Air Quality Impacts of Hydrogen Infrastructure and Fuel Cell Vehicles

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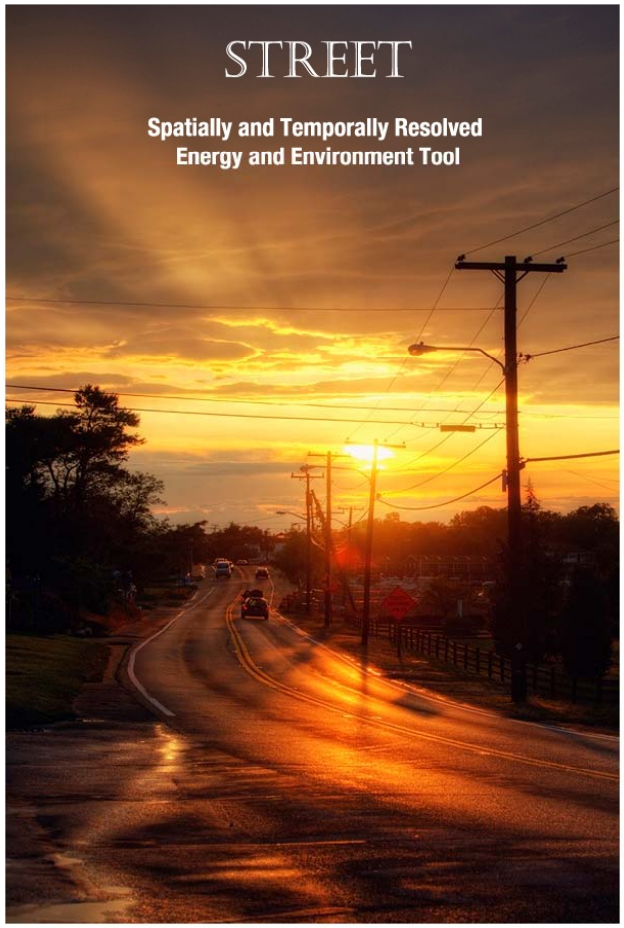
Capabilities at UC Irvine

Critical requirements for energy & transportation infrastructure planning

- Emissions and efficiency characterization of relevant technologies
- Geographic information systems (GIS) data to account for land use as part of a comprehensive infrastructure planning approach
- Emissions and energy use models that represent integrated (well-to-wheels) fuel cycle and energy infrastructure
- Ability to estimate spatial, temporal, and chemically speciated distribution of emissions
- Atmospheric chemical transport modeling to evaluate air quality impacts
- Parallel supercomputer infrastructure to perform simulations



CAPABILTIES

A **systematic** and **highly resolved land-use based** methodology to establish and evaluate **energy infrastructure** (e.g., hydrogen, natural gas, biofuel, electricity) and its **environmental impacts**

SUPPORT

- Air Resources Board
- South Coast Air Quality Management District
- San Joaquin Air Pollution Control District
- U.S. Department of Energy
- California Energy Commission
- U.S. Environmental Protection Agency

Illustrative Case Studies

Region: South Coast Air Basin of California (SoCAB)

Year: 2050

Scenarios:

Vehicle technology	Vehicle penetration	Vehicle population	Gasoline use (gal/day)	Hydrogen use (GGE/day)	Electricity use (MWh/day)
PHEV	100%	14,085,970	9,045,116	-	105,700
FCV	100%	14,085,970	-	7,294,718	-
PFCV	100%	14,085,970	-	2,596,920	105,700
Baseline (EMFAC Model)	Conventional vehicle mix	14,085,970	24,907,630	-	-

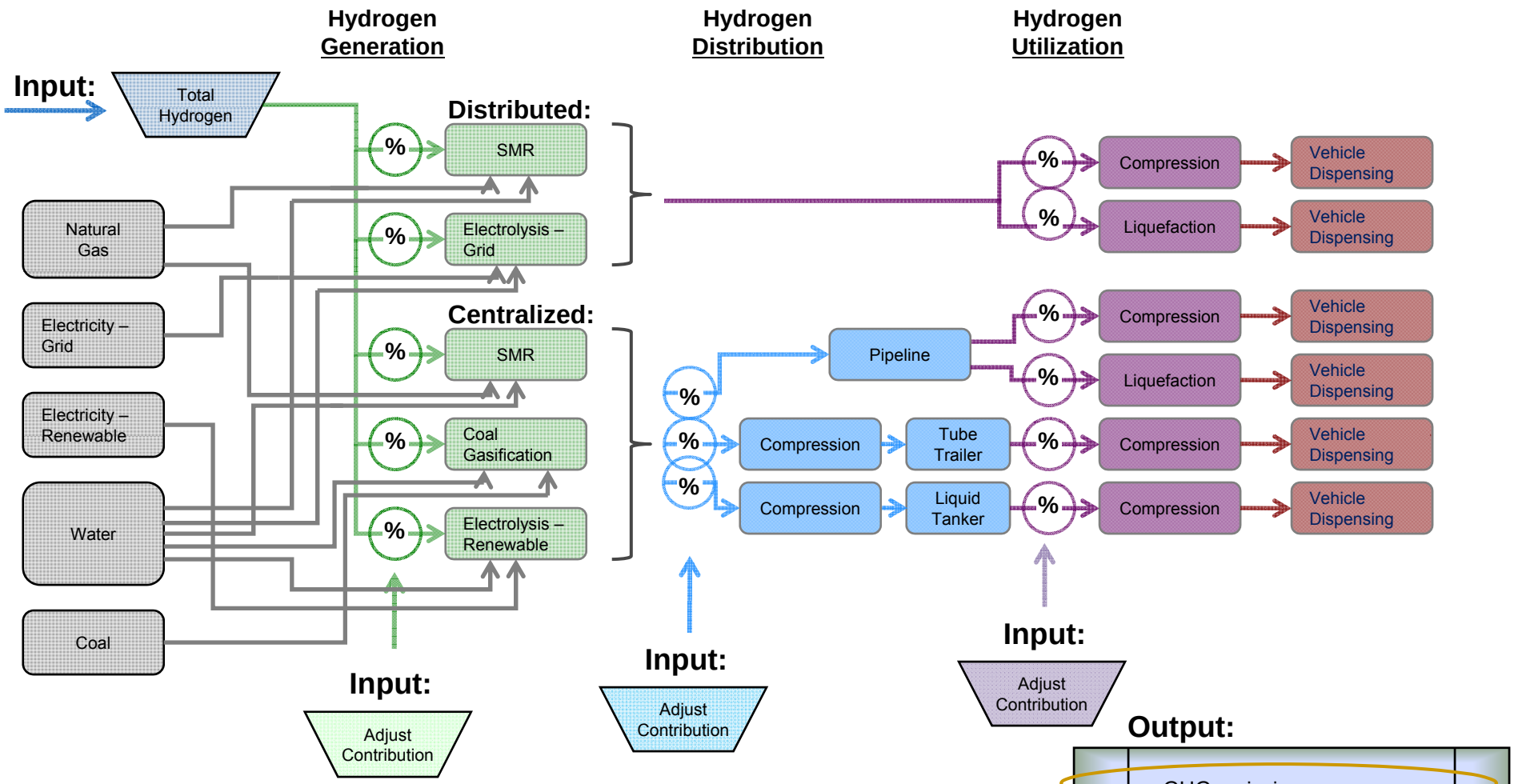
PHEV – Plug-in hybrid: gasoline/battery-electric vehicles with 40 miles all electric range

FCV – Hydrogen fuel cell vehicle

PFCV – Plug-in hybrid: hydrogen fuel cell/battery vehicle with 40 miles all electric range

Baseline – EMFAC projected mix of conventional automobile technologies (gasoline ICE, and gasoline hybrids)

Integrated Fuel Cycle Analysis - Hydrogen



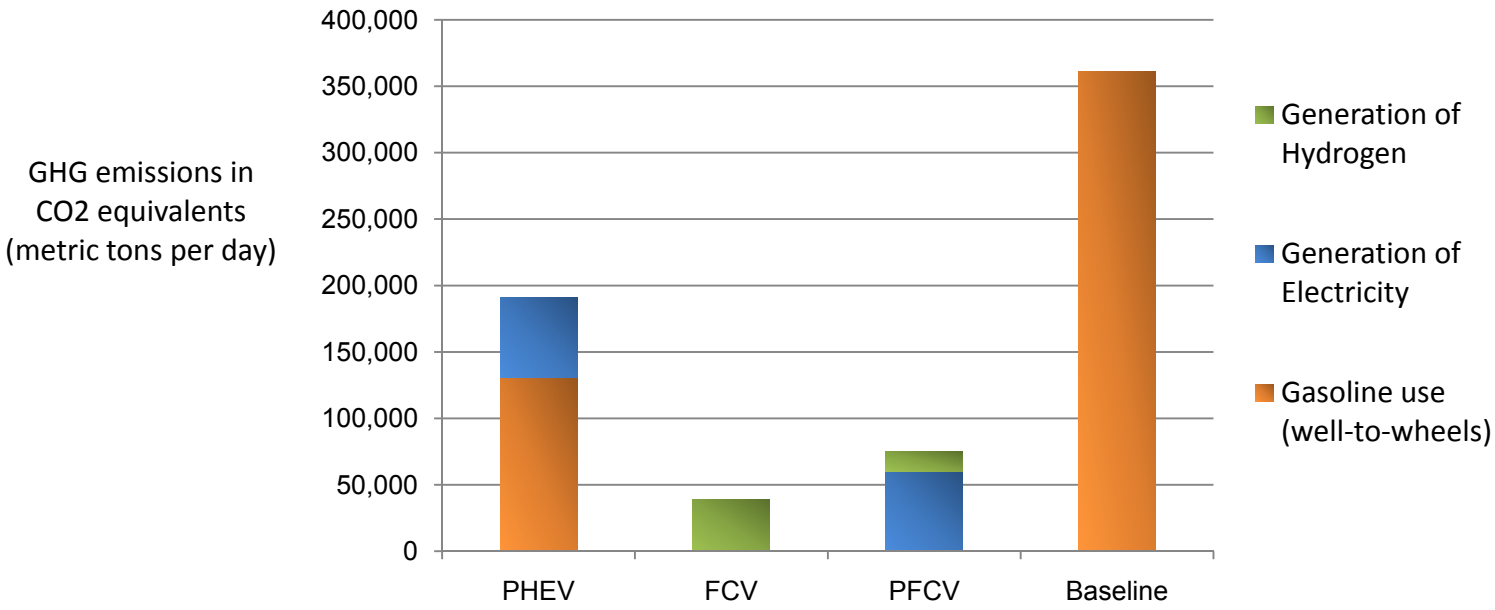
Output:

- GHG emissions
- Energy consumption
- Criteria pollutant emissions
- Water consumption

Well-to-Wheels Greenhouse Gas Emissions

- GHG emissions
- Energy consumption
- Criteria pollutant emissions
- Water consumption

ons associated with passenger vehicles in the SoCAB for several scenarios



	Scenario-R: H_2 generated from more renewable sources				Scenario-F: H_2 generated from more fossil fuel sources			
Population of HFCV				10,162,500				10,162,500
Hydrogen demand (kg/day)				5,943,730				5,943,730
VKT/day by HFCV[a]				573,807,694				573,807,694
Hydrogen Generation	Number of facilities	H_2 output (kg/day)	Percent contribution	Location relative to the SoCAB	Number of facilities	H_2 output (kg/day)	Percent contribution	Location relative to the SoCAB
Centralized								
Steam Methane Reforming	15	2,022,285	34.0%	Inside	16	2,157,104	36.3%	Inside
Coal IGCC[b]	5	641,560	10.8%	Outside	12	1,539,744	25.9%	Outside
Petroleum Coke IGCC[c]	0	0	0.0%	Inside	2	247,466	4.2%	Inside
Electrolysis[d]	7	1,905,133	32.1%	Outside	7	429,196	7.2%	Outside
Distributed								
Steam Methane Reforming	155	135,700	2.3%	Inside	155	135,700	2.3%	Inside
Stationary Fuel Cell[e]	2,023	736,372	12.4%	Inside	2,560	931,840	15.7%	Inside
Electrolysis[f]	950	305,942	5.1%	Inside	950	305,942	5.1%	Inside
Home or Office Fueling	39,348	196,738	3.3%	Inside	39,348	196,738	3.3%	Inside
Hydrogen Distribution	Distance (km/kg H_2)	H_2 throughput (kg/day)			Distance (km/kg H_2)	H_2 throughput (kg/day)		
Remote pipelines	80	2,546,693			80	1,968,940		
Urban pipelines	24	3,064,615			24	3,064,615		
Liquid tanker	48	1,504,363			48	1,308,895		
Hydrogen Refueling		H_2 delivered (kg/day)	Percent contribution			H_2 delivered (kg/day)	Percent contribution	
140 bar gaseous fueling		4,108,125	70%			4,108,125	70%	
350 bar gaseous fueling		1,760,625	30%			1,760,625	30%	

[a] Represents 75% of expected passenger vehicle kilometers travelled (VKT) in the SoCAB, year 2060 (ref-EMFAC)

[b] Coal-fired integrated gasification combined cycle plant with carbon capture and storage cogenerating hydrogen and electricity

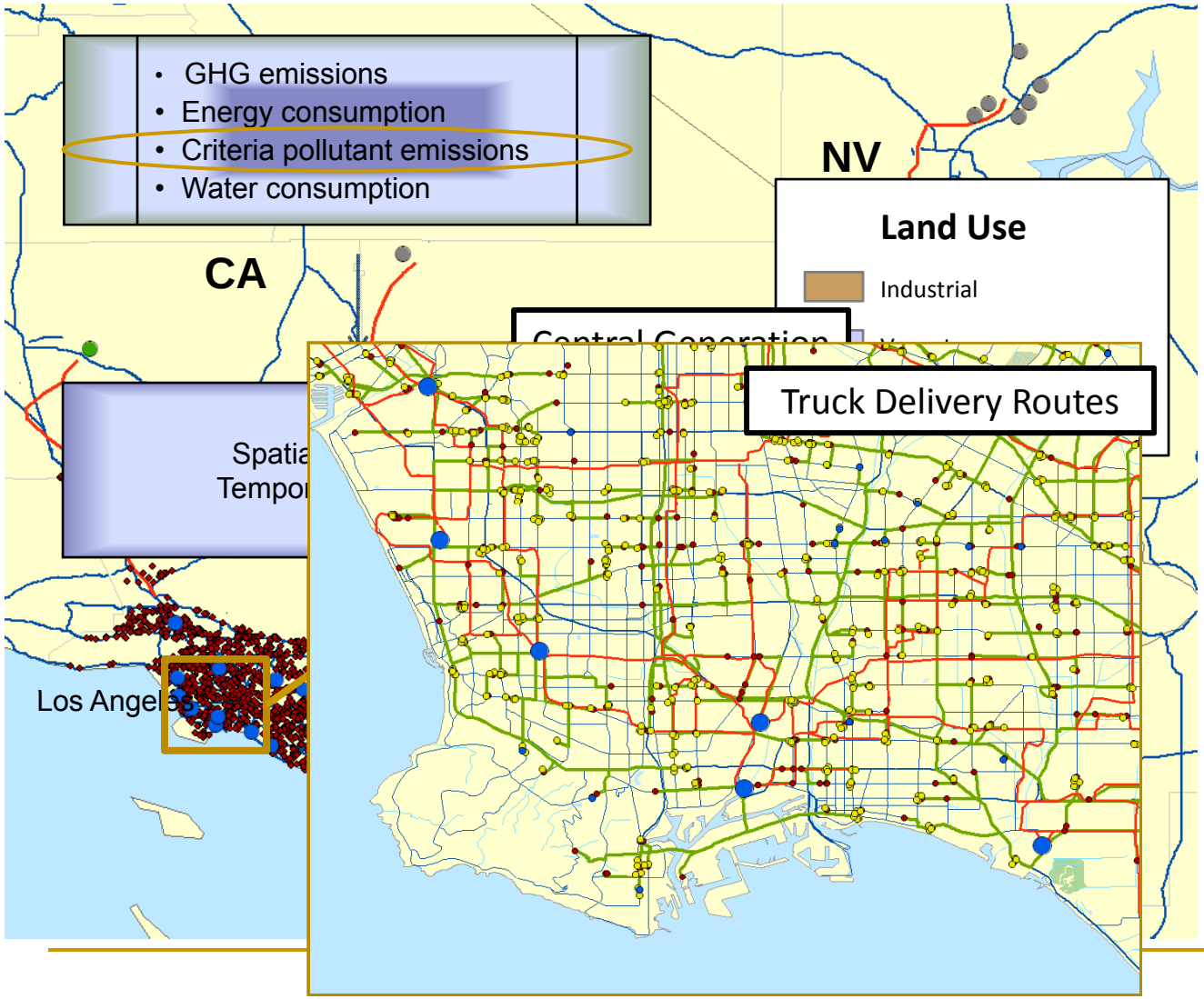
[c] Petroleum coke-fired integrated gasification combined cycle plant cogenerating hydrogen and electricity

[d] Electrolysis is powered by mostly renewable and some nuclear electricity

[E] Cogenerates hydrogen, electrical power, and heat

[f] Electrolysis is powered by photovoltaic electricity

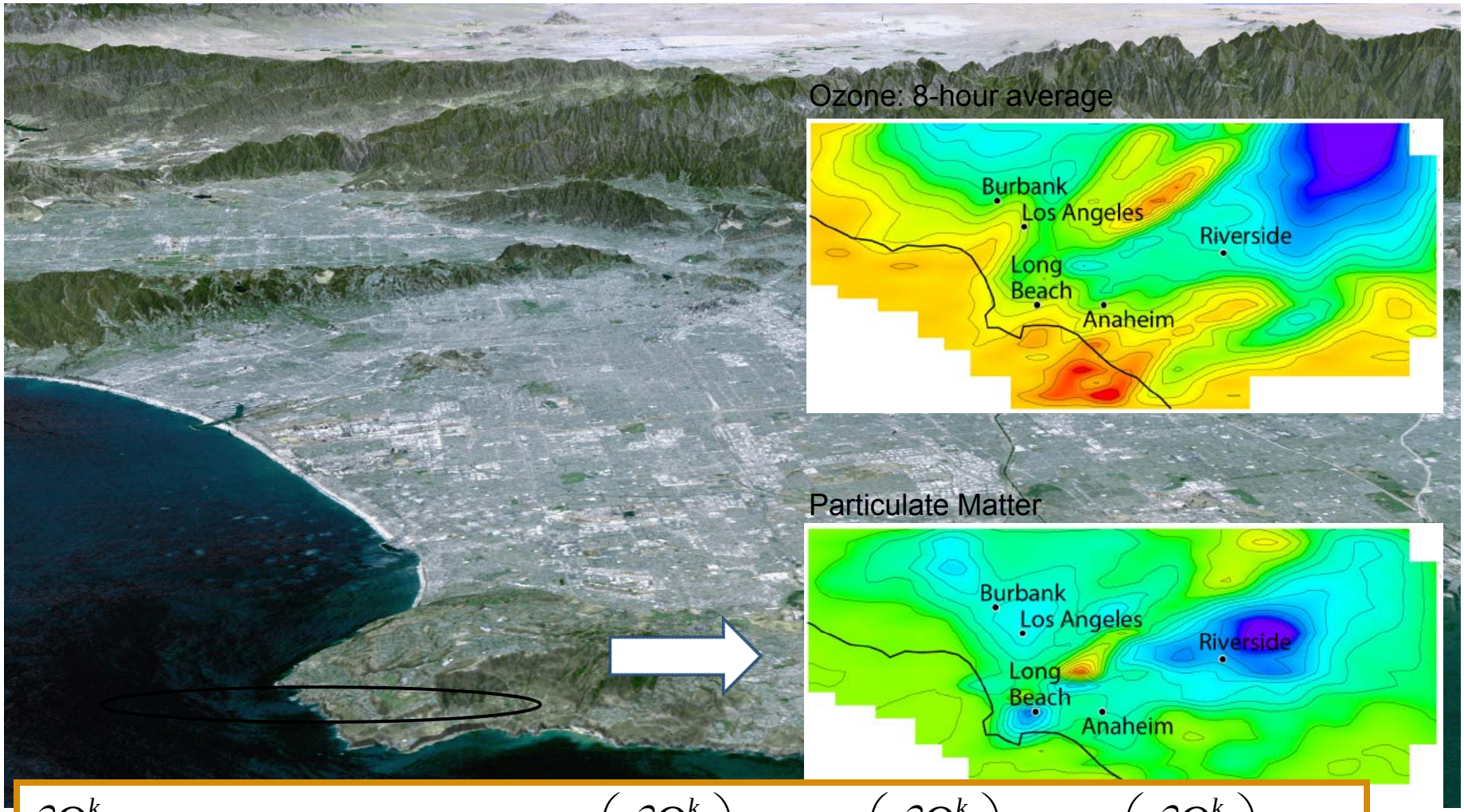
Spatial & Temporal Distribution of Emissions



Southern California
Year: 2050

- H2 Fueling Stations
- Regional SMR
- Regional Petroleum Coke
- Central Coal/Biomass
- Central Renewable /Nuclear
- Local High-Temp Fuel Cells
- Distributed SMR
- Interstates & Freeways
- H2 Pipelines
- H2 Truck Deliver Routes

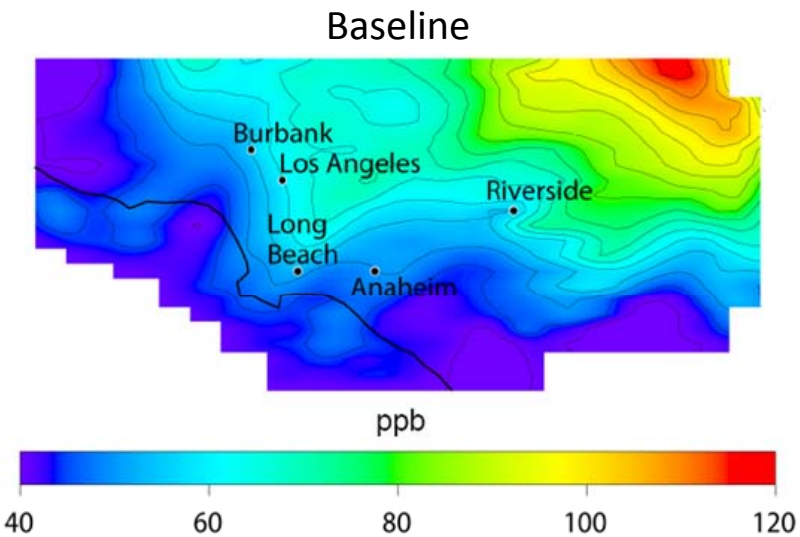
Air Quality Pollutant Emissions

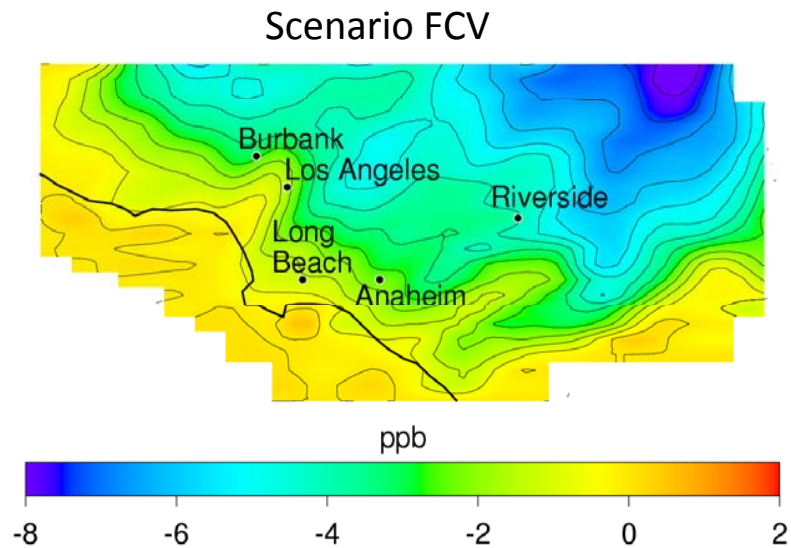


$$\frac{\partial Q_m^k}{\partial t} + \nabla \cdot \left(u Q_m^k \right) = \nabla \cdot \left(K \nabla Q_m^k \right) + \left(\frac{\partial Q_m^k}{\partial t} \right)_{\substack{sources/\\sinks}} + \left(\frac{\partial Q_m^k}{\partial t} \right)_{aerosol} + \left(\frac{\partial Q_m^k}{\partial t} \right)_{chemistry}$$

Results: Ozone

Ozone: 8-hour average
[Δ Scenario vs. Baseline]

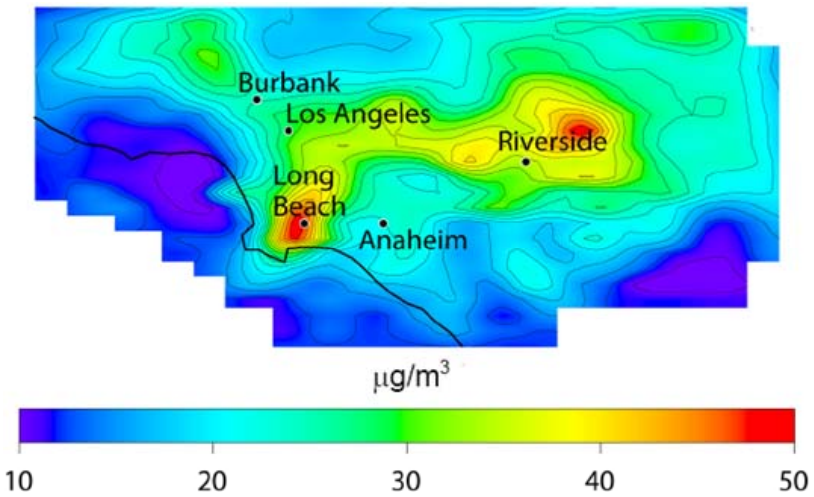




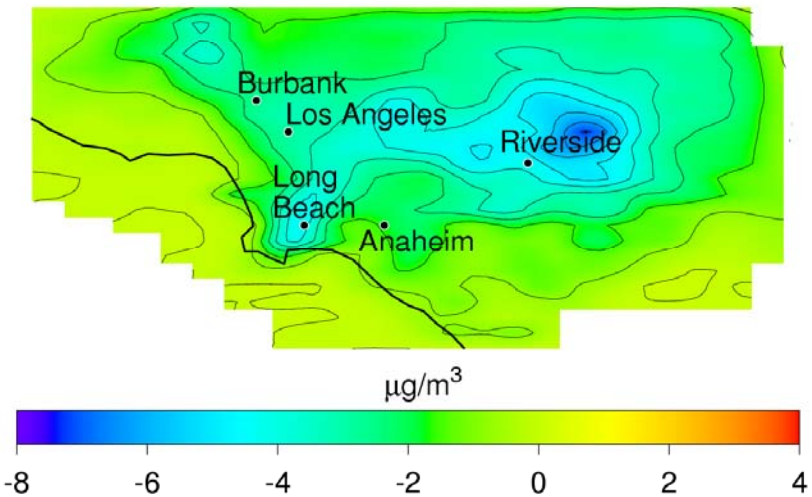
Results: $PM_{2.5}$

$PM_{2.5}$: 24-hour average
[Δ Scenario vs. Baseline]

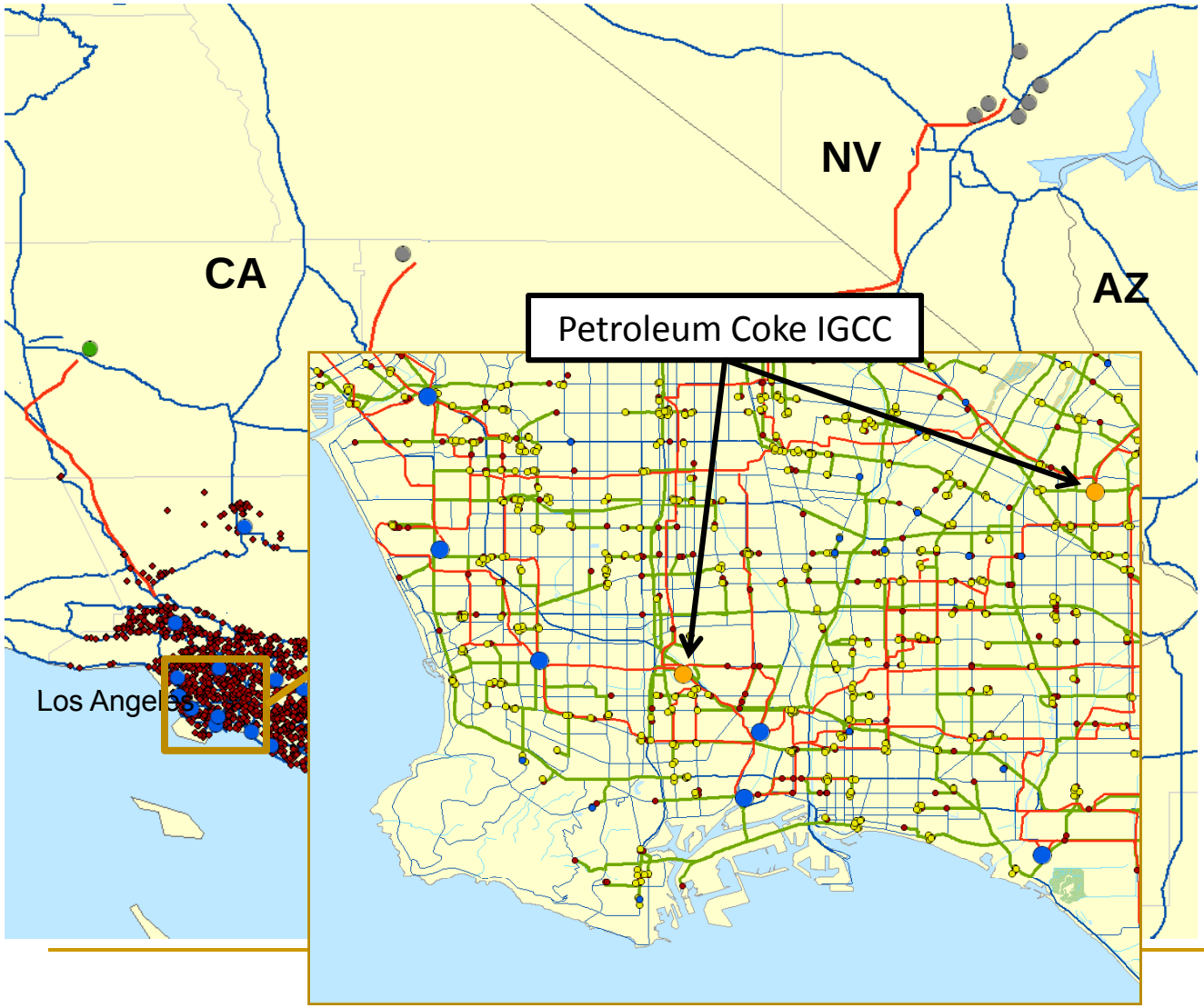
Baseline



Scenario FCV



Spatial & Temporal Distribution of Emissions



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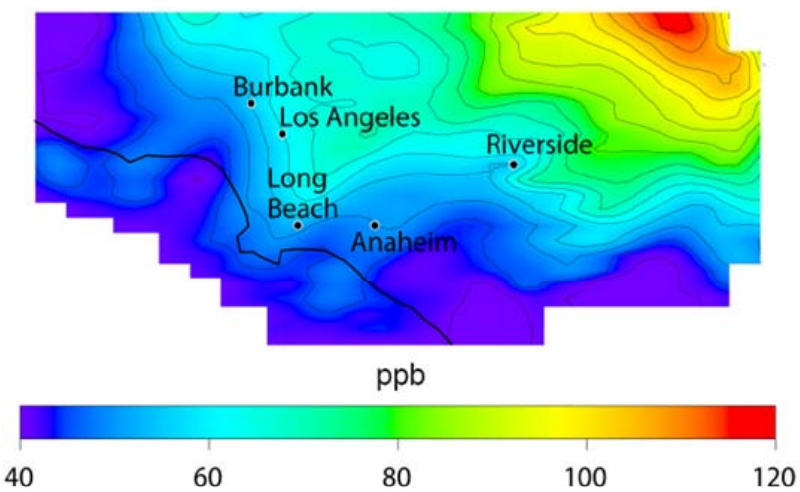
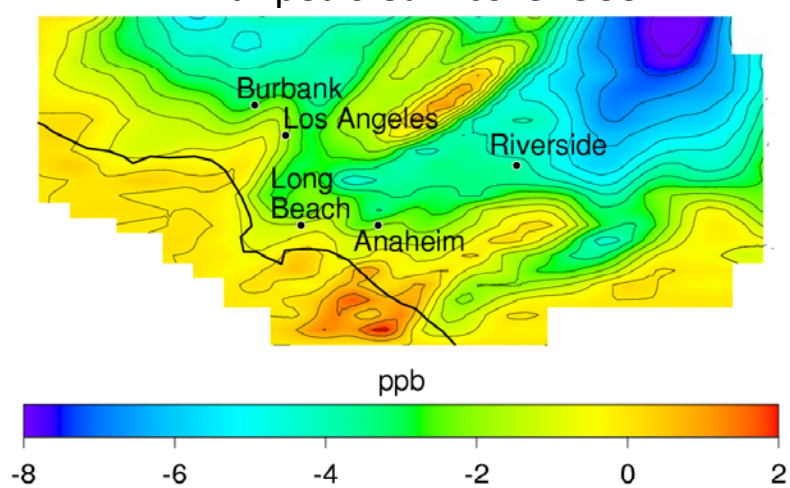
Baseline



With petroleum coke IGCC



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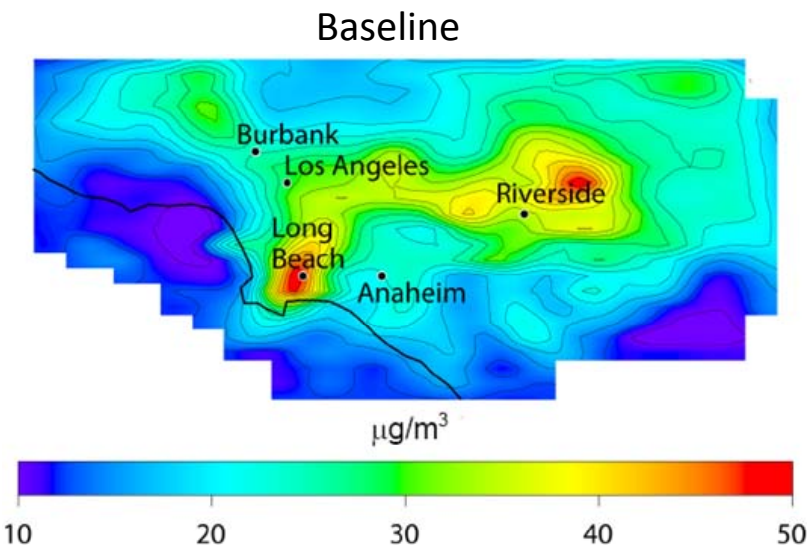

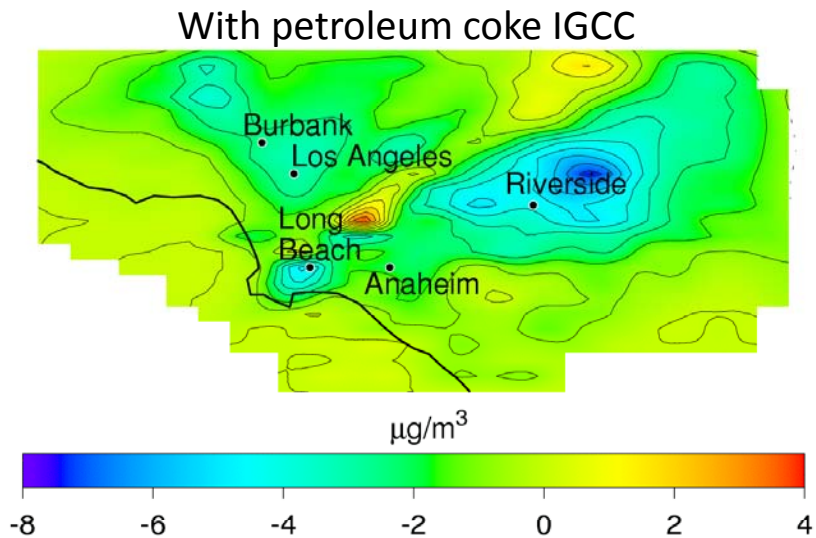

Conclusion

- First highly-resolved module to couple H_2 infrastructure and vehicles with air quality model
- Future work to include additional fuel paths and highly resolved infrastructure deployment

- Stephens-Romero S.D., Samuelsen G.S., **2008**. Demonstration of a novel assessment methodology for hydrogen infrastructure deployment . *International Journal of Hydrogen Energy*. 34, 628-641.
- Stephens-Romero S.D., Carreras-Sospedra M., Dabdub D., Brouwer J., Samuelsen G.S., **2009**. Determining Air Quality Impacts of Hydrogen Infrastructure and Fuel Cell Vehicles. *Environmental Science Technology.* 43, 9022-9029.

Thanks!

PARTNERS
Air Products, Toyota, Honda, General Motors,
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NATIONAL FUEL CELL RESEARCH CENTER
NFCRC
SUPPORT
South Coast Air Quality Management District
San Joaquin Air Pollution Control District
Air Resources Board
California Energy Commission
U.S. EPA
U.S. Department of Energy