. TI is more strongly integrated into the city's sustainability efforts and has faced stronger local pressure to provide affordable housing and social services.

TI also faces substantial risks, since it is a low-lying manmade island, contaminated from former military use, and highly susceptible to damage from earthquakes and sea level rise. This significant "horizontal" redevelopment, or land preparation, is quite different from the challenges posed by retrofitting residential housing. But it might be parallel to the extent that structural building repairs, utility pole replacement or undergrounding, or water infrastructure replacement or upgrades might need to be addressed in the course of project development.

The "scalability" of an EcoBlock financial and legal model thus could be contingent upon the extent to which the preexisting physical and policy context of the initial block were shared by subsequent areas identified for block development. Although this study found no precedents in the United States for a community-scale retrofit program across multiple different localities, Eco-Town developments in the UK could serve as a useful point of comparison in considering what "scaling up" an EcoBlock project could involve (Morris 2011).

Eco-Towns

In 2007, the UK's Labour government called for ten new "eco-towns" to be built by 2020. These towns were to address the joint challenges of climate change and affordable housing by "bring[ing] together models of environmental, economic and social sustainability," and providing "testbeds" for methods for delivering affordable housing, green infrastructure, zero carbon buildings, and waste management (Morris 2011, 113). Britain had strong pre-World War II legacy of state-led housing programs in the Utopian, Model New Towns, and Garden City New Towns developments. After a postwar focus on inner city regeneration dominated, the late 1990s and early 2000s brought renewed interest in the New Town program, of which the Eco-town might be seen as a small contemporary version (Ibid.).

The Eco-town sites were selected based on "(a) an environmental appraisal; (b) a transport assessment; (c) a sustainability appraisal; and (d) a community involvement statement (Morris 2011, 119)." One Eco-town was defeated for its inability to incorporate local needs. There, residents demanded that the Eco-town effort focus instead on redeveloping vacant properties and neglected suburbs rather than build new housing. Due to local opposition and funding scarcity, four of the ten were selected to move forward. But as late as 2012, no progress had been made on construction. Finally, in 2017, the Conservative Party closed the Eco-town program and instead announced 17 prospective garden village and garden town sites. The Committee to Protect Rural England has remained a vocal opponent of the project (BBC News 2017).

Scaling up sustainable communities

In light of the challenges that community-based retrofits face, what does "scaling-up" mean in practice? For van Doren et al., success of low-carbon urban developments is "dependent on operational arrangements at the organistional level of the initiative, and influenced by the wider institutional environment outside the initiative (2018)." The EcoBlock project emphasized scaling-up as an *end* (in terms of socioeconomic and environmental impact), but included some consideration of the *means* through which this might be attained (innovative application of financing models and local governance). Taking into consideration the two ways scaling is interpreted, van Doren et al. (2018) constructs a useful typology of scaling across its *horizontal* (spatial) and *vertical* (institutional) dimensions. Vertical scaling occurs when an initiative inspires or influences policy and institutional changes necessary to create an enabling environment for further low-carbon urban development efforts. Without both horizontal and vertical scaling, low-carbon urban developments merely remain "islands of excellence (van Doren et al. 2018)," where a successful pilot might be realized but without broader implementation.

Van Doren et al. offer several factors that may facilitate or inhibit scaling that resonate with those discussed in this report. For low-carbon urban developments to reach beyond environmentally conscious consumers, they should "be low in complexity, reliable, and guarantee a long-term financial advantage (van Doren et al. 2018, 186)." If measures are more experimental and require more behavioral change, time and transaction costs go up. However, where Van Doren implies that local, small-scale initiatives have homogenous contextual environments, this study finds that this may not always be so. As they also point out, the conditions that facilitate development of a pilot project may differ from those required to achieve scaling-up.

Moreover, an implemented first pilot project is not necessary for its lessons to be applied elsewhere (Chang 2017). The Dongtan Eco-City plan was critically acclaimed but never built, owing to several practical site and financing limitations that emerged after the design was finalized. Despite its failure, the project conditioned and helped facilitate a model eco-city project development in Tianjin, China (2016). Dongtan's failures—in trying to build on arable land, on including a range of expensive technologies, and an overly ambitious Western-style plan—formed a negative point of reference for future efforts. Yet the tools that the project yielded, and especially its integrated resource management software, were applied to new initiatives.

The conditions for scaling become ever more numerous and contingent in the context of retrofitting programs. In the case of retrofits, scaling can often mean a trade-off between widespread adoption and equity. Hodson and Marvin (1987), in their study of retrofit programs in Manchester, UK, constructed a typology of retrofit programs: Retrofitting ON involves large national programs, which face challenges translating into embedded capacity, and Retrofitting IN involves ad-hoc, hyper-local programs, which face challenges with funding and fragility.

> *What this means is, on the one hand, strategic intent, built on a narrow economic agenda, with limited capacity and capability to realise this; and, on the other hand, episodic and piecemeal retrofit often developed around a range of localist, social justice and ecological concerns. That means that there is potential in developing more productive relationships between these two positions. (Hodson and Marvin 2016, 1212)*

They propose "Retrofitting WITH" as a way to resolve the problems that these two other types of retrofit present. Indeed, the EcoBlock planning process might be seen as retrofitting WITH, since attention to scalable financial structures and equitable local participation were both part of the project's goals.

Towards just and sustainable cities

Richard Register's (1987) *Ecocity Berkeley* is perhaps not the first, but the best-known early codification of eco-city principles and proposed actions for a world reaching ecological crisis. Register's vision is a city-wide and regional one: re-envisioning land use, transportation, and proximity between work, home, and recreation is central to a more ecological city; not only implementing the most energy and water-efficient technologies in the existing built environment. Some of Register's proposed modifications seem prescient—like the daylighting of creeks trapped in culverts throughout the city—and others fantastical, like a mini-venetian village in the present-day Berkeley marina, infill left to wash away with natural tidal flows.

The impact of Register's work is not so much as a concrete blueprint for eco-city development as a touchstone for imagining alternative sustainable futures. The 1990s saw the rise of the concept of "sustainable development," in which the goals of economic growth, environmental protection, and social justice were seen as broadly compatible (Rapoport 2014). Several early successful projects, including Hammarby Sjöstad in Stockholm, Vauban and Reiselfeld in Freiburg, Germany; and Bo01/Western Harbour in Malmö, Sweden, demonstrate this optimism suffusing smaller district-scale development projects (2013).

Joss (2011a) points out that Register's vision of an ecological city did not mention climate change or carbon dioxide emissions as such—only following the 1997 Kyoto Protocol did eco-city justifications begin to more directly address high urban carbon emissions. The later 2000s saw the rise of more ambitious eco-city projects. These projects depart from early eco-city visions as growth that is implicitly aware of its limits, and seeking the "health and vitality of humanity and nature (Register 1987)." Instead, they aimed to transcend or redefine ecological limits, and thus resolve contradictions between economic development and sustainability (Hodson and Marvin 2010).

The imaginative utopianism of early eco-city visions was reinterpreted within a sustainable development discourse in the 1990s and 2000s that didn't see such stark trade-offs between economy, sustainability, and social justice. The projects that emerged from this period of growth, while showcasing the potential for sustainability technology, remain critiqued for their failures—particularly to address the social equity issues that motivate them.

The disproportionate attention eco-cities tend to pay to experimental technology may result in projects that are inaccessible to many, and that could exacerbate patterns of inequality and exclusion (Rapoport 2014). For example, new-build eco-cities have been criticized as "premium ecological enclaves" that benefit only the well-off (Hodson and Marvin 2010). Still, the EcoBlock is designed as a retrofit project precisely to reach those who are not "already able" to benefit from sustainability initiatives. Yet, because of residents' personal decisions to participate or not, the benefits from the project could play out unevenly, even within the selected block.

Viewing the EcoBlock in light of a broader genealogy of eco-city projects shows how some of the challenges the project faces are common to other urban sustainability initiatives, including establishing locally feasible and scalable governance, attracting the private sector finance and public support for an experimental project, and earning the trust of the local community to carry it out. The EcoBlock extends, but also departs from, this history, in its attempt to focus on an extremely small-scale local case, but cast in the context of trans-local and global aspirations. In so doing, it challenges the assumed trade-offs between scalability and equity.

The City of Oakland embraced the EcoBlock project as part of its Resiliency planning, an effort supported by the city's membership in the Rockefeller Foundation's 100 Resilient Cities initiative. The French Rexell Foundation was one of its additional funders, and as the project reached its conclusion, the Fronteer consulting group from Amsterdam invited EcoBlock staff to a sustainable city design workshop at the Dutch Consulate in San Francisco. These connections illustrate the global salience of the EcoBlock's goals.

At the municipal level, the City of Oakland has begun to formalize race and equity analyses for all of its programs. It launched a dedicated race and equity program in 2016 (Swan 2016), and placed racial equity and social justice as central elements of its own planning as a Rockefeller 100 Resilient Cities member (City of Oakland 2016). Even though the EcoBlock project was not among other Advanced Energy Community projects that focused on disadvantaged communities, equity was central to its motivation and rationale:

> *Projects at this scale are needed to move beyond piecemeal, incremental energy, water, carbon savings; to drive major ratepayer savings and increased public health and environmental equity benefits, especially to lower-income communities. (Oakland EcoBlock Grant Application Executive Summary)*

To some degree, residents also echoed this attentiveness to equity, although it did not arise in environmental justice terms—if anything, residents saw themselves as relatively well-off in comparison to other areas of Oakland, such as West Oakland, or other parts of the state, such as the Central Valley. Arguably, if EcoBlocks became widespread they could relieve some of the negative impacts of fossil-fuel based electricity generation and transportation, but this consideration was far more remote in residents' minds. Instead, resident concerns over equity arose primarily in terms of financial equity and access to affordable housing.

The following subsections briefly review California policies that pertain to environmental justice and climate change mitigation, as well as the equity implications of potential EcoBlock investments in the context of a gentrifying neighborhood.

Environmental justice and equity in California climate policy

This section provides a brief contextual overview of environmental and health equity in the context of California's climate investment programs, the Electricity Program Investment Charge (EPIC) program, and the City of Oakland's resiliency planning. It then discusses the equity implications of household-scale and community-scale retrofit programs. Finally, it touches upon the financial and housing equity concerns raised by residents within these broader statewide policy contexts, adding relevant background from the housing sector.

Equity and justice demands have become increasingly persistent in California environmental policymaking, although environmental justice advocates remain skeptical as to whether longstanding environmental health disparities will be meaningfully addressed (Sze et al. 2009). Senate Bill 535 codified "Disadvantaged Communities," based on a variety of environmental and social criteria, and mandated that these communities benefit from at least 25 percent of the state's greenhouse gas reduction fund spending (CalEPA 2017). This spending comes primarily in the form of "climate investments"—in clean energy technology, electric vehicles, and transit-oriented development.

Energy efficiency investments extend prior generations of energy policy, albeit under climate change and energy equity goals, rather than addressing fuel poverty. The 1970s energy crisis spurred the creation of several emergency energy assistance programs, out of which the Department of Energy's Weatherization Assistance Program was born. The Crude Oil Windfall Profits Tax Act of 1981 formalized the Low-Income Heating Assistance Program (LIHEAP), the first federal assistance program of its kind (Kaiser and Pulsipher 2003). LIHEAP and the later generation of block-grant funded programs at the state level were found to often fail to serve those with the highest energy burdens, prompting Higgins and Lutzenhiser (1995) to label the program as attaining only "ceremonial equity."

It remains unclear whether foundational environmental health issues will be resolved by clean energy and vehicle programs. For example, California's booming solar industry also has a mixed record when it comes to "high-road," well-paying jobs (Zabin, Martin, Morello-Frosch, Pastor, and Sadd 2016), and even the best-intentioned programs still face barriers to adoption (DeShazo, Gattaciecca, and Trumbull 2017). Transit-oriented development, central to meeting California's long-term climate and housing needs, may gentrify more affordable housing areas and even result in displacement (Zuk et al. 2017).

But successive generations of policy development and program innovation can help realize the state's climate goals and benefit disadvantaged and low-income communities. For example, under AB 523, signed in October 2017, the EPIC program adopted formal thresholds for energy research, development, and demonstration programs to benefit low-income and disadvantaged communities (Reyes 2017). In May 2018, the Energy Commission held its first workshop to develop criteria for evaluating proposals for work in disadvantaged communities and mechanisms for ensuring community benefit (California Energy Commission 2018). Considerations like these are arguably not pertinent only to projects in disadvantaged communities, but to any projects involving the public, especially those that might involve retrofitting or technology demonstration.

While retrofits can benefit those who are typically excluded from environmental incentive programs, they also can be incredibly time- and resource-intensive undertakings for their putative beneficiaries. In the case of the Hedebygade retrofit project in Denmark, the pilot block of 12 apartment buildings was a vessel for the competing and far-reaching aspirations of planners and engineers, becoming "battlefield of ideas" in which the "only losers [were] the residents (Jensen 2004)." If community-*based* projects are not community-driven, the priorities and needs of experts may diverge from those of residents and participants.

Miriam Greenberg summarizes the contradictions inherent to visions of sustainability: "while our idealized future may be inclusive across lines of race, class, and geography, they also draw boundaries that exclude. They have been portrayed as monolithic and consensual, while necessarily being shaped by multiple and often competing imaginings (Greenberg 2014)." Overcoming these contradictions and their attendant dilemmas requires answering some deceptively simple questions: "What is to be sustained and what is not? And who gets to choose and who does not?" Doing so reveals the "inherently political nature of sustainability," and it forces one to acknowledge what of the many notions of sustainability their vision is in service of (Greenberg 2014).

Housing equity: Financing the EcoBlock in a gentrifying neighborhood

Gentrification was a clear emergent theme in residents' experiences of life in the neighborhood. Cultural and income differences often become more pronounced in gentrifying neighborhoods, and further condition neighborhood politics—not only in the informal domains of pets and parking, but also in terms of negotiating broader changes in the community. Where can and should community investments be focused? How should benefits accrue and be distributed? These questions are some of the most persistent in urban policy and planning, and are likely to manifest in the context of EcoBlock implementation.

Since investments in the built environment will become increasingly devalued, whether or not greenhouse gas emissions are stabilized, Sayre (2010) argues that policies should be crafted "with the goal of completely redesigning and rebuilding our built environment over the next 20 to 50 years (Sayre 2010)." The EcoBlock project, and retrofit investments in general, pose a compelling response to this problem of devaluation.

Gentrification is propelled by these very cycles of neighborhood decline and reinvestment, and the cultural and social shifts that make formerly underinvested neighborhoods "desirable" (Lees et al. 2008). It can bring a variety of improvements to the local environment, not least to property owners in terms of appreciated housing values. But rising housing prices can lock low-income people out of the market, unable to move into or stay in neighborhoods as they revitalize around them (Chapple 2014). Particularly in California and the Bay Area's strained housing market, gentrification raises profound political, economic, and social issues.

Urban greening projects carry a particularly strong association with gentrification—what some have termed "green gentrification (Gould and Lewis 2017)" or "environmental gentrification (Checker 2011)." When new environmental amenities like parks, healthy food stores, and access to transit come to a historically disinvested neighborhood, local property values can rise, so these green amenities are seen as triggering or accelerating displacement (Anguelovski 2016). The EcoBlock aims to achieve its sustainability and resiliency goals through intensive investments and upgrades in existing housing. Gentrification processes can be triggered by investments in devalued housing. So the EcoBlock could potentially mean both "classic" gentrification as neighborhood reinvestment, along with the proximate impacts of "green gentrification."

Gentrification undoubtedly brings benefits to neighborhoods in terms of better maintained infrastructure and buildings, safety, and economic activity and opportunity. However, critics challenge the assumption that increases in property value will yield universally positive outcomes. Gentrification can also threaten lack of affordability, political exclusion, and displacement (DeFilippis 2007). If capital investment doesn't match up with community needs, local mobilization and control in planning processes is critical to steering efforts toward more just outcomes (Chapple 2014). This can help ensure that the benefits from investment accrue equitably, don't result in displacement, and allow for the quality of neighborhood amenities to improve without preventing low-income move-ins.

Resolving tensions between community upkeep and displacement becomes increasingly challenging when so many community investments are financed through property taxes. As resident accounts reflected, those who bought their home in an inflated market might feel they pay a disproportionate amount for public goods. One household termed this "gentrification without gentrification," since they were seeing demographic change, and property prices and taxes were skyrocketing, but not resulting in commensurate improvements in local infrastructure and amenities. In this sense, the investments and upgrades promised by the project would fulfill some of these residents' expectations about improvements to the built environment.

Still, property owners also stand to benefit disproportionately from public investments. Although the majority of these expenses would go toward collective infrastructure and not individual building upgrades, these investments could clearly increase property values. Indeed, this is framed as a benefit in the project report:

> *Finally, a considerable projected benefit is increased real estate value for individual homeowners, and greater employment in the communities in which they live due to the extensive construction activity needed to implement EcoBlocks—a tide that can lift all boats. (EcoBlock Report)*

In suggesting that the project would be a "tide that can lift all boats," the EcoBlock frames its benefits in the same terms as proponents of gentrification:

> *Gentrification rebalances a concentration of poverty by providing the tax base, rub-off work ethic, and political effectiveness of a middle class, and in the process improves the quality of life for all of a community's residents. It is the rising tide that lifts all boats. (Duany 2001)*

It is challenging to fully predict or explain the potential consequences of EcoBlock investments, but residents anticipated the potential for increased property values or rents. Several residents asked if the upgrades would affect rent control on their properties. The team discussed the need to establish agreements to prevent sales for windfall gains. Ensuring that the project does not exacerbate the potential negative impacts of gentrification or result in displacement will require thoughtfully crafted agreements among owners and tenants, since existing protections under the rent stabilization ordinance may not fully protect tenants who live in rent controlled properties.

Rent Control

Oakland rent control allows increases for reimbursements for up to "70% of the cost of improvement amortized over its useful life[4] (Oakland Rent Adjustment Program 2017a)." As such, any project expenses borne by the owner could potentially be transferred to tenants through rent increases. In addition, "substantial retrofits," defined as investments in the property that exceed 50 percent of its fair-market value, can permanently exempt a building from rent control (Oakland Rent Adjustment Program 2017b). This suggests that a landlord *would* be able to pass on some of the costs associated with EcoBlock development, above the allowable yearly increase; landlords interested in releasing their properties from rent control altogether may arguably have grounds to do so.

A just cause for eviction does include cases in which "the owner wants to perform substantial upgrades to the unit which cannot be completed with the tenant living there (Oakland Rent Adjustment Program 2017c)." As such, the Phase 2 agreements would likely need to include custom covenants or other legal arrangements to prevent dramatic rent increases or evictions resulting from project development.

Community Facilities District

A Community Facilities District (CFD) administered by a Joint Powers Authority is the preferred legal model for communal asset management for an EcoBlock. A two-thirds affirmative vote from registered voters in the CFD is required, although the boundaries of the

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[4] Since some questions raised by residents fell outside the scope of the financial and legal team's work and the City of Oakland's regulatory and permitting analysis, they are discussed here. This cursory reading of City of Oakland Rent Adjustment Program policies should not be taken as definitive legal analysis.

CFD could be drawn to include only those willing to participate, yielding an effective 100 percent vote, which is generally preferred for these arrangements. However, given the potential impacts of construction, the project could encounter substantial opposition to City Council approval if the selected block, and adjacent areas, are not unanimously in support of project development.

As the CFD structure functions as a fixed percentage add-on to property taxes, this also raises potential equity concerns as those residents with an already high property tax burden would pay disproportionately more into the CFD. Accompanying legal structures could account for this by levying additional fees on residents with lower property tax burdens, but the process of establishing the rates at which these fees would be collected, and how they would be managed, would require extensive planning and negotiation with participating residents.

Other models

Community land trusts emerged in the United States in the late 1960s as collective property ownership reform ideals and were linked to notions of community control during the civil rights movement (DeFilippis, Stromberg, and Williams 2017). In community land trusts, a community organization owns and manages the land, while residents "own" only the housing units on the land (DeFilippis 2004). Community land trusts are an important legal tool for many eco-villages, but are also used for affordable housing. Local land trusts include the San Francisco and Oakland Community Land Trusts, and the Sogorea Te' land trust led by Ohlone women. Pilot EcoBlock development might be more feasible for a group of residences that are already legally organized in a fashion that would prevent individual windfall gains and keep rents affordable.

For example, the Dudley Street Neighborhood Initiative (DSNI) in Boston is a resident-driven development effort. The nonprofit holds all properties in a community land trust, and issues 99-year ground leases that keep the land available for affordable housing (Agyeman 2013). Yet such a model might be in tension with widespread scaling, since convincing all property owners to participate in a land trust could be a lengthy process. Widely adopted land trusts could also affect real estate markets and the very financing mechanisms necessary for upgrades.

Globally, other new models are addressing these financing challenges, at least in the context of new affordable apartment construction. In Australia, the Nightingale 1.0 apartment project used a financing model that connected architects directly with owner-occupiers, yielding savings on developer and marketing expenses (Stead 2016). Investor profits are capped at 15 percent, rather than the customary 20, and there's a 20-year limit and profit limit to apartment sales. This model has attracted widespread public interest and appears to be spreading.

Conclusion

Sustainability "deals with, and cuts across the economic, social, and environmental pillars of policy-making—and does so at multiple levels (from the local to the global, and involving a mix of state and non-state actors (Joss 2011a)." Sustainability also involves long timescales that stretch past typical political and economic cycles, and involve significant complexity and uncertainty. Thus, localized sustainability efforts devolve spheres of governmental, institutional, and individual responsibility, to involve more decentralized, informal, shared, and collective decision-making structures. However, descaling climate responsibility to regions and localities might highlight the inherent tensions between economic growth and sustainability, rather than resolving them (Castán Broto and Bulkeley 2013).

The EcoBlock project exemplifies the opportunities and challenges intrinsic to addressing climate change in urban environments. Its motivations were multiple and varied, aimed at reaching an array of broad social and technical goals:

> *Projects at this scale are needed to move beyond piecemeal, incremental energy, water, carbon savings; to drive major ratepayer savings and increased public health and environmental equity benefits, especially to lower-income communities. The project's community-scale financing models are structured to promote urban renewal without gentrification: a key requirement for widespread, social demand. (Oakland EcoBlock Grant Application: Executive Summary)*

Justice claims can play an important role in assembling experiments and making them compelling, particularly by "aligning climate change with other co-benefits in order to address a variety of urban challenges (Bulkeley, Broto, and Edwards 2014)." Yet in an equity context, the phrase "urban renewal" sounds discordant, as it recalls a legacy of Oakland urban planning programs that demolished predominantly African-American neighborhoods to make way for highway construction, to deeply damaging effect (Rhomberg 2004). "Without gentrification" is also nebulous, since gentrification is inherently linked to cycles of disinvestment and reinvestment, much like those required for substantial sustainability upgrades (Lees, Slater, and Wyly 2008).

The potential contradictions in the project's aspirations do not make the EcoBlock exceptional among urban sustainability initiatives, but in fact very much part of the tradition of eco-city, district, and eco-village projects. The cases discussed in this appendix show how the challenges the EcoBlock project faced during Phase 1 are commonplace. Even longstanding weatherization programs face barriers of trust and community engagement, let alone completely novel and cutting-edge technology testing and deployment.

However, it is encouraging that the California Energy Commission and EPIC program are clearly receptive to the overlapping issues emergent at the intersections of sustainable urban systems, housing, transportation, and social equity. In the California Public Utilities Commission proceeding on EPIC, social science researchers underlined the need for funding research that conducted empirical analyses of electricity policy (Campbell 2017). Environmental justice advocates highlighted the importance of EPIC resources being dedicated to projects located in and benefitting disadvantaged communities (Stano et al. 2017).

The findings from this research underline the importance of the broader positions taken by these groups, but might offer an additional important insight. Simply earmarking resources for specific geographies does not ensure that a project's design and implementation will realize the environmental and social justice goals implicit in making such targeted investments; as this research shows, those most enthusiastic about participating, are, as with other retrofit programs, disproportionately the relatively well-off, even in areas with lower incomes on average. If the Energy Commission wishes to address equity issues in its funding, more social research, in economics and beyond, is necessary to understand the drivers and barriers to equitable adoption of sustainable technologies, especially for community-scale initiatives.

The EcoBlock planning team acknowledged the demands that the project would place on residents, reflected in the flexibility of the final master plan. Given the unique nature of the pilot, it will also be essential to build strong relationships with residents who, while sure to potentially gain from the investments, would also necessarily extend their time and effort to participate in its realization.

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