Energy Research and Development Division

FINAL PROJECT REPORT

Research Roadmap for Advancing Technologies in California's Industrial, Agriculture and Water Sectors

California Energy Commission

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public research investments to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The Energy Commission and the state's three largest investor-owned utilities – Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company – administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Research Roadmap for Advancing Technologies in California's Industrial, Agriculture, and Water Sectors is the final report for the project (Contract Number 300-15-010) conducted by Energetics. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, go to www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The California Energy Commission's Electric Program Investment Charge (EPIC) Program funds clean energy research, development, demonstration, and deployment (RDD&D) projects that improve electricity reliability, affordability, and safety. Meeting those goals requires a strategic portfolio, so a roadmap was commissioned to identify the most important opportunities to produce the greatest benefit for electric ratepayers. The roadmap focuses on the industrial, agricultural, and water sectors. The process was tailored to identify critical technology gaps in these sectors and offer potential solutions. The project included a technical assessment and roadmapping activities. For the technical assessment, analysts conducted an extensive literature review of existing technologies across six technology areas: (1) industrial processing, (2) industrial facilities, (3) industrial power, (4) agriculture, (5) bioenergy, and (6) water and wastewater. The roadmapping effort consisted of 19 webinars and 34 online surveys to engage experts and stakeholders in the different technology areas. Participants identified and discussed high-impact technologies, their potential impacts, barriers to market entry, actions that could support market entry, and success indicators. This project resulted in 123 recommendations of energy-saving technologies in the six technology areas, 81 are state-of-the-art and 42 are in the research and development stage. This roadmap provides a path forward for the EPIC Program, helping inform decision-making for California's energy RDD&D portfolio.

Keywords: *EPIC, research, development, roadmap, energy, bioenergy, technology, industry, agriculture, water, wastewater, efficiency*

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EXECUTIVE SUMMARY

Project Background and Purpose

California is forward-leaning in its goals to reduce energy costs and environmental impacts of energy use while ensuring reliable energy supply. The California Energy Commission's Electric Program Investment Charge (EPIC) Program is responsive to the state's goals to improve electricity reliability, affordability, and safety. EPIC was established in December 2011 to support investments in clean energy technologies that provide benefits to California's electricity ratepayers. The program funds clean energy research, development, demonstration, and deployment (RDD&D) projects that support the state's energy goals.

Recent California legislation and executive orders have set an even higher bar for energy providers and users in the state, seeking to increase energy efficiency, ramp up the generation of renewable power, and reduce emissions contributing to global climate change. To meet these goals, EPIC requires an RDD&D portfolio that strategically targets the right mix of scientific and technological advancements, sets and meets appropriate milestones, and leverages available resources to accelerate the delivery of effective products and practices.

To inform RDD&D portfolio development, EPIC commissioned this roadmap to identify the most important opportunities to yield the greatest benefit to electric ratepayers. The roadmap focuses on the industrial, agricultural, and water sectors. These sectors are vital to California's economy and rely on an affordable and sustained supply of energy, using nearly 30 percent of all energy consumed in California according to the California Energy Commission.

Project Approach

The roadmapping process identified critical technology gaps in the industrial, agricultural, and water sectors and potential solutions. Analysis was divided into six major technology areas: industrial processing, industrial facilities, industrial power, agriculture, bioenergy, and water and wastewater. Three areas were further divided into 13 subareas. Eighty percent of the focus was on state-of-the-art technologies, with the remaining 20 percent on commercially unproven technologies still in the research and development (R&D) stages.

The project consisted of two major phases: the technical assessment and roadmapping activities. For the technical assessment, analysts conducted an extensive literature review of existing technologies across all technology areas and subareas. The objective was to identify, describe, and prioritize current best-in-class technologies and promising R&D technologies. The resulting assessment helped develop a clear, actionable roadmap.

For the roadmapping effort, the Energy Commission and the project team compiled a list of experts and stakeholders in the different technology areas and invited them to participate in the process. The experts were engaged through 19 webinars and 34 online surveys.

In the first two rounds of surveys and webinars, participants identified and discussed high-impact state-of-the-art technologies, their potential impacts, barriers to market entry, actions that could support market entry, and success indicators. The final round focused on high-impact R&D, including potential long-term “game-changing” technologies.

The surveys had 249 responses from 134 unique participants, while the webinars had 117 participants.

Project Results

This project produced recommendations for 123 energy-saving technologies in the six technology areas. Of these 123 technologies, 81 are state-of-the-art and 42 are in the R&D stage. Industrial metals manufacturing had 20 recommendations identified - the most of any of the technology subareas. Water and wastewater treatment was close behind with 17 technology recommendations. The technologies recommended include redesign or replacement of processes, new materials, and enhanced controls.

This roadmap establishes a path forward for the EPIC Program, guiding decision-making for California’s energy RDD&D portfolio and facilitating cost-effective investments that will meet the needs of the state’s electricity consumers.

Technology/Knowledge Transfer Activities

The decision by California Energy Commission to conduct virtual roadmapping activities for this project allowed for a greater reach of involvement and knowledge transfer than may have been possible with an in-person workshop. Nineteen webinars ranging in length from one to two hours were conducted, providing discussions in a variety of different technology areas. Read-ahead materials and technology weighting surveys allowed participants to review technology ideas at their own time and comment accordingly.

Benefits to California

This roadmap identifies promising state-of-the-art and R&D technologies that are considered to be of greatest current value to California in the industrial, agriculture and water sectors. Results of this roadmap are based on a thorough investigative process, including literature research, prioritization and input from technology experts working in these technology areas. The benefit of this roadmapping process and resulting roadmap report is having a single reference that documents current recommended technologies, based on an unbiased and uniform process of evaluation.

CHAPTER 1: Introduction and Method

Objectives of the Roadmap

Recent California legislation and executive orders have set a high bar for energy providers and users in the state. California electric utilities and various classes of end users must achieve 50 percent renewable generation by 2030; double the energy efficiency of buildings. They are also required to:

- Facilitate the generation, transmission, and distribution of renewable energy, including needed interconnections and control systems
- Update the scoping plan to reduce carbon and other greenhouse gas emissions
- Remove the extreme fire hazard presented by drought- and pest-impacted woody biomass
- Address other drought-related laws and executive actions related to water conservation, storage, and supply (California Air Resources Board 2017; Governor of California 2015; Governor of California 2017; State of California 2015).

The EPIC Program conducts RDD&D activities to that benefit ratepayers by improving electricity reliability, affordability, and safety. The roadmap was commissioned to help achieve California's forward-leaning legislative goals to increase energy efficiency, ramp up the generation of renewable power, and reduce emissions contributing to global climate change. To meet these goals, EPIC requires a portfolio that targets the right mix of scientific and technological advancements, sets and meets appropriate milestones, and leverages available resources to accelerate the delivery of effective products and practices. Broad market uptake of these new technologies is essential to attaining state energy and environmental goals.

EPIC wants to accelerate RDD&D progress in meeting the critical needs and expectations of its utilities, ratepayers, and customers in the industrial, agricultural, and water (IAW) sector. This will help California to achieve its energy and water goals. This roadmap frames the technology priorities that EPIC can use to further these efforts.

Method

Roadmap Framework

To provide a useful roadmap for EPIC activities, the process identified critical technology gaps in the IAW sectors and potential solutions. The project was developed under the direction of the Energy Commission's IAW representatives, and a technical advisory committee provided periodic input on outreach activities. Energetics led the 18-month project with support from subcontractors: DAV Energy; TSS Consultants; the University of California, Davis (UC Davis); and RCM International. The project's goal was to identify the most important opportunities to yield the greatest benefit for electric ratepayers.

The project involved the technical assessment and roadmapping activities. The assessment conducted an extensive literature review to identify and prioritize IAW sector electrical energy-saving technologies. Energy Commission IAW managers indicated their preferences in prioritizing state-of-the-art technology opportunities, technologies with proven full-scale application. It was decided early to devote 80 percent of the technology focus to state-of-the-art technologies, with the remaining 20 percent on technologies in the R&D phase and commercially unproven. The technical assessment was used as the basis for roadmapping outreach and engagement with experts. To engage a large number of experts in the different technology areas, online surveys and webinars were conducted to discuss priority state-of-the-art technologies and technologies in the R&D phase, barriers to market entry for these technologies, and actions that can be taken to speed up market entry of high-impact technologies.

Technology Identification Focus:

80 percent state-of-art
(proven full-scale application)

20 percent R&D
(commercially unproven)

In the technical assessment and virtual roadmapping meetings, analysis was divided into six major technology areas: (1) industrial processing, (2) industrial facilities, (3) industrial power, (4) agriculture, (5) bioenergy, and (6) water and wastewater. Three areas were further divided into subareas, for a total of 13 subareas.

Table 1 outlines the six technology areas and 13 subareas of study in this report.

High-opportunity technologies were identified in 16 of the 19 technology areas of study.

Technical Assessment

Building a research roadmap for investing EPIC funds requires assessing the existing state-of-the-art and R&D technologies in the IAW sectors. The assessment identified, described, and prioritized current best-in-class IAW sector technologies, as well as the most promising R&D technologies, including performance attributes. This information provided a basis of reference in subsequent research roadmap activities.

In developing the assessment, analysts with diverse subject matter expertise conducted an extensive literature review across all technology areas and subareas in the IAW sectors. The team identified and prioritized technology needs for achieving California's goals for advancing energy efficiency in these sectors. Technologies identified through the literature search were prioritized with input from Energy Commission IAW managers.

Table 1: Technology Areas and Subareas in the IAW Roadmap

Technology Area	Technology Subarea
Industrial Processing	
	Glass Manufacturing
	Cement Manufacturing
	Metals Manufacturing
	Chemicals Manufacturing
	Plastics Manufacturing
	Pulp and Paper Manufacturing
	Petroleum Refining
	Oil and Gas Extraction
Industrial Facilities and Power	
Data Centers	
Bioenergy	Anaerobic Digestion
	Gasification
Agriculture	
	Electricity-Intensive Agriculture
	Irrigation
	Food and Beverage Processing
Water and Wastewater	

Source: Energetics

The assessment focused on areas of greatest potential impact to California electricity ratepayers. After identifying promising advanced energy technologies and strategies, the analysts worked with Energy Commission IAW managers to prioritize those technologies and strategies, identifying which should be further evaluated. Priority ranking was based on the potential value to ratepayers. The ranking considered both improved performance and reduced cost, allowing decision makers to make cost-effective investments that will meet the needs of the state's electricity consumers. Criteria for prioritization also included data quality, data quantity, and R&D technology readiness level. The effort reduced the number of technologies recommended for further evaluation from 325 to 91.

The resulting assessment served as a reference in developing a clear, actionable roadmap, presenting the findings in a uniform format that had quantitative cost and energy performance data.

Roadmapping

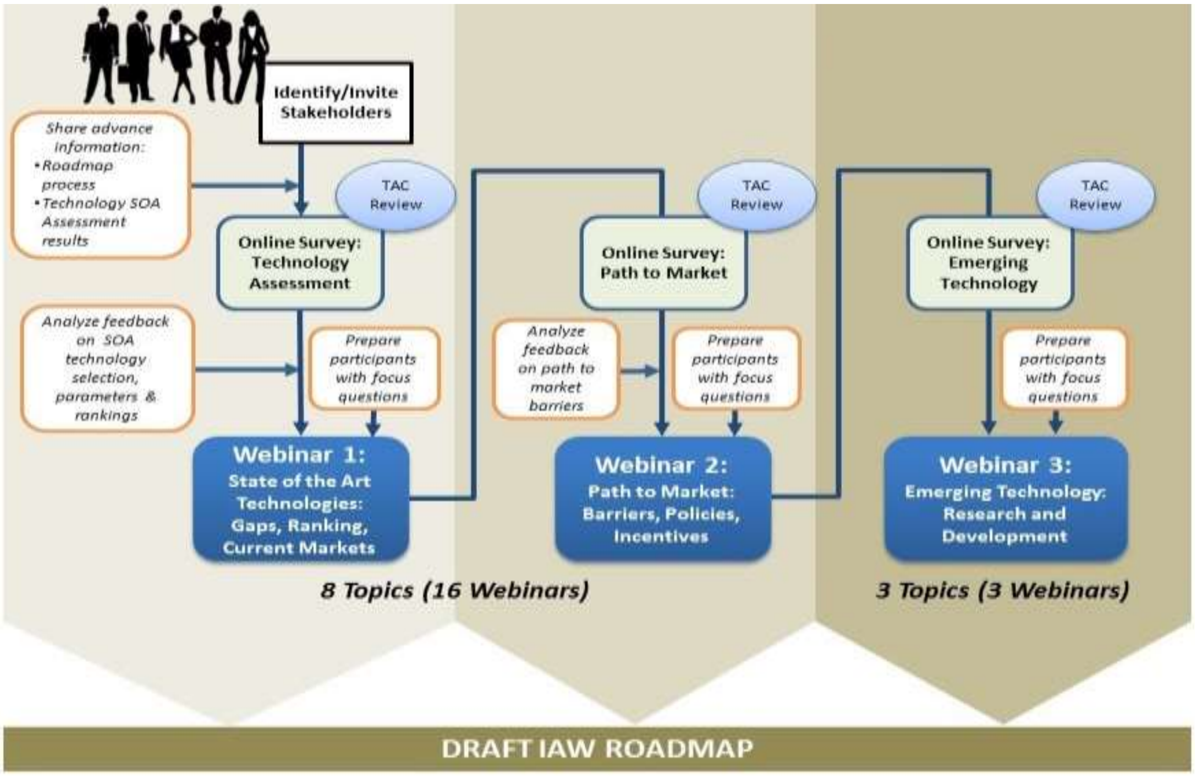
For the roadmapping effort, the project team used virtual meetings to engage experts in the different technology areas. Three rounds of webinars, for a total of 19 webinars, were held. Before each webinar, participants were provided read ahead materials and asked to complete an on-line survey whose results were used as a starting point for the webinar discussions. For each technology area, the Energy Commission and the project team compiled a list of experts and stakeholders who were invited to participate in the process, as well as a contacts catalogue to track the affiliations and participation of identified individuals.

In the first round of surveys and webinars, participants identified high-impact state-of-the art technologies and evaluated their potential impacts. The second round focused on barriers to market entry for identified high-impact state-of-the-art technologies, actions that can be taken to support market entry of the technologies, and success indicators. In the final round, participants identified high-impact R&D, including potential long-term "game-changing" technologies, as well as actions to hasten market entry of these technologies. Figure 1 provides a high-level overview of the roadmapping process.

The process involved 34 online surveys and 19 webinars. The surveys yielded 249 responses from 134 unique participants, while the webinars had 117 participants. Among participants in both the surveys and webinars, individuals with backgrounds in industry were most heavily represented, followed by individuals with backgrounds in consulting and government work.

Table 2 provides a summary of participation in the webinars and surveys.

Figure 1: Energetics' Virtual Roadmapping Process Flow



Source: Energetics

Table 2: Webinar Attendance Statistics

Attendance Statistics		
	Surveys	**Webinars**
Total Submissions/Attendance	249	182
Number of Unique Participants	134	117
Participant Backgrounds		
	Surveys	**Webinars**
Academia	14	8
Consultant	29	14
Government	27	14
Industry	43	22
Technology Developer	21	9
Unknown	0	50
Total	134	117

Source: Energetics

Importance of the Industrial, Agricultural, and Water Sectors

The IAW sectors in California consume significant amounts of energy. To better understand the sectors that have the greatest potential for energy savings and where the Energy Commission should focus its activities and investments, it is helpful to compare energy consumption patterns in these industries in relative energy terms.

Energy consumption data for the different IAW sectors has been estimated based on utility data, as well as reported state and federal data. Figure 2 provides 2016 electrical and natural gas energy consumption estimates by sector. This information is from investor-owned utility (IOU) data in California. Figure 3 provides estimated 2014 electrical and total energy consumption in California by sector based on reported federal and state data from the U.S. Energy Information Administration (EIA) and the U.S. Census Bureau.

EIA data from the 2014 Manufacturing Energy Consumption Survey (MECS) for the Western region[1] was used to determine regional electrical and total energy consumption; North American Industry Classification System (NAICS) codes were aligned with the IAW sectors (Figure 3). The Census Bureau's County Business Patterns (CBP) surveys were used to determine the number of employees by sector. The Census Bureau's Annual Survey of Manufacturers (ASM) was used to determine the total value of shipments and receipts for services by sector. The project's analysts used these sources to estimate annual electrical and total energy consumption. MECS Western region conversion factors were multiplied by state-level statistics from CBP and ASM to estimate energy consumption by sector. For example, 1,575 million Btu (MMBtu) per employee (MECS 2014 reference) was multiplied by 74,445 employees in the

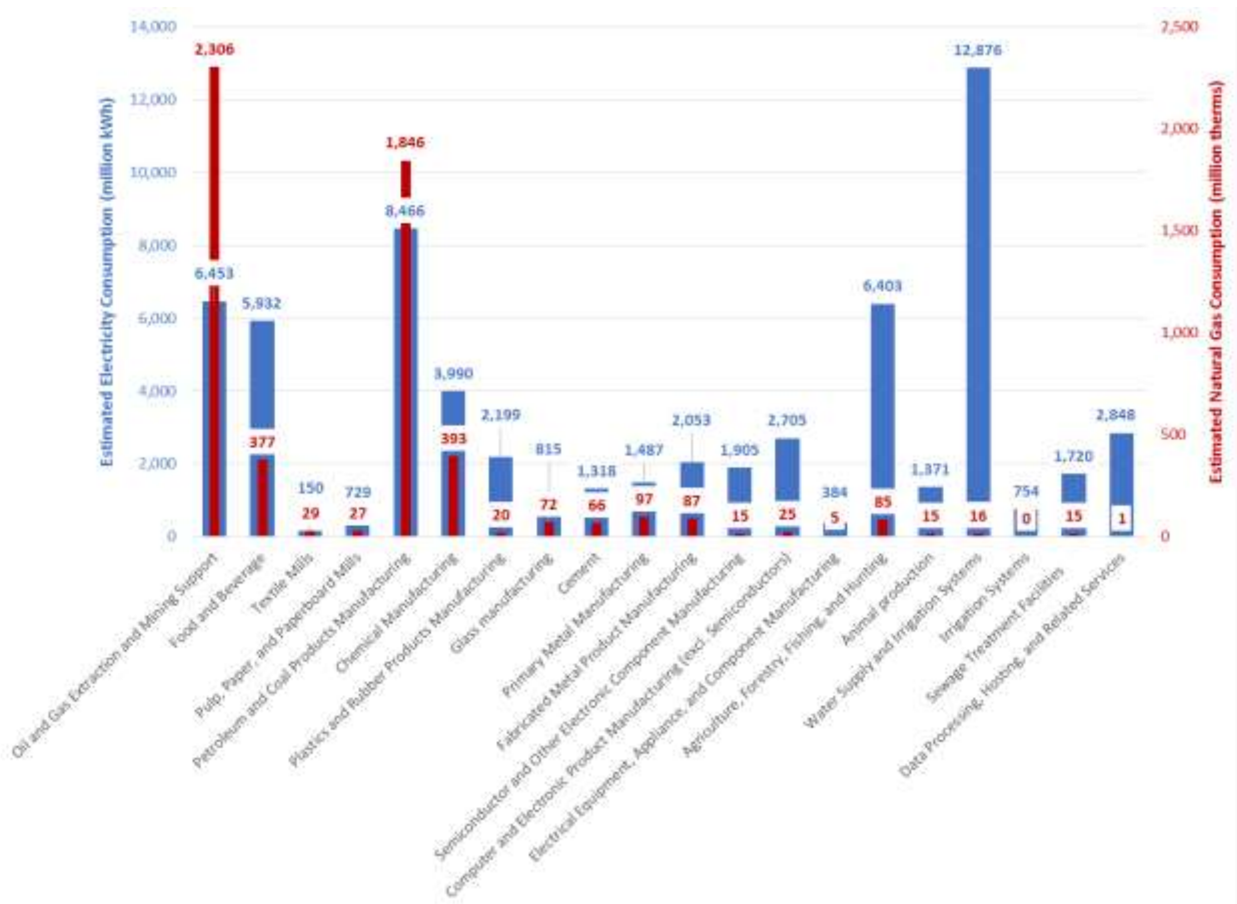
[1] States in the West Census region are Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf

chemicals sector in California in 2014 (CBP reference), to estimate 117 trillion Btu (TBtu) per year. To improve the validity of this estimation approach, a second state-level statistic from ASM was used: value of shipments and receipts for services in 2014. The MECS conversion estimates using two different state-level statistics (CBP and ASM) were averaged to determine the values in Figure 3. For the example, estimated chemicals sector consumption referencing ASM statistics was 153 trillion Btu per year, resulting in an average of 135 TBtu per year total energy consumption in 2014.

The state consumption estimates based on federal data serve as a secondary verification source for the IOU data estimates in Figure 2. Both summaries are provided here to align with the IAW roadmap technology areas and subareas of study (

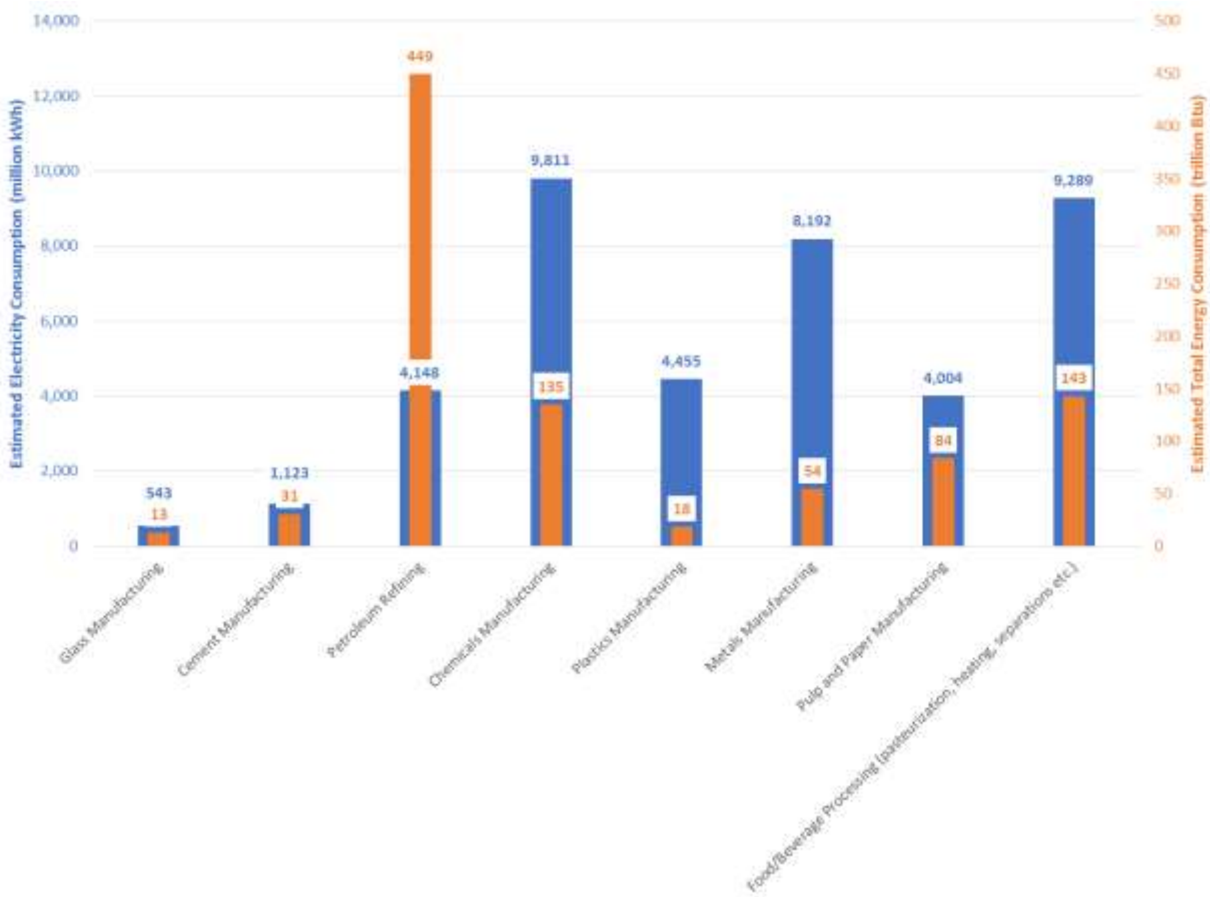
Table 1). In some cases, the sector estimates in Figure 3 differ, sometimes significantly, from Figure 2 estimates. Figure 2 estimates should be considered a more accurate representation of consumption, owing to the estimating approach.

Figure 2: Electrical and Natural Gas Energy Consumption in California for IAW Sectors, Referencing State IOU Sector Estimate Data, 2016



Source: California Energy Commission 2016

Figure 3: Estimated Electrical and Total Energy Consumption in California for IAW Sectors, Referencing Federal and County Data, 2014



Sources: EIA 2014 (MECS), U.S. Census Bureau 2014a (ASM), U.S. Census Bureau 2014b (CBP), and U.S. Census Bureau 2014c (NAICS definitions)

CHAPTER 2: Relevant California Policies

Identifying the technology opportunities in California requires looking at the relevant state policies and legislation. Table 3 outlines the large range of California policies and legislation that have impacts on the technologies identified in the roadmapping project.

Appendix B describes these policies and legislation and a summary of the functions for each California state policy or legislation. In the subsequent chapters, specific technologies are aligned with these policies and legislative directives. Appendix C provides excerpts for these policy and legislative directives, in alignment with the six technology areas studied.

Table 3: Summary of California Policies and Legislation that Affect Technological Development within the Proposed Task Areas

State Policy or Legislation	Industrial Processing	Industrial Facilities and Power	Data Centers	Bioenergy	Agriculture	Water and Wastewater
California Air Resources Board						
California's 2017 Climate Change Scoping Plan	X	X	X	X	X	X
CARB AB 32 Scoping Plan				X	X	
Short-Lived Climate Pollutant Reduction Strategy				X		
Assembly Bills						
AB 32	X			X	X	
AB 221	X					
AB 262	X					
AB 324	X					
AB 758	X	X	X			
AB 1158	X					
AB 1594				X		
AB 1613	X	X				
AB 1826				X		
AB 1923				X		
AB 2717						X
California Department of Food and Agriculture (CDFA)						

State Policy or Legislation	Industrial Processing	Industrial Facilities and Power	Data Centers	Bioenergy	Agriculture	Water and Wastewater
Dairy Digester Research and Development Program				X		
California Department of Forestry and Fire Protection (CAL FIRE)						
Forest Climate Action Team				X		
California Department of Resources Recycling and Recovery (CalRecycle)						
Greenhouse Gas Reduction Grant and Loan Program	X			X		
Recycled Fiber, Plastic, and Glass Grant Program	X					
California Codes						
Public Resources Code 25601	X	X	X			
Public Resources Code 25620	X	X	X	X	X	
Warren–Alquist Act	X	X	X	X	X	X
California Public Utilities Commission						
Energy Efficiency Strategic Plan	X				X	X
Renewables Portfolio Standard				X		
Self-Generation Incentive Program				X		
California Energy Commission						
Bioenergy Action Plan				X		
Building Energy Efficiency Standards		X	X			
Energy Action Plan	X			X	X	X
Energy Commission Energy Innovations Small Grant (EISG) Program	X			X	X	
Integrated Energy Policy Report	X	X	X	X	X	X

State Policy or Legislation	Industrial Processin g	Industrial Facilities and Power	Data Centers	Bioenergy	Agriculture	Water and Wastewater
Executive Orders						
Clean Energy Jobs Plan	X	X			X	
Executive Order B-29-15						X
Executive Order B-30-15	X			X	X	
Executive Order B-37-16					X	
Executive Order B-40-17					X	
Executive Order S-03-05	X			X	X	
Executive Order S-06-06				X		
Executive Order S-18-12	X	X	X			
Governor's Proclamation of State of Emergency, 10/30/2015				X		
Other						
Western Regional Climate Action Initiative	X				X	
Senate Bills						
SB 32	X			X	X	
SB 71	X					
SB 332	X					
SB 350	X	X	X	X	X	X
SB 966						X
SB 1106	X					
SB 1122				X		
SB 1250						X
SB 1300	X					
SB 1383				X		
SB 1389						X
SB X1-2	X			X	X	
SB X7-7					X	X

Source: Energetics

CHAPTER 3:
Industrial Processing State-of-the-Art Opportunities

Industrial Processing Introduction

Industrial processing is the broadest technology area in this roadmap. Table 8 shows eight distinct industrial processing subareas of study. In California, industrial processing energy use is approximately 56 percent of total electrical energy use and 99 percent of total natural gas use. This estimate is based on California utility data provided to the Energy Commission's demand analysis office, where combined industrial processing energy consumption totals 29,025 million kilowatt-hours (kWh) electric and 517 trillion British thermal units (TBtu) of natural gas consumption in 2016 (California Energy Commission 2016). Industrial processing companies are also some of the largest employers in the state, with 10,631 establishments and 316,924 employees as of March 12, 2014 (U.S. Census Bureau 2014b). The total number of employees and facilities by subarea are provided in this chapter.

Table 4: Industrial Processing Subareas of Study

Technology Area of Study	Subareas of Study
Industrial Processing	Glass
	Cement
	Metals
	Chemicals
	Plastics
	Pulp and Paper
	Petroleum Refining
	Oil and Gas Extraction

Source: Energetics

Glass Manufacturing

The total energy consumption for glass manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region and assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption for glass manufacturing in California, 13 TBtu and 542 million kWh, respectively. In Table 5, energy consumption is further broken down by type of glass manufactured.

Table 5: Glass Products Manufacturing Statistics in California, 2014

Sector*	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Flat Glass	327211	3.8	215	16	806
Other Pressed and Blown Glass and Glassware	327212	1.2	100	66	615
Glass Containers	327213	6.3	214	10	1,750
Purchased Glass Products	327215	1.7	13	162	4,933
Total	**—**	**13**	**542**	**254**	**8,104**

***Fiberglass manufacturing is not listed in this statistics table, as this falls under NAICS 327993 (Mineral Wool Manufacturing). Mineral wool manufacturing is not included here because it includes mineral wool from rock and slag (outside of the scope of glass manufacturing).**

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Glass Manufacturing Technical Assessment

The assessment identified three priority state-of-the-art technologies for electricity savings. The assessment report provides further details on the technology impacts and development status and the references consulted.

State-of-the-Art Technologies from the Technical Assessment

- **Electric melting** – Electric melters offer higher direct thermal efficiency than fuel-fired burners.
  - Process(es) affected: glass melting and refining, preferred for fiberglass manufacturing rather than container or flat glass
  - Impacts:
    - Thermal efficiency of electric furnaces estimated to be 2 to 4 times greater than air-fuel-fired furnaces
    - Significantly lower air emissions
    - Lower capital cost but shorter campaign life (refractory life is much shorter for all-electric furnaces)
    - Possible higher energy cost, depending on electricity rates
    - Some limitations in operations with electric furnaces, e.g., pull rates and glass colors

- **Increased cullet rate** – In glass furnaces, using cullet instead of constituent raw materials lowers the melting energy requirement. Advanced cullet-sorting machines are another way to increase cullet rate.
  - Process(es) affected: glass melting
  - Impacts:
    - Typically, a 2.5 to 3.0 percent reduction in furnace energy consumption for every 10 percent extra cullet (example given for container glass)
    - Emissions reduction due to reduced fuel usage
    - Increased furnace life due to decreased melting temperature
    - Economics depend on the availability and cost of cullet
    - Quality and color variability are issues when utilizing cullet for container glass; fiberglass manufacturing can utilize broader range of cullet
    - Cost of color sorting and contamination is a limiting factor; low-cost/more efficient methods are needed

A literature search identified additional state-of-the-art technology areas in glass manufacturing, from glass melting and heat recovery to materials-handling belts and drives and facility lighting controls. The assessment report provides the full list of technologies identified through literature review and prioritized.

Glass Manufacturing Roadmapping

During the roadmapping portion of the project, glass industry representatives were asked to contribute opinions on promising state-of-the-art technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Three surveys produced feedback from 18 individuals. Three webinars were held, attended by representatives from Gallo Winery, Praxair, Owens-Illinois, and Borton-Lawson, as well as consultants and national laboratory representatives.

The technologies identified in the assessment were vetted during the first round of outreach to the experts. Participants noted that increasing the cullet rate may increase natural gas and electricity consumption, and that these practices may already be in use commercially. Advanced sorting machines for cullet contamination remediation was a specific technology area suggested. The viability of electric melting as a technology of interest, was also discussed. Although overall energy may decrease, the electrical consumption would increase. Participants identified three additional state-of-the-art technologies for glass manufacturing:

- **Thermochemical regenerator (TCR) system** – This oxy-fuel-based system uses stored waste heat to convert natural gas and recirculated flue gas into hot syngas, resulting in efficient heat recovery and reduced fuel consumption.
  - Process(es) affected: glass melting
  - Impacts:
    - Reduction in natural gas, carbon dioxide (CO_2), and power
    - With heat recovery, estimated energy savings of 30 percent

- **Capturing waste heat for electricity generation using the Organic Rankine Cycle (ORC)** – The ORC can use waste heat from industrial-scale furnaces and generate electricity.
  - Process(es) affected: glass melting
  - Impact:
    - Significant opportunity for energy savings in generating electricity
- **Advanced sensors and controls** – Improved process controls and sensors can be used to optimize glass melting, which can save energy. Controls may be used in optimizing combustion air intake.
  - Process(es) affected: glass melting
  - Impact:
    - Improved energy efficiency

Survey feedback suggested advanced refractory materials for furnaces and servo-based forming machines as other technology areas of interest. Those technologies, however, are not included as recommendations since webinar participants provided no further input.

The California Air Resources Board (CARB) published a draft paper in 2008 that summarizes strategies for reducing greenhouse gas (GHG) emissions from California glass manufacturing facilities. Maximizing cullet use and optimizing melt operations are the two areas identified for achieving the greatest total energy savings in this sector. For each percent increase of cullet use, energy consumption in glass container manufacturing can decrease by 0.2 to 0.5 percent, according to the paper. The paper does not make the distinction between total and electrical energy impact. Optimized melting operations is broken down between changes to existing furnaces (controls, combustion air optimization, and waste heat recovery), new furnace designs (for example oxy-fuel furnaces), and batch and cullet preheating when the process allows (California Air Resources Board 2008).

Technology Barriers

Thermochemical regeneration is found at only two plants in the world. The technology has not been proven in the United States. The high capital cost and relatively low cost of natural gas in this country are barriers to adoption. Installing waste heat recovery on glass furnaces (and other furnaces) is cost-prohibitive, and the technology cannot be easily purchased in the market and readily installed, according to webinar participants. R&D may be needed to further develop this technology. In addition, there are other ways to recover heat efficiently.

The primary barriers for recovering waste heat for electricity generation are cost (i.e., extremely expensive up-front cost and a payback that is difficult in the current, low-cost natural gas market) and perceived early adopter risk, given that this technology is not widely used in glass plants. It was unclear whether ORC waste heat recovery is actually state-of-the-art. This is very complex and may require more research. A roadmapping participant pointed out that steam ORC can require large quantities of water for cooling and boiler make-up, making it less attractive in California. Waste heat recovery equipment must be able to withstand high temperatures, and most exhaust equipment may not be designed for up to 1300˚F.

There were no specific barriers discussed for air leak detection or sensors and controls.

General Barriers

General barriers identified by participants in this roadmapping effort were in line with feedback from other technology areas: risk of capital investment versus return; lack of technical, cost, and performance information; and insufficient proof of concept.

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies in the glass manufacturing sector in California, participants suggested the following:

- Investigation supporting demonstration sites
- Testing to demonstrate viability
- Financial support for first users
- Increased availability of renewable and biogas energy

When asked to identify indicators of success, the responses included:

- Uptime reliability.
- Realization of savings and performance to justify the expense.
- Second user of technology without subsidies.
- Internal rate of return of 25 percent via rebates on capital investment

Participants agreed that while the economics for energy savings are not that attractive, investing in in high-impact technologies such as thermochemical regenerators and waste heat recovery would be very valuable to California and for United States industry. These technologies can make a difference in carbon intensity for the glass manufacturing industry and will be an important step toward future sustainability of the industry. Establishing links between technology development and the market is helpful to industry. While many technologies/materials are being developed, it is not always clear to manufacturers how these advances will benefit them.

Glass Manufacturing Relevant Policies and Legislation

The five state-of-the-art glass manufacturing technologies are listed in Table 6, with indications of which state policy or legislation is applicable to the technology. Excerpts from the California policies and legislations are in Appendix D and aligned to the various technology areas.

Table 6: Glass Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms					
State Policy or Legislation	Industrial Processing				
	Glass				
	Electric melting	Increased cullet rate	Thermochemical Regenerator System	Waste heat recovery with ORC	Advanced sensors and controls
California Codes					
Warren-Alquist Act	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X
California Energy Commission					
Energy Action Plan	X	X	X	X	X
Integrated Energy Policy Report	X	X	X	X	X
Energy Commission Energy Innovations Small Grant (EISG) Program	X	X	X	X	X
Executive Orders					
Clean Energy Jobs Plan					X
Executive Order S-3-05	X	X	X	X	X
Executive Order B-18-12					X
Executive Order B-30-15	X	X	X	X	X
Senate Bills					
SB 32	X	X	X	X	X
SB 332		X			
SB 350	X	X	X	X	X
SB 1106		X			X
SB X1-2	X	X	X	X	X

Source: Energetics

Cement Manufacturing

The total energy consumption for cement manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in cement manufacturing in California, 30.6 TBtu and 1,123 million kWh respectively. Cement manufacturing sector statistics are included in Table 7.

Table 7: Cement Manufacturing Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Cement Manufacturing	327310	30.6	1,123	18	1,265

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Cement Manufacturing Technical Assessment

Cement manufacturing technologies considered in the assessment focused on potential electricity savings in manufacturing cement and handling raw materials. Of the state-of the-art technologies, four were identified in the prioritization process and are described below. Further details on the technology impacts and development status, along with references consulted, are in the assessment report. The report also lists the references consulted and any outreach to experts.

Technologies from the Technical Assessment

- **Horomill** – The Horomill bed compression grinding system promises lower energy use than vertical roller mills and a higher-quality cement product.
  - Process(es) affected: cement crushing and grinding
  - Impacts:
    - Energy savings of 35 to 70 percent over conventional milling processes
    - Electricity consumption during milling of less than 24 kWh per metric ton of cement processed
    - Low noise level
    - No water consumption
    - Ability to grind a variety of materials such as slag, fly ash, minerals, and cements
    - Reduction in CO_2 emissions by approximately 8 to 20 kilogram (kg) per metric ton of cement
- **Gravity-fed homogenizing silos** – Using gravity leads to much lower energy consumption of homogenizing silos, although the technology is somewhat less efficient in blending.
  - Process(es) affected: cement storage
  - Impacts:
    - Reduction in energy consumption of 0.9 to 2.3 kWh per metric ton of raw material
    - Retrofit costs of $5 per metric ton of cement and $3.30 per metric ton of raw material
    - Emptying efficiency of 99 percent

        - Reduction in CO_2 emissions of approximately 0.8 to 2.5 kg per ton of raw material processed
- **Waste heat recovery** – Captured waste heat can be used to generate power through associated cogeneration units
    - Process(es) affected: heat recovery and utilization (waste heat is currently vented)
    - Impacts:
        - Ability to produce 25 to 30 percent of total power consumption at a cement facility using waste heat
        - Improvement in earnings before interest, taxes, depreciation, and amortization (EBITDA) margins of cement plants by 10 to 15 percent
        - Costs of approximately $1.6 to $2.0 million per unit
        - Relatively large amount of waste heat available (40 percent of heat input available as waste in the dry process; technology not applicable in the wet process)
        - Reduction in indirect CO_2 of 25 kg CO_2 per metric ton of clinker produced
- **High-efficiency vertical roller mill** – This alternative to conventional mills for grinding raw meal and coal is the most energy-efficient, widely used design. High-efficiency vertical roller mill refers to the best available vertical roller mill technologies.
    - Process(es) affected: cement crushing and grinding
    - Impacts:
        - Up to 40 percent energy savings over traditional systems
        - Capital costs 10 to 20 percent higher than traditional systems (for example, $14 million for 2,500 metric tons per day clinker production, with a payback period of three to four years)
        - Does not require water, saving up to 23 liters per metric ton of cement
        - Ability to handle large variations in throughput, from 5 to 1,200 metric tons per year

The literature review identified eight technologies (five state-of-the-art and three R&D) in this industrial processing subarea, ranging from high-efficiency milling and grinding, waste heat recovery, and specialty silos to high-efficiency fans and motors. The assessment report provides the full list of technologies identified through literature review.

Cement Manufacturing Roadmapping

During the roadmapping portion of the project, cement manufacturing industry representatives offered opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Three surveys produced feedback from 15 individuals representing a range of sectors, including academics, consultants to experts in energy efficiency in industrial processes, and individuals representing cement manufacturing associations and cement companies (e.g., LeHigh Cement). Several survey respondents participated in the webinars.

The cement manufacturing technologies identified in the assessment were vetted during the first round of outreach to experts in this technology area. Participants confirmed that grinding and crushing consume most of the electricity associated with manufacturing processes. The participants also discussed the need to capture waste heat and CO_2, since cement manufacturing is a large contributor of CO_2 emissions in California. The captured CO_2 could conceivably be put into limestone for cement or converted into chemicals and fuels. The feedback from the first webinar survey also indicated several other potential means of electricity savings, including the use of high-efficiency raw material classifiers and separators, variable speed drives (VSDs) for motors with variable loads, and improved grinding media. Participants also mentioned using alternative fuels such as biomass and municipal solid waste and renewable energy sources such as solar, wind, and hydroelectric.

Participants identified one additional technology, which was the appropriate sizing and use of most efficient motors for crushing and grinding. It is not included in the assessment report briefs but is described below. Also, participants suggested more emphasis on CO_2 capture during waste heat/flue gas recovery to produce limestone, which could be blended with cement.

- **Appropriate sizing and most efficient motors for crushing and grinding** – Grinding and crushing operations consume the most electricity. Appropriate sizing and use of the most efficient motors in these operations could save electricity.
  - Process(es) affected: cement crushing and grinding
  - Impact: reduction in electricity use

One participant mentioned incorporating cellulosic nanofibers into cement. The commenter stated that tests have shown that adding cellulosic nanofibers can increase concrete strength by 20 percent. However, the technology does not appear to be market-ready at this time.

Technology Barriers

The cement manufacturing industry has barriers similar to those in the glass manufacturing industry, with waste heat recovery and flue gas contaminants. Although there are numerous cement plants in China (and elsewhere) where waste heat is being recovered for electricity generation, cement plants in the United States and California primarily use coal and natural gas, which is relatively cheap. Unlike China, California lacks government incentives and has less competition. Waste heat recovery in Chinese cement plants is mandated in some case. In the United States, cement manufacturers can make their own decision about whether to implement waste heat recovery. The potential increase in the use of cooling tower and boiler blowdown water also makes waste heat recovery less attractive in California.

Other barriers are the cost of capital investment and prognosis for financial return on the investment for retrofitting milling, grinding, and crushing equipment and systems, as well as revamped raw materials storage silos. Participants in this industrial sector did not identify any technology-specific barriers to the listed priority systems and equipment.

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of these technologies in the cement manufacturing sector in California, suggestions from participants were:

- Financial incentives
- Investigating why cement manufacturing facilities are not implementing commercially available state-of-the art technologies
- Studying the barriers to commercialization of emerging technologies

The indicators of success for state-of-the-art technology use in the cement manufacturing sector included:

- Dissemination of information in the sector showing past experience of any technology implementation (in the United States, California, and elsewhere), and the results of that implementation and commercialization status
- Quantification of kilowatt-hours and Btu saved, along with criteria and GHG emissions avoided

Cement Manufacturing Relevant Policies and Legislation

The five cement manufacturing state-of-the-art technologies identified are listed in Table 8, along with the additional technology identified, with indications of which state policy or legislation applies the technology. Excerpts from the referenced California policies and legislations is located in Appendix D and aligned to the various technology areas.

Table 8: Cement Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms					
State Policy or Legislation	Industrial Processing (non-metals)				
	Cement				
	Gravity-fed homogenizing silos	High-efficiency vertical roller mill	Horomill	Waste heat recovery	Crushing/grinding motor optimization and sizing
California Codes					
Warren-Alquist Act	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X
California Energy Commission					
Energy Action Plan	X	X	X	X	X
Integrated Energy Policy Report	X	X	X	X	X
Energy Commission Energy Innovations Small Grant (EISG) Program	X	X	X	X	X
Executive Orders					
Clean Energy Jobs Plan	X	X	X	X	X
Executive Order S-3-05	X	X	X	X	X
Executive Order B-18-12	X	X	X	X	X
Executive Order B-30-15	X	X	X	X	X
Senate Bills					
SB 32	X	X	X	X	X
SB 350	X	X	X	X	X
SB X1-2	X	X	X	X	X
Assembly Bills					
AB 32	X	X	X	X	X
AB 221		X	X		X
AB 758	X	X	X	X	X
AB 1158				X	
AB 1613				X	
California Air Resources Board					
2017 Climate Change Scoping Plan	X	X	X	X	X
California Public Utilities Commission					
Energy Efficiency Strategic Plan	X	X	X	X	X
Other					
Western Regional Climate Action Initiative				X	

Metals Manufacturing

The total energy consumption for metals manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in metals manufacturing in the state of California, 54.3 TBtu and 8,552 million kWh, respectively. Table 9 further breaks down energy consumption by type of metals manufactured.

Table 9: Metals Manufacturing Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Primary Metal Manufacturing	331	32.0	5,512	402	15,533
Fabricated Metal Product Manufacturing	332	22.3	3,040	6,401	129,307
Total	**—**	**54.3**	**8,552**	**6,803**	**144,840**

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Metals Manufacturing Technical Assessment

The metals manufacturing assessment identified 10 priority state-of-the-art technologies for electricity savings, which are described below. Further details on the processes affected, impacts, and technology development are available in the technical assessment report for these technologies. The report also lists references consulted and any outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

A number of technology areas in metals manufacturing were identified through literature search, from metals recycling and heat recovery to improved process controls via neural networks. Given the prioritization criteria identified, these 10 technologies were used for the roadmapping outreach effort.

- **Use of pre-baked anodes** – Automatic multiple feeding points for alumina into the electrolytic cell increase its ability to dissolve, mix, and disperse rapidly in the electrolyte.
    - Process(es) affected: aluminum smelting; conventional Hall–Héroult electrolysis
    - Impacts:

    - Reduces electricity consumption of 10 to 30 percent, depending on the starting technology and cell design
    - Ability to keep average alumina concentration in the electrolyte within the desired range
    - Fewer anode effects, which cause cell voltage fluctuations and generate large amounts of GHGs
- **Optimized point feeding system with computer control** – Center-worked or side-worked pre-baked cells are converted to point-feed pre-baked cells.
  - Process(es) affected: aluminum smelting; conventional Hall–Héroult process feeding mechanism
  - Impacts:
    - Unit electricity consumption reduction of 10 to 30 percent
    - Gas collection efficiencies of up to 98 percent for the point-feed prebake process
    - More precise electrolysis control
    - Less sludge
    - Stabilized temperature
- **Minimizing losses from rectifiers, auxiliaries, and pollution control** – Hall–Héroult electrolysis cells are enhanced to minimize these losses in aluminum smelting/ electrolysis.
  - Process(es) affected: aluminum smelting; conventional Hall–Héroult electrolysis
  - Impacts:
    - An additional 5 to 7 percent energy savings with respect to current best practices of aluminum electrolysis
    - In the smelter, computer controls and point-feeding of aluminum oxide to the centerline of the cell that help reduce emissions, including emissions of organic fluorides such as tetrafluoromethane (CF_4) which can be held at less than 0.1 kilogram per ton (kg/t) aluminum
    - Reduced discharge of pollutants through improved life of the lining through better construction and operating techniques
    - Improved cell efficiency
- **Direct casting with aluminum transferred hot to alloying furnace** – This method is used in aluminum alloy manufacture instead of ingot casting.
  - Process(es) affected: aluminum ingot casting
  - Impacts:
    - Reduced energy consumption (best practice final electricity use is estimated to be 0.35 gigajoules per ton GJ/t aluminum ingot)
    - Better control of material properties
- **Oxy-fuel burners/lancing** – This technology can be installed in electric arc furnaces (EAFs) to reduce electricity consumption in steel manufacturing by substituting electricity with oxygen and hydrocarbon fuels.
  - Process(es) affected: EAF steelmaking
  - Impacts:

        - Reduced energy consumption; electricity savings of 0.14 GJ/t crude steel and fuel savings of up to 50 percent
        - Increased melting speed (improved heat distribution, leading to reduced tap-to-tap times of about 6 percent, causing a 50 percent increase in throughput capacity and an estimated annual cost savings of $4.0/ton)
        - Reduction of emissions by up to 23.5 kg CO_2/t-steel
        - Reduction of the steel's nitrogen content, improving product quality
        - Decreased scaling losses, improving the material yield
- **Natural-gas-based Midrex process with CO_2 removal system** – The process includes a reformer to convert natural gas into a high-quality syngas that is used directly for iron ore reduction in a shaft furnace.
    - Process(es) affected: EAF steelmaking
    - Impacts:
        - Reduced energy consumption (electricity consumption can be reduced about 20 kWh/t liquid steel for each 100°C increase in direct reduced iron charging temperature)
        - Reduced stack emissions due to removal of CO_2 from the top gas
- **Hot charging of slab reheat furnaces** – Slabs are charging at an elevated temperature into the reheating furnace of the hot rolling mill. The process includes furnace controls and efficient burners and motors.
    - Process(es) affected: hot rolling of steel
    - Impacts:
        - Reduced energy consumption by optimizing the slab forming temperature
        - Potential to eliminate some hot rolling requirements
        - Lower operational costs
- **Continuous annealing** – Continuous annealing replaces batch annealing for steel finishing of different steel products.
    - Process(es) affected: steel finishing, annealing
    - Impacts:
        - Reduced energy consumption compared to batch annealing
        - Improved product uniformity and surface cleanliness
        - Versatility to produce a wide range of steel grades
- **High-pressure grinding rolls** – High-pressure grinding rolls are used for gold ore comminution instead of other technologies, such as ball mills.
    - Process(es) affected: gold ore comminution
    - Impacts:
        - Reduced energy consumption by 15 to 30 percent
        - Reduced operating costs
- **Recycling gold** – Gold is recycled as an alternative to primary production.
    - Process(es) affected: primary gold manufacturing
    - Impacts:
        - Reduced energy requirements associated with primary extraction and manufacture

        - Reduced environmental impact of gold mining
        - Mitigated water consumption

Metals Manufacturing Roadmapping

During the roadmapping portion of the project, metals manufacturing industry representatives were asked to provide opinions on promising SOA technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Three surveys solicited feedback from 15 individuals. Participants included representatives from academia, the American Iron and Steel Institute (AISI), and Lawrence Berkeley National Laboratory. Experts in industrial energy efficiency also provided input. Several of these survey respondents participated in the webinars as well.

The first round of roadmapping identified five additional SOA metals manufacturing technologies. Among those five, metals recycling seemed to be the most readily impactful near-term solution for metals manufacturing because it reduces the need for more energy-intensive primary metal production. The other four technologies were added for roadmapping consideration: process sensors and controls for integrated steel mills and EAF steelmaking; new forming methods for next-generation advanced high-strength steel (AHSS); advanced sensors and controls for metals manufacturing; and heat recovery. These technologies are further described below.

- **Smart sensors and control systems for integrated steel mills and EAF steelmaking** – Improving the process control in integrated steel mills and EAF steelmaking can optimize operations.
    - Process(es) affected: integrated and EAF steelmaking
    - Impacts:
        - Reduced electricity consumption
        - Reduced raw material use and remelting because of improved product quality
- **New forming methods for next-generation AHSS** – Novel production, processing, and use opportunities for AHSS can reduce energy consumption.
    - Process(es) affected: steel finishing operations and auto manufacturing
    - Impacts:
        - Reduced energy consumption in processing
        - Increased fuel efficiency for vehicles through lightweighting
- **Improved recycling of other metals** – Improved recycling of aluminum, titanium, and magnesium alloys reduces the need for primary metal production. This process may require sorting or separation of grades prior to recycling.
    - Process(es) affected: primary and secondary metals manufacturing
    - Impacts:
        - Ability to extract and reuse high-value metals and alloys from scrap streams at relatively high purity
        - Reduced energy requirements and environmental impacts associated with primary metal production

- **Advanced sensors and controls** – Using more advanced sensors in metals manufacturing can reduce operating costs while improving product quality.
  - Process(es) affected: general metals manufacturing
  - Impacts:
    - Reduced energy requirements
    - Cost savings
    - Potential production increases
- **Heat recovery in metals production** – Process off-gases are captured and reused.
  - Process(es) affected: general metals manufacturing
  - Impacts:
    - Reduced energy requirements
    - Cost savings

The metals manufacturing technologies identified in the assessment report were vetted during the first round of outreach to experts in this area. Participants confirmed that most electricity is saved by increasing recycling programs, installing heat recovery at plants, and "lightweighting" end-use applications. The participants discussed the need for material substitutions for energy- and carbon-intensive applications—such as transportation—in California. Replacing a conventional part with one made from lighter-weight materials, such as AHSS, can reduce energy and carbon consumption over the part's lifetime. Feedback from the first webinar survey also indicated several other sources of potential electricity savings, including machine learning and artificial intelligence in arc furnaces, use of metals as an energy storage medium, and novel titanium winning technologies. Although not necessarily considered metals manufacturing technologies (but rather smart manufacturing), roll-to-roll semiconductor manufacturing and additive manufacturing were mentioned.

In addition, one participant mentioned post-scrubber heat recovery economizers for steel furnaces. The commenter stated that this crosscutting technology can recover heat from highly corrosive flue gas at high temperatures but has many site-specific challenges. However, this technology did not receive any additional feedback from webinar attendees, so it was not considered as a state-of-the-art technology.

Technology Barriers

The barriers to adopting state-of-art technologies across the metals manufacturing sector were characterized as either non-technical or technology-specific. Associated non-technical barriers are primarily concerned with costs and regulations. Steel and aluminum manufacturing is limited in the state because of the high cost of energy and regulatory compliance. With its ports and large population, California has an opportunity to be a manufacturing center with lower business costs. The trade-off between capital expenses for new technologies versus potential savings in operational expenses currently also limits the adoption of newer, more efficient technologies.

There are also many technology-specific barriers associated with implementing state-of-the-art metals manufacturing technologies. Technology implementation usually requires significant downtime, especially if any additional revisions to implementation plans are needed. Companies also prefer that a technology be completely proven prior to implementing it. For the following prioritized metals manufacturing processes, technology-specific barriers identified in the surveys and webinars need to be addressed before the technologies are implemented in California.

- Oxy-fuel burners/lancing – While there are no major technology-specific issues, there is a small number of customers in California.
- Advanced sensors and controls – Sensors need to be able to withstand harsh environments.
- New forming methods for next-generation AHSS – More durable dies and lubricants are needed to handle the higher strength of the new steels.
- Direct casting with aluminum transferred hot to alloying furnace – There is not enough data on solidification and surface modeling.

Path to Market

The key motivators for metals manufacturing technology growth and innovation are energy costs and potential savings in new extraction and forming processes, as well as market access. Other motivators include the need for developing lighter-weight metals and alloys, federal and state government status and policies, California's Cap and Trade Program, and the desire to reduce energy intensity (and, by extension, carbon footprint). These motivators help establish critical indicators of success with respect to the previously stated technical and non-technical barriers. The indicators of success for metals manufacturing include:

- Performance targets, such as increased tonnage of recycled metals, reduced tonnage of CO_2 and nitrogen oxide (NO_x) emissions, improved part manufacturing using sensors and process controls, and production of lightweight components from recyclable, reinforced polymers.
- Deployment of technology as a metric.
  - Quantification of the potential adopters and determination of near- and long-term targets (for example 20 percent adoption in three years and 45 percent in seven years), and then measurement of actual adoption to determine success.
  - Return on investment (ROI) for new technologies that is less than 24 months.
- An assessment of the current stock of technology in California.
  - If a facility is at the end of life, then these updates should be considered; otherwise, the existing stock for relatively new retrofits would be run for the next 30 to 40 years.
  - Benchmarking increases or decreases in metal production capacity also provide insight on how much state-of-the-art technology can still be implemented.

Based on the survey and webinar results, the potential actions to support market entry of these technologies for metals manufacturing include the following:

- Increased efficiency of metal recycling processes to reduce the consumption of raw materials, the energy needed to produce primary metals, and the emissions associated with primary metal production
- Accelerated depreciation schedules for required capital equipment
- Access to capital at preferred rates
- Public policies that enable further technological adoption by addressing financial barriers
- Streamlining of the permitting process for technologies (and reduction of the associated time and legal fees) in California
- Technology "roadshow" looking at other states and their success for technology implementation (e.g., facility managers from California visiting plants around world)

Metals Manufacturing Relevant Policies and Legislation

Table 10 and Table 11 describe the relevant policies and legislation for the metals manufacturing sector. These include California public resources codes, executive orders, Senate bills, Assembly bills, scoping plans, and policy reports.

Table 10: Metals Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms													
	Industrial Processing (Metals)												
	Steel							Aluminum				Gold	
State Policy or Legislation	Continuous annealing	Hot-charging of slab reheat furnace	Natural gas-based MIDRES process with CO_2 removal system	Oxy-fuel burners/lancing	Metals recycling for crude steel production	Integrated steel mills and more efficient EAF steelmaking	New forming methods for next generation advanced high strength steels (AHSS)	Direct casting with aluminum transferred hot to the alloy furnace	Minimizing losses from rectifiers, auxiliaries, and pollution control	Optimized point-feeding system with [illegible]	Use of pre-baked anodes and point feeders	High-pressure grinding rolls	Recycling gold
California Codes													
Warren-Alquist Act	X	X	X	X	X	X	X	X	X	X	X	X	X
Public Resources Code 25601	X	X	X	X	X	X	X	X	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X	X	X	X	X	X	X	X	X
California Energy Commission													
Integrated Energy Policy Report	X	X	X	X	X	X	X	X	X	X	X	X	X
Executive Orders													
Clean Energy Jobs Plan			X	X	X	X		X	X			X	
Executive Order S-3-05			X		X				X				X
Executive Order B-18-12				X	X	X		X	X	X	X	X	
Executive Order B-30-15			X		X				X				X
Senate Bills													
SB 32			X						X				X
SB 350	X	X	X	X		X	X	X	X	X	X	X	X
Assembly Bills													
AB 32			X					X			X		X
AB 758	X	X	X	X	X	X	X	X	X	X	X	X	X
Air Resources Board													
California's 2017 Climate Change Scoping Plan	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 11: General Metals Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms		
State Policy or Legislation	Industrial Processing (Metals)	
	Metals (General)	
	Advanced Sensors and Controls	Heat Recovery
California Codes		
Warren-Alquist Act	X	X
Public Resources Code 25601		X
Public Resources Code 25620	X	X
California Energy Commission		
Integrated Energy Policy Report	X	X
Executive Orders		
Clean Energy Jobs Plan	X	X
Executive Order S-3-05	X	X
Executive Order B-18-12	X	
Executive Order B-30-15	X	X
Senate Bills		
SB 32	X	X
SB 350	X	X
Assembly Bills		
AB 32	X	
AB 758	X	
AB 1613		X
Air Resources Board		
California's 2017 Climate Change Scoping Plan	X	X

Chemicals Manufacturing

The total energy consumption for chemicals manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in chemicals manufacturing in the state of California, 135 TBtu and 9,811 million kWh, respectively. Chemicals manufacturing sector statistics are shown in more detail in Table 12.

Table 12: Chemicals Manufacturing Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Chemicals Manufacturing	325	135.0	9,811	1,552	74,445

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Chemicals Manufacturing Technical Assessment

Chemicals manufacturing technologies considered in the assessment focused on potential electricity savings in the chemicals industry. The literature review identified six technologies (three state-of-the-art and three R&D) in this industrial processing subarea. However, no chemicals manufacturing technologies were identified. No technology briefs are reported here.

Chemicals Manufacturing Roadmapping

Roadmapping was not done for this sector since no chemicals manufacturing technologies were identified.

Plastics Manufacturing

The total energy consumption for plastics manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in plastics manufacturing in the State of California, 18.5 TBtu and 4,455 million kWh, respectively. Plastics manufacturing sector statistics are shown in more detail in Table 13.

Table 13: Plastics and Rubber Products Manufacturing Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Plastics and Rubber Manufacturing	326	18.5	4,455	1,344	51,963

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Plastics Manufacturing Technical Assessment

Plastics manufacturing technologies considered in the assessment focused on potential electricity savings in manufacturing plastics. Eight state-of-the art technologies were identified in the prioritization process and are described briefly below. The assessment report provides further details on the researched technology impacts and development status, along with references consulted and outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

- **Extrusion barrel heating using electrically heated thermal oil and insulation** – An electrically heated thermal oil system circulates thermal oil to manage extrusion barrel temperatures.
  - Process(es) affected: plastics extrusion
  - Impacts:
    - Energy savings of 30 to 40 percent
    - Benefits to production and facility heating systems (building and hot water) from heat recovery from the pneumatic system
    - More precise control (due to thermal oil) of extrusion barrel heating and cooling to minimize waste heat
- **Extruding polymer directly after drying** – This process minimizes the time between drying and extrusion of the polymer to save energy.
  - Process(es) affected: polymer drying and extrusion
  - Impacts:
    - An estimated 25 percent energy savings in use of extrusion machines
    - Use of some of the thermal energy from drying to get the polymer to the necessary temperature for extrusion
- **Variable speed drive (VSD) on chilled water pump** – A VSD modulates the speed of the chilled water pump based on chilled water tank temperature. Pressure and flow rate can also be used as signals to tune the system with the VSD. This technology reduces temperature variations and provides improved process control.
  - Process(es) affected: water pumping

- Impacts:
  - Savings for plastic automotive manufacturers of 30 percent (reduced from 11 kW to 7 kW)
  - VSDs designable for a ramp-up (fixed-speed motors have on/off controls only)
  - Lower noise
- **Insulation on barrel heaters** – Barrel insulation jackets can be applied to barrel heaters to reduce wasted heat.
  - Process(es) affected: injection molding
  - Impacts:
    - Estimated energy savings from the barrel heating component of the machine of 20 to 22 percent
    - Reduced loss of energy and minimized energy required for heating the polymer through application of an insulation jacket to the injection molding barrel
- **Switching from hydraulic to all-electric injection molding machines** – Electric injection molding machines can be a direct replacement for hydraulic injection molding machines and are typically significantly more energy efficient.
  - Process(es) affected: injection molding
  - Impacts:
    - Potential for an estimated 74 percent energy savings
    - High-speed electric servo motors (found in electric injection molding machines) that use less energy than their hydraulic equivalents and eliminate the need to cool the hydraulic oil, resulting in additional savings
- **Radiant heater bands for plastic extrusion** – Insulated heater bands can be applied to extrusion machines for better thermal management.
  - Process(es) affected: plastics extrusion
  - Impacts:
    - Energy savings applied to extrusion machines of up to 33 percent
    - Reduced heat loss from added insulation and a more efficient heat transfer to the polymer
- **Low–pressure drying** – A vacuum is applied to the dryer cabinet to accelerate drying.
  - Process(es) affected: injection molding, extrusion, and blow molding requiring material drying
  - Impacts:
    - Energy savings of up to 65 percent
    - Reduced drying times from the application of a vacuum that drives water vapor out of the polymer granules
- **High-efficiency motors for extruder drive system** – Higher-efficiency motors are used, and attention is paid to choosing the correct size and speed of the motor for the application.
  - Process(es) affected: injection molding, extrusion, blow molding
  - Impacts:
    - An estimated 20 percent energy savings applied to the extruder drive
    - A reduction in electricity use of 1 to 4 percent for high-efficiency motors versus standard motors

The literature review identified 15 technologies (10 state-of-the-art and 5 R&D) in this industrial processing subarea, including different heating and drying technologies for extrusion, high-efficiency motors and VSDs, and better insulation. The assessment report provides the full list of technologies identified through literature review.

Plastics Manufacturing Roadmapping

During the roadmapping portion of the project, plastics manufacturing industry experts were asked to provide opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Five individuals provided feedback on the three surveys. These individuals represented industry, national laboratories, and consulting.

Participants identified three additional plastics manufacturing technologies during the roadmapping activities. Although not contained in the assessment report briefs, they are briefly described below.

- **Specific process control strategy using one VSD for multiple parallel motors** – This strategy reduces drives for motors.
    - Process(es) affected: operations that involve motors
    - Impacts:
        - Reduces electricity use
- **More effective separation of plastics recycling** – This strategy improves the efficiency of the recycling process and increases the amount of plastic waste that can be recycled.
    - Process(es) affected: plastics recycling
    - Impacts:
        - Reduces volume of plastics that must be landfilled
        - Higher quality and value of recycled materials
- **Foam-blowing agents** – These substances can produce a cellular structure via a foaming process in a variety of materials that undergo hardening, such as plastics.
    - Process(es) affected: plastics hardening
    - Impacts:
        - Lighter-weight products
        - Reduction in electricity use
        - Reduction of GHGs

Technology Barriers

Survey and webinar participants offered only a few barriers to implementing these technologies, but they were critical ones. General barriers included:

- Lack of incentives for facilities to implement complex programs involving state-of-the-art technologies that can potentially reduce energy usage. Demonstration of the energy reduction benefits would increase the implementation of the more sophisticated and effective technologies.

- Cost of capital investment for installing the technologies and prognosis for financial return on that investment are critical in the business culture of the plastics manufacturing industry.

Specific technology barriers identified by survey and webinar participants included:

- Lack of industrial-scale demonstration of the technologies
- Limitations to economically reusing or recycling plastics produced using some of these technologies

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of these technologies in the plastics manufacturing sector in California, suggestions from participants included the following:

- Financial incentives
- Incentive programs configured such that complex projects with the greatest potential to reduce electricity usage are incentivized the most
- Dissemination to the industry of a portfolio of technology evaluations and information
- Studying the barriers to commercializing emerging technologies

Participants were asked to identify indicators of success for technology use in the plastics manufacturing sector. Suggested indicators included:

- Quantifying kilowatt-hours and Btu saved, along with criteria and GHG emissions avoided
- Quantifying energy and cost savings achieved by those who adopt state-of-the-art technologies

Plastics Manufacturing Relevant Policies and Legislation

Eight plastics manufacturing state-of-the-art technologies identified are listed in Table 14, along with the three additional technologies identified in the roadmapping process, with indication of which state policy or legislation is applicable to the technology. Appendix D provides excerpts from the referenced California policies and legislations, aligned to the various technology areas.

Table 14: Plastics Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms											
State Policy or Legislation	Industrial Processing (non-metals)										
	Plastics										
	Extruding Polymer Soon After Drying	Extrusion Barrel Heating Using Electrical Heated Oil	High Efficiency Motors for Extruder Drive System	Insulation on Barrel Heaters	Low Pressure Drying	Radiant Heater Bands for Plastic Extrusion	Switching from Hydraulic to All-electric Injection Molding	Variable Speed Drive (VSD) on Chilled Water Pump	Foam Blowing Agents	Improved Process Control Systems and Sensors	More Effective Separation of Plastics Recycling
California Codes											
Warren-Alquist Act	X	X	X	X	X	X	X	X	X	X	X
California Energy Commission											
Integrated Energy Policy Report (IEPR)	X	X	X	X	X	X	X	X	X	X	X
Energy Action Plan	X	X	X	X	X	X	X	X	X	X	X
Energy Innovations Small Grant (EISG) Program	X	X	X			X				X	X
Executive Orders											
Executive Order S-3-05	X	X	X	X	X	X	X	X	X	X	X
Executive Order B-18-12	X	X	X	X	X	X	X	X	X	X	X
Executive Order B-30-15	X	X	X	X	X	X	X	X	X	X	X
Senate Bills											
SB 32	X	X	X	X	X	X	X	X	X	X	X
Assembly Bills											
AB 32	X	X	X	X	X	X	X	X	X	X	X
California Public Utilities Commission (CPUC)											
Energy Efficiency Strategic Plan	X	X	X	X	X	X	X	X	X	X	X
California Air Resources Board (CARB)											
California's 2017 Climate Change Scoping Plan	X	X	X	X	X	X	X	X	X	X	X
CA Department of Resources Recycling and Recovery (CalRecycle)											
Greenhouse Gas Reduction Grant and Loan Program		X		X		X	X			X	X
Recycled Fiber, Plastics, and Glass Grant Program										X	X

Pulp and Paper Manufacturing

The total energy consumption for pulp and paper manufacturing in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in pulp and paper manufacturing in the state of California, 83.7 TBtu and 4,004 million kWh, respectively. Pulp and paper manufacturing sector statistics are shown in more detail in Table 15.

Table 15: Pulp and Paper Manufacturing Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Paper Manufacturing	322	83.7	4,004	402	20,975

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Pulp and Paper Manufacturing Technical Assessment

Pulp and paper manufacturing in California is limited to paper converting facilities, which take raw paper and "convert" it into finished products, such as corrugated cardboard, tissue, paper towels, and magazine/book paper. California currently has no pulping operations, as the last one closed down in 2012. There are also paper mills in California that recycle paper into paper and cardboard products. Pulp and paper industry representatives report that most California paper plants have low electricity use and have already implemented many energy efficiency measures.

The assessment identified one additional priority state-of-the-art technology for electricity savings, which is briefly described. The assessment report contains further details on the researched technology impacts and development status, along with references consulted and any outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

- **High-consistency forming** – In this process, the furnish pulp that enters the forming stage has more than double the consistency of normal furnish pulp.
  - Process(es) affected: drying, calendering, and reeling
  - Impacts:
    - Estimated electricity savings of 18 percent, or about 41 kWh/t of paper

- Primary energy savings of 2.57 million Btus per ton (MMBtu/t) during the papermaking process
- Reduction of approximately 6.9 pounds of carbon emissions per tonne of paper produced
- Investment cost estimated as $70/t paper

From the literature search, a number of technology areas were identified from delignification and improved lime kilns to high-efficiency motor systems and reduced air requirements. Given the prioritization criteria, the five technologies listed above were carried forward to the roadmapping outreach effort. Oxygen delignification, use of acid hydrogen peroxide and other organic additives, and biopulping were technologies prioritized during the literature search. However, they were removed following the first round of roadmapping because they are only used at pulp mills, none of which are operating in California (Alliance for Pulp & Paper Technology Innovation 2017). Participants in the first survey and webinar recommended that Condebelt drying technology be removed.

Pulp and Paper Manufacturing Roadmapping

During the roadmapping portion of the project, stakeholders and experts were asked to provide opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 15 individuals on the three surveys, email correspondence, and conference calls. Representatives included consultants, individuals representing the Alliance for Pulp & Paper Technology Innovation, and Procter and Gamble.

The technologies from the assessment were vetted during the first round of outreach to experts. Technologies suited only for pulp mills were eliminated from further consideration in the roadmapping effort.

Three additional technologies were identified through the first round of roadmapping and in discussion with paper mill representatives (Proctor & Gamble 2018):

- **Efficient washing of pulp** – Better washing efficiency can ensure maximum removal of dissolved material while using a minimum amount of water, potentially saving energy and reducing steam consumption.
  - Process(es) affected: pulp bleaching and refining
  - Impacts:
    - Reduced energy consumption
    - Reduced environmental emissions
    - Potentially lower consumption of bleach and other chemicals
- **Higher-efficiency boilers and turbines** – More energy-efficient boilers and turbines can enable energy recovery and savings in paper mills.
  - Process(es) affected: chemical recovery, heat recovery, and general papermaking
  - Impacts:
    - Reduced energy consumption
    - Reduced environmental emissions

- **Vibratory shear-enhanced processing (VSEP)** – The system uses micro-, ultra-, or nanofiltration membrane modules to treat the white water filtrate. This process separates fibers, fines, and fillers, generating a permeate stream that meets the water reuse or environmentally safe discharge criteria.
    - Process(es) affected: white water filtration
    - Impacts:
        - Electricity savings from reduced pumping requirements
        - Improved quality and performance efficiency of the paper machine
        - Recovery of up to 90 to 98 percent of the paper-making process water as clean water for reuse or discharge, with 2 to 10 percent (or less) recycled or discharged as concentrate

Technology Barriers

The barriers in this sector were characterized as either non-technical or technology-specific barriers to technology adoption. In general, the pulp and paper industry is conservative in accepting new technologies. Large capital cost is a deterrent in this established industry, and technology innovation is focused on new products from wood such as composites or carbon fiber. New technologies in this industry are typically accepted only if the economics are deemed favorable.

Path to Market

The key motivators for technological growth in the area were established in terms of critical indicators of success. These indicators include:

- Finding a second user without subsidy
- Reports showing past experience, rate of learning, past expansions, and indication of growth
- Commercialization status
- Energy and carbon emissions savings metrics (e.g., kilowatt-hours saved, Btu saved, and emissions avoided)

Based on the survey and webinar results, the potential actions to support market entry include the following:

- Financial support
- Cheaper electricity
- Educational outreach to give users confidence in purchasing new technologies
- Sharing of experiences about successes in other countries or industries
- Incentives to encourage industries under financial pressure to make investments
- Identification of benefits beyond energy efficiency (energy efficiency is a lower priority in the pulp and paper industry)

Pulp and Paper Manufacturing Relevant Policies and Legislation

The single technology identified above that made prioritization status is listed in Table 16 below, along with the three additional technologies subsequently identified. This table indicates which state policy or legislation is applicable to each technology. Appendix D provides excerpts from the referenced California policies and legislations, aligned to the various technology areas.

Table 16: Pulp and Paper Manufacturing Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms				
	Industrial Processing (non-metals)			
	Pulp and Paper			
State Policy or Legislation	High Consistency Forming	Efficient Washing of Pulp	Higher Efficiency Boilers and Turbines	Vibratory Shear
California Codes				
Warren-Alquist Act	X	X	X	X
California Energy Commission				
Integrated Energy Policy Report (IEPR)	X	X	X	X
Energy Action Plan	X	X	X	X
Executive Orders				
Executive Order S-3-05	X	X	X	X
Executive Order B-18-12	X	X	X	X
Executive Order B-30-15	X	X	X	X
Senate Bills				
SB 32	X	X	X	X
Assembly Bills				
AB 32	X	X	X	X
California Public Utilities Commission (CPUC)				
Energy Efficiency Strategic Plan	X	X	X	X
California Air Resources Board (CARB)				

State Policies and Legislation: Relevance to Technology Platforms				
California's 2017 Climate Change Scoping Plan	X	X	X	X
California Department of Resources Recycling and Recovery (CalRecycle)				
Recycled Fiber, Plastics, and Glass Grant Program	X			

Petroleum Refining

The total energy consumption for petroleum refining in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in petroleum refining in the state of California, 449.5 TBtu and 4,148 million kWh, respectively. Petroleum refining sector statistics are shown in more detail in Table 17.

Table 17: Petroleum Refining Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Petroleum Refineries	324110	449.5	4,148	24	8,275

Sources: [1] U.S. Census Bureau 2014c; [2] EIA 2014; [3] U.S. Census Bureau 2014b; [4] U.S. Census Bureau 2014a

Petroleum Refining Technical Assessment

Petroleum refining technologies considered in the assessment focused on potential electricity savings in producing downstream petroleum products. Of the technologies, three were identified in the prioritization process and are described below. The assessment report provides further details on the researched technology impacts and development status, along with references consulted and any outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

- **Fiber optics sensors** – Monitoring critical physical parameters such as temperature, pressure, and deformation in refineries requires reliable sensing systems such as online monitoring of refinery streams.
  - Process(es) affected: numerous refinery operations, including separation processes
  - Impacts:
    - 25 percent reduction in energy requirements for process heating
    - Improved plant reliability

- **Advanced distillation techniques** – A hybrid distillation column is mixed with other separation processes (membranes or adsorption).
  - Process(es) affected: distillation (atmospheric, vacuum, etc.)
  - Impact:
    - 25 percent reduction in energy requirements for process heating
- **Integrate increased natural gas into refining** – The availability of cheap natural gas from hydraulic fracturing presents an opportunity to offset products of refining (refinery fuel gas and others) that are typically used to provide heat and energy for refining processes, including hydrogen production. In addition to fuel for a variety of processes, natural gas can be used as a feed for hydrogen production (steam methane reforming).
  - Process(es) affected: naphtha reforming and steam methane reforming to produce hydrogen
  - Impact:
    - 25 percent reduction in energy requirements for process heating

The literature review for petroleum refining identified eight technologies (five state-of-the-art and three R&D) in this industrial processing subarea, including energy management software and monitoring sensors in refineries, advanced distillation columns, increased use of natural gas in the refining process, and recovery of low-level heat streams. The report provides the full list of technologies that were identified through literature review.

Petroleum Refining Roadmapping

During the roadmapping portion, petroleum refining industry representatives were asked to contribute opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 10 individuals on the three surveys. Participants included representatives from industry, national laboratories, and consulting. However, only a few survey respondents participated in the webinars as well.

Participants identified one additional petroleum refining technology during the roadmapping activities. Although not in the assessment report briefs, it is briefly described below.

- **In-furnace cameras for oil refineries** – Enhanced thermal imaging for oil refinery furnaces leads to stable and efficient combustion, which can ensure continuous, high-quality output.
  - Process(es) affected: furnace monitoring
  - Impacts:
    - Increased efficiency for petroleum product output
    - Lower energy input to furnace systems

Technology Barriers

The petroleum refining industry in California is very large, with 18 operating refineries (ranked third in the United States behind Texas and Louisiana). California petroleum refining contributes 30 percent of the GHG emissions from the state's industrial processing sector. The survey and webinar participants identified several barriers for introducing new technologies, including the following:

- Refineries may be hesitant to install new technologies if the impact on savings is not competitive with productivity investments. A payback of one to two years is a typical return on investment (ROI) threshold in this industry.
- There are potential barriers specific to California, such as the need to switch gasoline formulations at certain seasons.
- Refinery operators are concerned about accidents and are very risk-averse.
- Natural gas from hydraulic fracking of wells is often not near refineries in California, so this option may be limited.

Refinery operations in California are highly regulated by a variety of state agencies, much more so than many other states. This generally gives pause to refinery operators in embracing new technologies.

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies in the petroleum refining sector in California, suggestions from participants included:

- Identifying the refineries that would be beneficiaries of advanced technologies, soliciting their interest, and securing their feedback
- Determining which technologies would be better adapted to California refineries and their suite of downstream petroleum products
- Conducting a study on barriers to commercialization of emerging technologies
- Finding champions at California refineries who would embrace new technologies

Participants were asked to identify success indicators for technology use in the petroleum refining sector, and responses were similar to other industrial processing sectors:

- Acquire data and operational information from operators and facilities using the identified technologies
    - Focus on adoption and adoption rates of technologies
    - Identify the efficiency of the technology at individual facilities, along with energy savings achieved and electricity cost savings
    - Determine the capital and operating expenses for these technologies in real time
    - Quantify kilowatt-hours and Btu saved, along with criteria and GHG emissions avoided
    - Gather information for dissemination in the sector showing past experience of any technology implementation (overall in the United States, specifically in California, or elsewhere), and the results of that implementation and commercialization status

Petroleum Refining Relevant Policies and Legislation

The four technologies identified here are listed in Table 18, with indication of which state policy or legislation is applicable. Appendix D provides excerpts from the referenced California policies and legislations, aligned to the various technology areas.

Table 18: Petroleum Refining Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms				
State Policy or Legislation	Industrial Processing (non-metals)			
	Petroleum Refining			
	Advanced distillation techniques	Fiber optic sensors	Integrating natural gas into refining	In-Furnace cameras for oil refineries
California Codes				
Warren Alquist Act	X	X	X	X
Public Resources Code 25620	X	X	X	X
California Energy Commission				
Energy Action Plan	X	X	X	X
Integrated Energy Policy Report	X	X	X	
Energy Commission Energy Innovations Small Grant (EISG) Program	X	X	X	X
Executive Orders				
Clean Energy Jobs Plan		X	X	X
Executive Order S-3-05	X	X	X	X
Executive Order B-18-12	X	X	X	X
Executive Order B-30-15	X	X	X	X
Senate Bills				
SB 32	X	X	X	X
SB 71	X	X	X	X
SB 350	X	X	X	X
SB 1300	X	X	X	X
SB X1-2	X	X		X
Assembly Bills				
AB 32	X	X	X	X
AB 758	X	X	X	X
AB 1613	X	X	X	X

State Policies and Legislation: Relevance to Technology Platforms				
Air Resources Board				
California's 2017 Climate Change Scoping Plan	X	X	X	X
California Public Utilities Commission				
Energy Efficiency Strategic Plan	X	X	X	X
Other				
Western Regional Climate Action Initiative	X	X	X	X

Oil and Gas Extraction

The total energy consumption for oil and gas extraction in California was estimated using data from federal agencies. EIA's MECS data provides the average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the natural gas and electricity consumption in oil and gas extraction in California, 255.9 TBtu and 6,681 million kWh, respectively. Oil and gas extraction sector statistics are shown in more detail in Table 19.

Table 19: Oil and Gas Extraction Sector Statistics in California, 2014

Sector	NAICS Code [1]	Natural Gas Consumption (TBtu, estimated) [2]	Electricity Consumption (million kWh, estimated) [2]	Number of Facilities [3]	Number of Employees [3]
Oil and Gas Extraction	211	255.9	6,681	234	7,057

Sources: [1] U.S. Census Bureau 2014c; [2] 2014 IOU supplied data via Energy Commission Demand Analysis office; [3] U.S. Census Bureau 2014b

Oil and Gas Extraction Technical Assessment

Oil and gas extraction technologies considered focused on potential electricity savings in onshore wells and extraction operations. The literature review identified three technologies (two state-of-the-art and one R&D) in this industrial processing subarea. No technologies were identified in the prioritization process so no technology briefs are reported here.

Oil and Gas Extraction Roadmapping

As no technologies were identified for prioritization, roadmapping was not warranted.

CHAPTER 4: Industrial Facilities and Power State-of-the-Art Opportunities

Industrial Facilities and Power

The total energy consumption for electric power transmission, control, and distribution in California was unavailable from data collected by either investor owned utilities (IOUs) or federal agencies. The total industry size for electric power transmission, control, and distribution in California is reported here by NAICS code. The Census Bureau CBP survey data provides the total number of facilities and employees by sector in California. Electric power transmission, control, and distribution sector statistics are shown in more detail in Table 20.

Table 20: Electric Power Transmission, Control, and Distribution Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated)	Number of Facilities [2]	Number of Employees [2]
Electric Power Transmission, Control, and Distribution	**22112**	**Not available**	**283**	**37,500**

Sources: [1] U.S. Census Bureau 2014c; [2] U.S. Census Bureau 2014b

Industrial Facilities and Power Technical Assessment

The industrial facilities and power portion of the assessment identified four priority technologies for electricity savings, which are described below. Further details on the researched technology impacts and development status, and the references consulted, are available in the assessment report.

The industrial facilities topic area covered energy management practices, facilities energy efficiency, industrial maintenance activities, and data centers. Several potential high-impact technologies were identified including various advanced thermal management solutions, large batteries, capacitors, load shifting generators, and energy management controls. Large batteries were identified as a priority technology for further analysis. Since large batteries are a power-related technology, they were included in the group of industrial power technologies in subsequent analysis. Data center technologies are covered in Chapter 5.

State-of-the-Art Technologies from the Technical Assessment

- **Large batteries** – Large batteries can be charged when energy prices are low and discharged during peak demand when prices are high.
  - Process(es) affected: industrial facility demand response
  - Impact: When combined with solar panels, the large batteries become an excellent energy storage/generation option.
- **Industrial uninterruptible power systems (UPSs)** – This technology provides uninterrupted back-up power during short power outages.
  - Process(es) affected: power protection and management
  - Impact: Continuity of operations and process control is critical across a wide range of industrial sectors. Industrial UPSs, depending on the application, can save companies millions of dollars in potentially lost revenue. Increased electricity efficiency in industrial UPS units also means that the cooling load required for the units to run properly is reduced; for every kilowatt saved due to increased electricity efficiency, 0.3 kilowatts in cooling is also saved.
- **Solid-state power transformers** – These transformers are based on silicon carbide or other wide-bandgap materials and can efficiently scale voltages up or down, allowing for energy to be transferred from the grid to facilities, or from facilities to the grid.
  - Process(es) affected: industrial electrical load reduction
  - Impact: Solid-state transformers are components critical to creating a truly smart grid. Solid-state transformers can better handle the fluctuations associated with variable resources when compared to conventional transformers. Electricity savings are estimated to be about 8 percent based on a limited number of studies to date. A projected electricity savings of 8 percent would mean that 8 percent less power is needed to fuel the grid, resulting in savings on power production and component lifespan at multiple levels.
- **Advanced combined heat and power (CHP) systems** – Efficient and cost-effective CHP systems can replace more expensive grid power and provide other grid services, such as demand response.
  - Process(es) affected: facility and/or process power and heat supply
  - Impact: Advanced CHP is not a single technology but an approach to applying technologies. Conventional systems that produce heat and power separately have a combined efficiency of around 45 percent, while CHP systems can operate at up to 80 percent efficiency (accounting for a large use of low-temperature heat, year-round heating and cooling loads, and steam-driven equipment used at the facility). Depending on the plant size, equipment used, and other factors, significant emissions reductions can be realized.

A number of technology areas were identified in the industrial facilities and power area through literature search. Many of the identified technologies related to grid improvements and potential electricity savings from adjustable speed pumps, storage systems, and microgrids, but energy-efficient solutions related to building automation systems, strategic energy management, and incorporating efficiency into new building design and retrofits were also identified as potential areas for energy improvements and electricity savings. The assessment report provides the full list of technologies identified through literature review.

Industrial Facilities and Power Roadmapping

During the roadmapping portion of the project, industry representatives and other experts contributed opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 23 individuals on the three surveys. Numerous representatives from technology developers, trade groups, government, consulting firms, and academia joined the three webinars.

The top data industrial facilities and power technologies identified in the earlier assessment were vetted during the first round of outreach. Some participants noted that as intermittent renewable energy sources generate a growing share of California's electricity, electric utilities and other system operators face an increasing need for additional generation capacity to maintain grid stability and security. One potential solution is advanced CHP systems that seamlessly connect to the grid and can provide needed grid services.

Two additional promising technologies were identified by participants during roadmapping activities. These are listed below and are not described in the assessment report.

- **Ice storage** – Compressors that make ice at night (when the cost of electricity is low) and use the ice and forced air to cool buildings during the daytime.
    - Process(es) affected: industrial facility demand response
    - Impact: Ice stores plenty of latent heat via phase change, so discharging this latent heat reduces the load profiles during peak load or partial-peak load conditions during the day, which reduces energy consumption.
- **Flywheels** – Large rotating machines that spin in a near frictionless environment and can quickly generate electricity on demand. They store energy in the form of motion. These have been successfully deployed in data centers.
    - Process(es) affected: industrial facility demand response
    - Impact: Flywheels have a smaller footprint than conventional energy storage technologies and can provide backup power instantaneously.

Technology Barriers

In the surveys and webinar discussions, some attendees noted that the complexity of integration is the biggest technology barrier. Simpler integration of new technologies into the grid would enable rapid adoption. The user needs to see the technology as simple and easy. If there is some way to give the user quick assurance, the user will be more likely to adopt. Metrics are needed to show the user the effectiveness of any technology. Others stated that there is little market awareness for solid-state transformers, and no one knows how to use them. While demand response technologies can be effective and save electricity, a lack of aggressive time-of-use rates is a barrier to implementation. Some participants noted that the carbon impacts of CHP should be considered for California.

General barriers that were identified by participants in the roadmapping effort include a lack of knowledge and information, particularly not having a clear understanding of the total cost of ownership and benefits the solution provides. A second barrier is a lack of management buy-in. Businesses often do not see electricity as a high priority, and electricity costs are seen as minimal compared to total business costs. In addition, businesses want shares in the economic gains associated with the energy service providers by implementing the new technologies. Privately-owned systems encounter regulatory and policy barriers that prevent them from providing power to the electricity distribution system when needed. Participants noted that there is often confusion over local air emissions requirements.

Path to Market

General indicators of success related to market adoption of industrial power technologies include:

- A comparison of the levelized cost of energy to the cost of existing electricity from the utilities
- Carbon reduction (a useful metric is the cost of conserved carbon)

When asked to identify actions that the Energy Commission can take to support the market entry of technologies in the industrial power sector in California, suggestions from participants included the following:

- Support modification of policies and regulations that inhibit the generation of power on-site
- Sponsor pilots and monitor the results
- Educate manufacturers on new technologies, subsidize the introduction of new technologies

When asked to identify indicators of success for market entry of technologies, participants made the following suggestions:

- Consideration for the heat that is being replaced (advanced CHP)
- Increased use of absorption chillers in California (for advanced CHP)

Industrial Facilities and Power Relevant Policies and Legislation

Table 21: Industrial Facilities and Power Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms						
	Industrial Facilities and Power					
	Storage			**Other**		
State Policy or Legislation	Large batteries	Flywheels	Ice storage	Advanced combined heat and power systems	Industrial uninterruptible power systems	Solid-state power transformers
California Codes						
Warren-Alquist Act			X	X		X
Public Resources Code 25601			X	X		X
Public Resources Code 25620			X	X		X
California Energy Commission						
Integrated Energy Policy Report			X	X		X
Executive Orders						
Clean Energy Jobs Plan	X	X	X	X	X	X
Executive Order B-18-12	X	X	X	X	X	X
Senate Bills						
SB 350			X	X		X
Assembly Bills						
AB 758	X	X	X	X	X	X
AB 1613				X		
California Air Resources Board						
California's 2017 Climate Change Scoping Plan			X	X		X

CHAPTER 5: Data Center State-of-the-Art Opportunities

Data Centers

The total energy consumption for data processing, hosting, and related services in California was estimated using data from federal reporting agencies. The Census Bureau CBP Survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS code and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in data processing, hosting, and related services in California, <0.06 TBtu and 1,985 million kWh respectively. Data processing, hosting, and related services sector statistics are shown in Table 22.

Table 22: Data Processing, Hosting, and Related Services Sector Statistics in California, 2014

Sector	NAICS Code [1]	Natural Gas Consumption (TBtu, estimated) [2]	Electricity Consumption (million kWh, estimated) [2]	Number of Facilities [3]	Number of Employees [3]
Data Processing, Hosting, and Related Services	518210	<0.06	1,985	419	4,337

Sources: [1] U.S. Census Bureau 2014c; [2] 2014 IOU supplied data via Energy Commission Demand Analysis office; [3] U.S. Census Bureau 2014b

Data Centers Technical Assessment

The data centers portion of the assessment identified the two priority technologies for electricity savings described below. Further details on the researched technology impacts and development status, and the references consulted, are available in the assessment report.

State-of-the-Art Technologies from the Technical Assessment

- **Close-coupled cooling** – Use of layout, proximity, and orientation of cooling equipment to create an efficient overall system; examples include rear-door heat exchangers and in-row cooling devices
    - Process(es) affected: data center cooling
    - Impact: savings depend on multiple site-specific variables, but on average in-rack cooling systems lose less than 10 percent of the cooling energy to the environment
- **Liquid immersion cooling** – Technology uses a high-heat-capacity dielectric liquid for heat transfer; blade servers are immersed in this solution
    - Process(es) affected: data center cooling

- Impact: a liquid immersion cooling system can reduce overall cooling energy by up to 95 percent, allowing for data center energy usage to be cut significantly—often in half

A number of state-of-the-art technology areas were identified in data centers through literature search. Most of the identified technologies related to data center cooling, but energy-efficient solutions related to lighting, back-up power systems, and management of server utilization were also identified as potential areas for energy improvement. The assessment report provides the full list of technologies identified through literature review.

Data Centers Roadmapping

During the roadmapping portion of the project, data center industry representatives and other experts provided opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 19 individuals on the three surveys. Representatives from equipment manufacturers, utilities, trade groups, consulting firms, and national laboratories joined the three webinars.

The top data center technologies identified in the earlier assessment were vetted during the first round of outreach. Participants noted that close-coupled cooling covers more than one specific technology, including rear-door heat exchangers and in-row cooling devices. Some questioned if liquid immersion cooling is ready for the market. The use of liquid immersion cooling is limited to new data centers because converting existing data centers to this technology appears cost prohibitive.

Participants identified three additional promising technologies during roadmapping activities. These are listed below with a brief description and are not described in the assessment report.

- **Direct-to-chip liquid cooling** – Enclosed liquid cooling systems that use pipes, plates, or other methods to cool chips and system components; servers are not immersed in liquid
  - Process(es) affected: data center cooling
  - Impact: reduction in electricity consumption and easier utilization of captured waste heat
- **Dynamic cooling management** – Use of rack sensors, control modules, and intelligent software to optimize cooling systems based on real-time needs
  - Process(es) affected: data center cooling
  - Impact: reduction in electricity consumption without significant reconfiguration of existing data center infrastructure
- **Direct and indirect evaporative cooling** – Technology that removes heat by evaporating water within an airstream; in indirect evaporative cooling, water does not come in contact with the conditioned air
  - Process(es) affected: data center cooling
  - Impact: cost of operating an evaporative cooling unit can be as little as 25 percent of traditional cooling systems; eliminates need for harmful refrigerants

Several other energy-efficient technologies were brought up and discussed by webinar participants, including high-efficiency centrifugal chillers, server virtualization, avoidance of transformation steps in power distribution, and co-location of data centers with entities that can utilize generated waste heat. Based on the group's discussion and conducted surveys, the above-mentioned three technologies were deemed to have most significant energy savings potential.

Technology Barriers

In the surveys and webinar discussions, data center industry's very high aversion to risk was identified as a major barrier to new technology adoption. For data centers, the cost of operational disruptions can be very high. Even large energy savings pale compared to the cost of such disruptions. Data center owners are not willing to use new or unproven technologies that are considered risky. Protection from financial liability due to service interruptions can also be a major cost for developers of new technologies.

Another barrier identified by the experts was the cost and difficulty of retrofits. Data centers operate continuously—24 hours a day, seven days a week. In such an environment, major retrofit projects are difficult to implement. Space in data centers is often limited. As a result, differently configured or physically larger technology solutions may not be possible to implement without major additional costs.

Survey and webinar participants noted that most large data centers are adopting efficient technologies. Market entry for new efficient technologies is slower in small- and medium-sized data centers that lack the resources and staffing available at larger entities.

Lack of clear prescriptive energy-efficiency program incentives for data center improvements was also identified as a barrier. Because of the non-standard and often complicated nature of data center upgrades, utility efficiency programs typically only offer custom rebates for the improvements. Using custom incentives is more expensive and time consuming than prescriptive rebates, which further discourages implementing efficiency upgrades. Another challenge with utility incentives is that rebates cannot be used if energy benefits materialize outside of the utility's service territory. Sometimes potential upgrades being considered by data center operators involve more than one utility service area.

General Barriers

General barriers that were identified by participants in the roadmapping effort were typical, and in line with feedback from other technology areas: lack of robust and multiple demonstrations, lack of standards, information barriers, and cost.

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies in the data centers sector in California, suggestions from participants included the following:

- Technology demonstrations
- Proof of actual energy and cost savings
- Information sharing
- Financial incentives and some kind of financial liability guarantees
- Codes and standards enforcement
- More prescriptive utility incentives instead of custom incentives would increase program participation (making utility incentives available for improvements that involve more than one utility service territory would also be helpful)

When asked to identify indicators of success for market entry of state-of-the-art technologies, participants made the following suggestions:

- Increase in market share
- Number of installations and total installed capacity
- Energy efficiency program participation
- Number of vendors in the market.

Demonstration projects and case studies is an early indicator of success.

Compared to many other industries, the speed of innovation and frequency of systems replacement is very high in the data centers industry. In many data centers, servers are replaced every few years. Such frequent turnover in technology is both an opportunity and challenge. As technologies are being replaced regularly, these system updates are also opportunities for improving efficiency. During these upgrades, most operators focus on the core aspects of data center services, such as processing capacity and speed. Less attention is being paid to supporting services, including cooling and power systems.

Data Centers Relevant Policies and Legislation

The five data centers technologies identified are listed in Table 23, with indication of which state policy or legislation applies. Excerpts from the referenced California policies and legislations are provided in Appendix D, and aligned to the various technology areas.

Table 23: Data Centers Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms					
	Industrial Facilities				
	Data Centers				
State Policy or Legislation	Close-coupled cooling	Liquid immersion cooling	Direct-to-chip liquid cooling	Dynamic cooling management	Direct and indirect evaporative cooling
California Codes					
Warren-Alquist Act	X	X	X	X	X
Public Resources Code 25601	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X
California Energy Commission					
Integrated Energy Policy Report	X	X	X	X	X
Building Energy Efficiency Standards	X	X	X	X	X
Executive Orders					
Executive Order B-18-12	X	X	X	X	X
Senate Bills					
SB 350	X	X	X	X	X
Assembly Bills					
AB 758	X	X	X	X	X
California Air Resources Board					
California's 2017 Climate Change Scoping Plan	X	X	X	X	X

CHAPTER 6: Bioenergy State-of-the-Art Opportunities

Bioenergy

The bioenergy technology area of the technical assessment was composed of five subareas describing renewable energy generation and production technology: feedstock production, bioenergy to grid integration, gasification technologies, woody biomass facilities and harvesting, and anaerobic digesters for energy production. The 69 state-of-the-art and 11 R&D technologies were narrowed down to just the gasification and anaerobic digestion subareas. Of the five subareas, feedstock production, grid integration, and woody biomass facilities and harvesting were dropped since they were not directly tied to electricity savings or technology advances in renewable electricity generation.

Anaerobic Digestion

The total energy consumption for biomass electric power generation in California was not available from data collected by either IOUs or federal agencies. The total industry size is reported here with respect to an applicable NAICS code. The Census Bureau CBP Surveys data determined the total number of employees and firms within the industry. Biomass electric power generation sector statistics are shown in Table 24.

Table 24: Biomass Electric Power Generation Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated)	Number of Facilities [2]	Number of Employees [2]
Biomass Electric Power Generation	22117	Not available	12	125

Sources: [1] U.S. Census Bureau 2014c; [2] U.S. Census Bureau 2014b

Anaerobic Digestion Technical Assessment

Anaerobic digestion technologies considered in the technical assessment focused on potential renewable electricity generation by converting food and organic waste to energy. Of the technologies in the assessment, three were identified in the prioritization process and are described briefly. The assessment report provides further details on the researched technology impacts and development status, along with references consulted and any outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

- **Gas cleanup** - Adsorption has several methods: activated carbon (removing hydrogen sulfide (H_2S), carbon dioxide (CO_2), moisture, volatile organic compounds (VOCs), and siloxanes); zeolites (removing water (H_2O), H_2S, ammonia, mercaptans); molecular sieves (removing contaminants by allowing them to penetrate the sieve faster than methane);

alkaline solids (removing H_2S, CO_2, and mercaptans); iron sponge (H_2S); and silica gel (siloxanes and H_2O).

    - Water scrubbing is especially effective at removing H_2S, ammonia, VOCs, and siloxanes but will leave the biogas saturated with moisture. Any oxygen and nitrogen dissolved in the water from the atmosphere can be released into the biogas.
    - Biofiltration is used for biological metabolism of sulfur-oxidizing bacteria species to remove H_2S.
    - Refrigeration/chilling is used primarily to remove moisture from biogas after other contaminants have been removed by the other methods. Some ammonia and other trace amounts of compounds may also be absorbed into the water removed.
  - Process(es) affected: gas cleanup processes to remove constituents such as hydrogen sulfide, siloxanes, VOCs, and CO_2
  - Impacts:
    - Reduction or elimination of emissions of biogas contaminants
    - Significant parasitic loads, adding about2 cents per kWh of electricity generated
    - High cost of small-scale biogas cleanup (0 to 56 standard cubic feet per minute [SCFM]) because of high equipment investment costs
- **Enhanced anaerobic digester biogas production using enzymes** – Enhanced biogas production with enzyme pre-treatment
  - Process(es) affected: in-vessel anaerobic digestion systems
  - Impacts:
    - Biogas production increase of 15 percent
    - Reduced transportation requirements because less feedstock is needed
    - Reduced anaerobic digestion costs (about 10 percent)
    - Reduced substrate and digestate removal costs
    - Availability of enzymes to enhance the biogas production rate and yield from feedstocks containing lignocellulosic materials (such as wood)
- **Fixed film anaerobic digestion of dilute waste streams such as livestock and dairy manure** - This fixed film anaerobic digestion/treatment technology for dilute waste streams provides a low-cost, efficient physical media for packed bed digesters
  - Process(es) affected: anaerobic digestion of organic wastes, food wastes, and manure
  - Impacts:
    - Biogas yield is moderate compared to the low biogas production in a covered lagoon
    - Because it is a completely enclosed system, fixed film digester allows more complete anaerobic digestion of odorous organic intermediates found in manure
    - Capital cost is up to two times higher—or more—than that of covered lagoon anaerobic digesters
    - Fixed film hydraulic retention time can be as low as 2 to 3 days; in a covered lagoon, this period can be 30 to 60 days

        - The footprint is substantially smaller than a covered digestion lagoon when used for dairy and livestock manure conversion
        - Fixed film digesters can provide recyclable water for barn flushing, reducing the need for additional supplied water

Anaerobic digestion technologies considered in the assessment focused on potential renewable electricity generation by producing biogas and biomethane. The literature review identified 23 technologies (19 state-of-the-art and four R&D) in this bioenergy subarea. These included a wide variety of technologies including: gas cleanup and conditioning, innovative anaerobic digestion systems, pretreatment of waste feedstock, co-digestion at dairy digesters and wastewater treatment facilities, small-scale systems, and anaerobic digestion for lignocellulosic feedstocks.

Anaerobic Digestion Roadmapping

During the roadmapping portion of the project, bioenergy representatives and experts contributed opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Fifty-two people provided feedback on three surveys, and 34 individuals participated in three webinars. They were from a wide range of backgrounds including academia, consulting, national labs, federal and state agencies, and project and technology development. Several survey respondents participated in the webinars as well.

The technologies identified in the assessment phase were vetted during the first round of outreach to experts. In addition to the three technologies discussed above, two additional technologies not contained in the assessment were identified by participants and are described below.

- **Co-digestion** – Co-digestion allows for the anaerobic digestion of food and organic waste at dairy and livestock digesters and wastewater treatment plants in addition to their traditional feedstocks of manures or organic solids (such as sewage sludge).
    - Process(es) affected: dairy/livestock digesters and wastewater treatment facilities
    - Impacts:
        - Existing and widespread wastewater treatment facilities can be used for a wider variety of organic waste inputs
        - Low-energy-yielding manures can be augmented with higher-energy-yielding food waste to increase the efficiency of an anaerobic digestion system
- **Dry fermentation anaerobic digestion percent** – Anaerobic digestion using input material that has moisture content less than 75 percent, material that usually would be handled and fed as a solid
    - Process(es) affected: organic feedstock of lower moisture level
    - Impacts:
        - Closed loop liquid cycle — no additional liquid required following start-up, eliminating post-process wastewater treatment needs
        - Almost no limitations to inputs—over 3,000 inputs have been identified and researched
        - Lower energy yield than wet fermentation

Participants discussed developing economically viable small-scale anaerobic digestion systems that could be used as a distributed energy resource Additionally, they mentioned the need for advanced digester controls, which would increase the yield of the digester systems.

Technology Barriers

Survey and webinar participants identified barriers to adopting these technologies, including:

- Not enough demonstration projects and run time of systems
- Little, or conflicting, policy support, such as conflicts between policies and regulations of state agencies
- Inconsistent permitting between air districts, county/city planning departments (for land use permits)
- Lack of adequate funding for state grant and incentives programs for capital expenditures in particular
- Cost of feedstocks – dependency on tipping fees versus the cost of local landfills, lower cost due to dollars/ton credit from avoided landfill considerations
- Co-digestion at wastewater treatment – resistance from wastewater treatment operators to comingle non-sewage waste with wastewater treatment system (includes substrate homogenization and wastewater digester health management issues)
- Difficult economics for small-scale anaerobic digesters

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies for the anaerobic digestion sector in California, suggestions from participants included:

- Provide more state funding (particularly from cap-and-trade proceeds and EPIC funds) to assist in meeting the mandates of AB1826 (mandatory food/organic waste recycling) and SB 1383 (reduction of methane emissions)
- Require more balance renewable energy portfolio for California utilities so bioenergy has a chance against solar and wind
- Subsidize directly or lower the costs of interconnection to utility electricity grid system
- Streamline regulations and create a consistent regulatory environment
- Provide regulatory, technical, and financial assistance to companies to demonstrate small-scale anaerobic digestion systems that can process agribusiness and food processing byproducts into electricity
- Educate operators and owners of wastewater treatment works and other stakeholders about the economics and other benefits of co-digestion

Participants provided the following input when asked to identify indicators of success:

- Measurable reduction of greenhouse gases and improved air quality

- Achievement of SB 1383 landfill diversion goals (i.e., a 50 percent reduction in the level of landfill disposal of organic waste from the 2014 level by 2020, and a 75 percent reduction by 2025)
- Payback on capital within five years
- ROI above 10 percent
- Verifiable increase in biomethane production in wastewater treatment works for electricity generation when co-digestion is implemented
- Reasonable retention time for all digestion feedstocks when co-digestion is used

Anaerobic Digestion Relevant Policies and Legislation

Five of the technologies identified here are listed in

Table 25, with indication of which state policy or legislation is applicable. Excerpts from the referenced California policies and legislations are in Appendix D, and aligned to the various technology areas.

Table 25: Anaerobic Digestion Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms					
	Bioenergy				
	Anaerobic Digestion				
State Policy or Legislation	Fixed Film AD/Treatment Technology for Dilute Waste	Biogas Cleanup Systems	Enhanced AD Biogas Production Using Enzymes	Co-digestion	Dry Fermentation Anaerobic Digestion
California Codes					
Warren-Alquist Act	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X
California Energy Commission					
Integrated Energy Policy Report (IEPR)	X	X	X	X	X
Bioenergy Action Plan	X	X	X	X	X
Energy Action Plan	X	X	X	X	X
Executive Orders					
Governor's Executive Order S-03-05	X	X	X	X	X
Governor's Executive Order S-06-06	X	X	X	X	X
Governor's Executive Order B-30-15	X	X	X	X	X
Senate Bills					
SB 32	X	X	X	X	X
SB 350	X	X	X	X	X
SB X1-2	X	X	X	X	X
SB 1122	X	X	X	X	X

State Policies and Legislation: Relevance to Technology Platforms					
SB 1383	X	X	X	X	X
Assembly Bills					
AB 32	X	X	X	X	X
AB 1594					X
AB 1826	X	X	X	X	X
AB 1923	X	X	X	X	X
California Public Utilities Commission					
Renewables Portfolio Standard	X	X	X	X	X
Self-Generation Incentive	X	X	X	X	X
California Air Resources Board					
2017 Climate Change Scoping Plan	X	X	X	X	X
CARB AB 32 Scoping Plan	X	X	X	X	X
Short-Lived Climate Pollutant Reduction Strategy	X	X	X	X	X
California Department of Resources Recycling and Recovery (CalRecycle)					
Greenhouse Gas Reduction Grant and Loan Program	X	X	X	X	X
California Department of Food and Agriculture (CDFA)					
Dairy Digester Research and Development Program	X	X	X	X	

Gasification

Gasification Technical Assessment

The gasification technologies considered in the technical assessment focused on potential renewable electricity generation by conversion of woody biomass to energy. One technology identified in the assessment prioritization process is described. The assessment report contains further details on the researched technology impacts and development status, along with references consulted and any outreach to experts.

State-of-the-Art Technologies from the Technical Assessment

- **Sierra Energy FastOx®** – The FastOx® gasifier is designed for complex and mixed biomass resources (woody and non-woody cellulosic waste) as well as other mixed solid wastes
  - Process(es) affected: woody biomass gasification
  - Impacts:
    - 20 dry metric tons of woody biomass per day generates 1 MW of electricity
    - Gasifier uses inject oxygen instead of ambient air, which lowers thermal NO_x emissions downstream of gasifier, and, for the fuel gas out of the gasifier,

increases the energy content of the gas (that is the Btu/scf) by not bringing 80%-nitrogen air into the gasifier
        - Very fuel-flexible
        - No water consumption
        - Modular design allows for staged expansion of electricity production

Gasification technologies considered in the assessment focused on potential renewable electricity generation by producing syngas. The literature identified 23 technologies (20 state-of-the-art and three R&D). These included a wide variety of related technologies including syngas cleanup and conditioning and a wide variety of woody biomass and municipal solid waste gasifiers.

Gasification Roadmapping

During the roadmapping portion of the project, bioenergy representatives and experts provided opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 52 individuals on the three surveys, and 34 individuals in the three webinars. The participants were from a wide range of backgrounds including academia, consulting, national labs, federal and state agencies, and project and technology development. Several survey respondents participated in the webinars as well.

The technologies previously identified in the assessment were vetted during the first round of outreach to experts. In addition to the single gasification technology discussed above, one additional technology was identified by participants, and is briefly described.

- **Gasification with Organic Rankine Cycle (ORC) engine** – Gas directly out of the gasifier can be combusted externally from the gas turbine or gas engine to power an ORC process rather than requiring gas cleanup that would be needed with a standard natural gas turbine or internal combustion engine electricity generator set. The ORC also enables a cost-efficient power cycle at small size by matching the working fluid to the input temperature.
    - Process(es) affected: syngas cleanup
    - Impacts:
        - Eliminates the need for extensive syngas cleanup system, providing both technical and economic benefits
        - No generation of syngas cleanup system wastewater
        - Efficiency of electricity generation is lower, but the ORC gives cost-effective match of working fluid to the input temperature

Technology Barriers

Survey and webinar participants identified numerous barriers to adopting gasification technologies:

- Syngas cleanup systems are not sufficiently technologically advanced

- Not enough demonstration projects and run time of systems
- Little, or conflicting, policy support, such as conflicts between policies and regulations of state agencies
- Inconsistent permitting between air districts, county/city planning departments (for land use entitlements)
- Lack of adequate funding for state grant and incentives programs for capital expenditures in particular
- Cost of feedstocks – woody biomass generally has to be purchased (no tipping fee)
- Difficult economics for small-scale gasifier systems

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies for gasification systems in California, suggestions from participants included:

- Provide more state funding (particularly from cap-and-trade proceeds and EPIC funds) to assist in meeting the mandates of AB1826 (mandatory food/organic waste recycling, which includes woody biomass) and SB 1383 (reduction of methane emissions)
- Require more balanced renewable energy portfolio for California utilities so bioenergy has a chance against solar and wind
- Subsidize directly or lower costs of interconnection to utility electricity grid system
- Streamline regulations and create consistent regulatory environment
- Provide regulatory, technical, and financial assistance to companies to demonstrate small-scale gasification systems that can process urban, agricultural, and forest-sourced woody biomass

Participants provided the following input when asked to identify success indicators:

- Measurable reduction of greenhouse gases and improved air quality
- Achievement of SB 1383 landfill diversion goals (a 50 percent reduction in the level of landfill disposal of organic waste from the 2014 level by 2020, and a 75 percent reduction by 2025)
- Payback on capital within 5 years
- ROI above 10 percent

Gasification Relevant Policies and Legislation

The two technologies identified are listed in Table 26, with indication of which state policy or legislation is applicable. Excerpts from the referenced California policies and legislations are provided in Appendix D, and aligned to the various technology areas.

Table 26: Gasification Relevant Policies & Legislation

State Policies and Legislation: Relevance to Technology Platforms		
State Policy or Legislation	**Bioenergy**	
	Gasification	
	Mixed	Organ
California Codes		
Warren-Alquist Act	X	X
Public Resources Code 25620	X	X
California Energy Commission		
Integrated Energy Policy Report (IEPR)	X	X
Bioenergy Action Plan	X	X
Energy Action Plan	X	X
Executive Orders		
Governor's Executive Order S-03-05	X	X
Governor's Executive Order S-06-06	X	X
Governor's Executive Order B-30-15	X	X
Governor’s Proclamation of State of Emergency, 10/31/2015	X	X
Senate Bills		
SB 32	X	X
SB 350	X	X
SB X1-2	X	X
SB 1122	X	X
SB 1383	X	X
Assembly Bills		
AB 32	X	X
AB 1594	X	X
AB 1923	X	X
California Public Utilities Commission		
Renewables Portfolio Standard	X	X
Self-Generation Incentive	X	X
California Air Resources Board		
2017 Climate Change Scoping Plan	X	X
CARB AB 32 Scoping Plan	X	X
Short-Lived Climate Pollutant Reduction Strategy	X	X
California Department of Forestry and Fire Protection (CAL FIRE)		
Forest Climate Action Team	X	X

CHAPTER 7: Agriculture State-of-the-Art Opportunities

Irrigation and Electricity-Intensive Agriculture

The total energy consumption for agriculture in California was estimated using data from federal agencies. The total energy consumption for water supply and irrigation systems in California was estimated using federal data. The Census Bureau CBP Survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The Energy Commission estimated 0 TBtu natural gas and 1,229 million kWh electrical energy consumption for irrigation in California in 2014. Water supply and irrigation systems sector statistics are in Table 27.

Table 27: Water Supply and Irrigation Systems Sector Statistics in California, 2014

Sector	NAICS Code [1]	Natural Gas Consumption (TBtu, estimated) [2]	Electricity Consumption (million kWh, estimated) [2]	Number of Facilities [3]	Number of Employees [3]
Water Supply and Irrigation Systems^	221311	0*	9,264*	419*	4,337*

*** Note - water supply is more relevant to the Water and Wastewater tech area, it is combined here with irrigation systems as the data sources do not allow for this separation, the statistics are repeated in the Water and Wastewater chapter of this Roadmap.**

^Number of facilities and employees are for all water supply and irrigation systems (including water treatment, municipal water supply, etc.), while energy consumption estimates from the Energy Commission are for agriculture irrigation specifically.

Sources: [1] U.S. Census Bureau (USCB) 2014; [2] 2014 IOU supplied data via Energy Commission Demand Analysis office; [3] CBP Surveys 2014

Irrigation and Electricity-Intensive Agriculture Technical Assessment

In the assessment, two electricity-intensive agricultural, and five irrigation state-of-the-art technologies, were identified for electricity savings. These are listed with a brief description. Further details on the processes affected, impacts, technology development, and references consulted are in the assessment.

Electricity-Intensive Agriculture State-of-the-Art Technologies from the Technical Assessment

- **Dryeration** – Steeping method where grain is transferred hot at 2 to 3 percent moisture higher than the desired storage moisture to a bin and allowed to “steep” without air flow for 4 to 12 hours

    - Process(es) affected: Grain steeping
    - Impacts: Reduces energy input by 20 to 25 percent, provides high grain quality, increases drying capacity and efficiency
- **Water-cooled plate cooler** – pre-cooling milk with a water-cooled plate heat exchanger before entering the vat
    - Process(es) affected: Milk cooling, particularly in the vat
    - Impacts: Significantly reduces electricity consumption due to reduced refrigeration tank compressor energy requirement (thus also reducing greenhouse gas emissions). Provides faster cooling allowing higher volumes of milk to be cooled at a time and reducing bacteria count in the milk.

Irrigation State-of-the-Art Technologies from the Technical Assessment

- **Smart irrigation scheduling** – Using various methods to help optimize when to irrigate and how much water to apply at any one irrigation
    - Process(es) affected: Irrigation pumping systems
    - Impacts: Increased energy and water savings due to better management of water application to crops and of irrigation equipment
- **Micro-irrigation** – Systems such as bubblers and drip emitters that apply water near the base of individual plants. This reduces seepage and evaporation losses and requires low pumping power.
    - Process(es) affected: Overall irrigation process
    - Impacts: Lower operating pressure reduces pumping head requirements, operating costs, and water requirements and increases pumping energy savings and overall efficiency. Improvements in chemical and fertilizer placement. However, this can increase maintenance and additional component installation costs.
- **Controls and smart systems** – Sensors on irrigation systems, such as soil moisture and bore sensors, that help eliminate inefficiencies by providing feedback on key performance parameters. Timers and temperature sensors help ensure that fields get irrigated at optimal times and under optimal conditions
    - Process(es) affected: Overall irrigation process
    - Impacts: Bore sensors can alert controls on bore pumps to shut off automatically when water levels drop below a certain point, reducing energy use. Water use can be reduced without affecting crop yields.
- **Regulated deficit irrigation (RDI)** – RDI regulates or restricts the application of irrigation water limiting the vine water use to below that of a fully watered vine during times of limited water availability.
    - Process(es) affected: Overall irrigation process
    - Impacts: RDI has been shown to maintain or increase the yield in certain crops and save water and increase water use efficiency but is a new concept to farmers.

Low-energy precision application irrigation was removed from the list because participants determined it was not applicable and beneficial to California regions (explained in next section).

Irrigation and Electricity-Intensive Agriculture Roadmapping

During the roadmapping portion of the project, agriculture industry representatives contributed opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 15 individuals on the two surveys concerning technologies. Representatives from Ag H_2O, Pacific Gas and Electric Company (PG&E), Lyons-Magnus, PowWow Energy, Bonneville Power Administration (BPA), California League of Food Producers (CLFP), Fresno State, UC Davis, and consultant representatives joined the two webinars.

During the first round of outreach, experts provided feedback on the seven agriculture and irrigation technologies from the assessment. In general, there was more feedback and interest for irrigation rather than agriculture technologies. It was suggested that a protocol for pump rotation, maintenance, and losses was to be added, but this was agreed to be better managed by utilities rather than as a specific technology by the Energy Commission.

The low-energy precision application may be better applied to other areas of the country because water is applied too fast for California soils (0.5 inches or higher), which may not be widely useful. For controls and sensors, soil moisture stress sensors were noted as specific sensors multiple times by participants as well as digital flowmeters, well depth monitors, and pressure sensors that are tied to a data network for better monitoring. Annual monitoring of water and pump wear can help trigger maintenance rather than reacting to broken equipment and could improve overall pump system efficiency.

No specific technologies were suggested for the list, but participants agreed that irrigation would benefit from the use of smart management systems and modelling to increase precision, behavioral management, grower education for managing and monitoring fields, and developing a protocol for system manufacturers to accurately measure equipment water and energy efficiency. For agriculture, it would be beneficial to have a website available summarizing worldwide agricultural science and technology in practice.

Technology Barriers

For controls and sensors in irrigation smart systems, the most significant problem is the variability in sensor performance and cost (e.g., the most accurate sensors can run as much as $5,000 apiece). Until both sensor accuracy improves and cost is reduced, growers will be unable to afford the number required for the various soil/crop types in their respective fields.

Numerous issues were raised about smart irrigation scheduling. There are many technology providers but none that last for an extended time. Growers are hesitant to accept the technology because they do not want to end up with an unsupported product when a company goes out of business. Wider acceptance may be achieved when the number of options is reduced. The technology has potential yet is initially expensive, and its near-term availability needs to be determined. There are a larger number of crops in California (more than 360) and crop data currently available (climate zones, soil types, soil variability, etc.). The numerous types of scheduling have caused confusion among growers and there is no scientifically accepted procedure for determining hardware efficiency. BPA have offered incentives for decades. The technology has evolved over the last five years with smart apps, drones, 3D infrared photos, etc. and utilities must determine how they fit into the technology renaissance.

RDI stresses crops, which makes growers uncomfortable especially on permanent crops, unless it is proven successful over numerous years. However, this has become industry practice for some crops (e.g., grapes) for flavor. In order to improve the technology, the industry needs better crop coefficients.[2] Tomatoes are often grown with deficit irrigation at certain times of the crop cycle to increase crop density.

Micro-irrigation is standard practice for tree crops. Growers are moving away from flood irrigation (outside of rice) because it is unaffordable. However, micro-irrigation does not recharge the water table. Additionally, there is significant work ongoing at UC Davis investigating the soil microbiome. Micro-irrigation seems good in practice but will have to be tied to quality crop production.

Aside from barriers on the specific technologies, participants identified additional technology barriers. Time is needed to develop water-efficient crops including genetics programs to improve irrigated varieties. Crop transpiration needs must be satisfied to maximize production and water savings can be realized by minimizing evaporation losses. Focusing on technology that minimizes exposing irrigation water to the atmosphere or enhances soil intake rate could also help reduce those losses. There is no current accepted protocol to identify efficient irrigation equipment from manufacturers that would identify the energy and water consumption as a type of labeling. This protocol is needed to develop a fully efficient system and should include pumps and pipe losses.

General Barriers

Participants identified numerous general barriers, most notably for irrigation but which could extend to agriculture. These included educating growers on using technology correctly and its benefits. For example, utilities have deployed smart meters for irrigation, but users do not understand their use and educational outreach is needed. Developing hybrid crops and methods to assess resource use efficiency improvements has been challenging. Technology cost and the cost of capital significantly affect the ability of the grower to implement new technology. Since growers have only one chance per year for a harvest, they are very conservative in making changes that can potentially reduce yield.

There is proof of concept issues for bringing technologies to market. While the marketers for companies are bringing technologies to the field, sometimes it is not what is needed for the

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[2] Crop coefficients are defined as the ratio of the actual crop evapotranspiration (ET) to the reference crop ET. The reference crop ET is determined from weather data collected by the California Irrigation and Management Information System (CIMIS), a network of weather stations installed and maintained by the University of California and California Department of Water Resources. Crop coefficients vary depending on the crop type, and growth stage. While crop coefficients are regularly reported, actual crop ET is more commonly reported. For example, the actual crop ET has been estimated to be 21-30 inches of water (where one inch of water is equivalent to one acre-inch per acre, or 27,160 gallons per acre). Sources: Hanson n.d.; Hanson 2006

field conditions or growers' expertise level. The technology is not widely adopted and initial success is critical to acceptance. Sensitivity to appropriate technology needs to be exercised by companies.

Path to Market

Experts participating in feedback suggested potential actions to support market entry for technologies. These included supporting demonstration projects and development of resource use efficiency metrics. Innovative financing packages to help pay for technology deployment on farms would help to drive energy and water efficiency. It would be more effective to not push the costs onto farmers to report water usage.

Market entry might be accelerated without any further actions. The significance of the impact of the California Sustainable Groundwater Management Act (SGMA – 2014) may force water users out of their comfort zone and into a new era of advanced water management technology. This may push options such as water storage improvements to the near horizon.

Another issue in the larger energy-water balance was that the embedded energy of nitrogen-based fertilizers is much greater than pumping energy. Unfortunately, most fertilizers are manufactured outside California. The added benefit of reducing nitrogen is lessened nitrate intrusion in the ground table and fertilizer management education could be encouraged by the Energy Commission. One method could be subsidizing the purchase of groundwater pumping meters before it becomes required by law (e.g., rebates). Additionally, it was suggested that the Energy Commission work with National Resources Conservation Service (NRCS) and other efforts in this area.

Suggestions were also put forward for the specific irrigation technologies identified in the assessment. Education was key for smart irrigation scheduling. A systems approach would be helpful, with further coordination and collaboration in territories. For micro-irrigation, design standards that support an ENERGY STAR-based approach should be encouraged, where distribution uniformity is also incorporated.

There are numerous indicators of success for technological adoption and improved energy and water efficiency. These can be a general measurement of irrigation adoption market trends by crop type, away from gravity or flood irrigation towards types such as microspray or drip irrigation. Moisture measurements can be taken below the root zone to indicate effectiveness of irrigation technology.

The use of technologies over time should be tracked to determine their marketplace persistence. Year over year adoption increases are important but may not indicate that growers will continue to use the technology. Central Valley irrigation history is replete with supposed irrigation improvements that did not stand the test of time. Tracking technologies will also help with historical baselining, which has proved difficult since there are various parameters that affect the yield per food type. Well-controlled trials are needed to utilize yield as an indicator.

In terms of the specific irrigation technologies, there are indicators of success that could prove useful. For smart irrigation scheduling, when growers start measuring yield in terms of water used per energy input (like miles per gallon for vehicles), they will move towards thinking in terms of energy to make decisions. With RDI, one example could be the yield quantity per the amount of applied water. Controls and smart systems will be more difficult since the market is evolving. Data may not be available in terms of savings and how they are documented.

Food and Beverage Processing

The total energy consumption for food and beverage processing in California was estimated using data from federal agencies. EIA's (MECS data provides average energy consumption rate per employee and per value of shipments in the Western Census region, which was assumed to be representative of California. The Census Bureau CPB Surveys data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS code and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in food and beverage processing in California, 142.8 trillion Btu (TBtu) and 9,289 million kWh respectively. Energy consumption is further broken down by type of food and beverage manufactured in Table 28.

Table 28: Food and Beverage Processing Sector Statistics in California, 2014

Sector	NAICS Code [1]	Total Energy Consumption (TBtu, estimated) [2-4]	Electricity Consumption (million kWh, estimated) [2-4]	Number of Facilities [3]	Number of Employees [3]
Food Manufacturing	311	124.5	7,086	3,608	154,439
Beverage and Tobacco Product Manufacturing	312	18.3	2,203	1,741	42,352
Total	**-**	**142.8**	**9,289**	**5,349**	**196,791**

Sources: [1] USCB 2014; [2] MECS 2014; [3] CBP Surveys 2014; [4] ASM 2014

Food and Beverage Processing Technical Assessment

The assessment identified four priority state-of-the-art technologies for electricity savings. These are listed with a brief description. Further details on the processes affected, impacts, technology development, and references consulted are in the assessment.

State-of-the-Art Technologies from the Technical Assessment

- **Advanced carbon dioxide (CO_2) recovery systems** – Utilizing cold side of a CO_2 recovery system in a secondary cooling system
  - Process (es) affected: Breweries, wineries and carbonated beverages
  - Impacts: Carbon reduction in the atmosphere (carbon sequestration); Valorization of carbon dioxide (e.g. bubbling CO_2 into calcium hydroxide ($Ca(OH)_2$) solution produces calcium carbonate ($CaCO_3$) (chalk), which precipitates. It is filtered, stored,

and later transferred to biotech companies for use as CO_2 for growing algae or bacteria. Other research in CO_2 sequestration may include adsorption via catalysis and reaction by nanomaterials.

- **Blowers in compressed air systems –**
  - Process(es) affected: Soft drink manufacturing, especially air jet drying and displacement
  - Impacts: Compressed air is electrically inefficient to produce. Blowers provide low pressure, high velocity air and offer significant increases in energy efficiency over compressors.
- **Refrigeration improvements in wineries (and other applications) –**
  - Process(es) affected: Wineries, with potential application to other refrigeration systems
  - Impacts: Refrigeration-coupled thermal energy storage to reduce production facility peak load, allow load shifting for time-of-use cost structures, and act as energy storage at times of peak solar photovoltaic production or at night when energy costs are lower. Improves plant electrical efficiency while decreasing greenhouse gas and other pollutants from electricity generation.
- **Mechanical vapor recompression (MVR) evaporators in whey drying –**
  - Process(es) affected: Dairy, whey drying
  - Impacts: MVR will add capital cost but will have less steam consumption for the same evaporation capacity. Large-scale operations should be able to justify the use of MVR.

These four technologies, as well as additional others (continuous mixing, variable speed drives, heat exchanger improvements, etc.), were identified through a literature search, technologies identified through literature review and prioritized is available in the assessment report.

Food and Beverage Processing Roadmapping

During the roadmapping portion of the project, food and beverage processing industry representatives contributed promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 15 individuals on the two surveys concerning SOA technologies. Representatives from Ag H_2O, PG&E, Lyons-Magnus, PowWow Energy, BPA, CLFP, Fresno State, UC Davis, and consultant representatives joined the two webinars.

During the first round of outreach, experts provided feedback on the four food and beverage processing technologies from the assessment. Participants noted that these technologies have been available for some time (e.g., blower technology has been proven for many years), but not widely implemented so the issue may be implementation-related. Refrigeration is considered low-hanging fruit, so improvements could have a greater impact in the near term.

Two additional technologies were identified for food and processing, during roadmapping activities. These are listed with a brief description and are not in the assessment report.

- **Ambient temperature sanitization vs. steam and hot water** –Ambient temperature sanitization, such as using hydrogen peroxide with inorganic buffers, plus replacement of sodium with potassium salts in cleaning solutions can help reduce energy, water and cleaning chemistry requirements without creating residual environmental problems.
  - Process(es) affected: Wineries, breweries.
  - Impacts: Can reduce electrical energy requirements and provide clean residual solution that can be filtered and reused. Recovery of over 90 percent of the cleaning solution over 10 cycles leads to using 1/5 of the normal amount of water and chemicals.
- **Smarter use of jacket cooling in batch systems** – Pulsed cooling can be used instead of conventional jacket cooling involving full flow rate recirculation of the working fluid for batch processing
  - Process(es) affected: Wine, brewing, dairy and other beverage operations.
  - Impacts: Improves cooling efficiency by ensuring temperature difference between supply and return of chilled working fluid ("Delta-T"). If Delta-T is low, the chiller and/or pump energy increase to meet cooling loads. Pulse cooling allows time for the working fluid to warm via conductance (heat exchange with the product to be cooled. Pulse cooling allows time for the working fluid to warm via conductance (heat exchange with the product to be cooled) prior to returning working fluid to chiller.

Participants had additional suggestions for state-of-the art improvements. These included waste heat recovery and reuse in thermal driven processes, monitoring and automating cooling towers to take advantage of lower temperature periods, using smart modeling and management systems to increase energy efficiency, and implementing low-cost energy, gas, and water submetering in processing facilities. Monitoring water consumption and pump wear and promoting best practice technology can help trigger scheduled maintenance to reduce unscheduled downtime and improve pumping efficiency. For multi-effect evaporators, numerous improvements were noted as beneficial for energy efficiency, including insulating, further automation, supplementing vapors with live steam, and improved flash vapor design.

Technology Barriers

Certain barriers were noted for the technologies. For advanced CO_2 recovery systems for breweries, the technology may not be cost effective for smaller brewers, which do not produce as much CO_2. This may be a challenge in increasing its adoption, but similar technologies like these provide points for certifications such as Leadership in Energy and Environmental Design (LEED) may make it more attractive. Compressed air is energy intensive and losses are very high. The alternative technology of blowers from the assessment is more efficient but are also costly. Changing processes often require shutdowns, which affects productivity and is a significant barrier.

For other technologies, more operational data is needed from testing to help prove feasibility and long-term sustainability. When replacing one piece of equipment in the system to make improvements, there may be cascading unintended effects that needs to be better understood.

After installing technology, there is a lack of expertise in its operation and servicing which causes problems in its effective use. End users may not see all the benefits.

General Barriers

Participants identified barriers for food and beverage processing. In California, increasingly stringent air quality (e.g., NO_x) regulations have raised the cost of steam to process food, which coupled with high natural gas and electricity costs adds challenges in adopting new technologies. Food and beverage processors have a high seasonability element in their industry (e.g., long lead times to acquire equipment, budget restraints) which means a limited window to decide on implementing new technology. Additional cost barriers include labor, food safety, and managing water, wastewater, and waste.

Similar to irrigation and agriculture, utilities have deployed smart meters in this industry, but users do not understand their benefits and educational outreach is needed. There is confusion about available grants or incentive funding opportunities for processors. The industry also faces barriers that limits investments in energy efficiency such as continuous changes in consumer preferences, offshore competition, lack of profitability, and restrictions by investor-owned, public companies competing with nimbler private companies.

Path to Market

During the roadmapping, experts were asked what potential actions could facilitate market entry. As with other technology areas, participants agreed supporting demonstration projects for new technologies and developing resource use efficiency metrics and validation methods so producers know that measurements of technologies are reliable. Long bed trailers for demonstration projects were noted as an important education tool for end users and the public. While identifying volunteers for demonstration projects can be challenging, incentives or funding can help defray administrative costs and mitigate risks.

Identifying case studies where state-of-the-art technology is being tested today and working and making them available for feedback (e.g., through website, meetings, field days) can help shorten a technology's path to market. Stakeholders should be involved in meetings or events and provide feedback on technologies, including where they are being used and the associated post-harvest costs. In-person events where experts can answer questions and end users can see the technologies could be effective.

Additional training and guidance on opportunities available through current grants and incentive programs so industry can take advantage of commercial technologies would be beneficial.

Suggestions were also provided for specific technologies. For blowers that would replace compressed air systems, utilities could promote the technology and provide incentives based on energy savings that are supported by calculations. When replacing steam and hot water with ambient temperature sanitization, investigating regulatory considerations is important before demonstration to ensure wider adoption.

Indicators of success for all technologies include reduced water and energy intensity, reduced GHG emissions, the ability to measure operational efficiency of resources used, and use baselines to compare results. It would be beneficial to develop and publish energy standards for products (kWh per unit of output) for the industry for baselining purposes. Additionally, the Energy Commission should track the use and progression of technologies to see how well the market adopts them.

Agriculture Technical Area Relevant Policies and Legislation

The 10 technologies identified for the agriculture technology area in the assessment and two that were added in food and beverage processing after the first webinar are listed in

Table 29, with indication of which state policy or legislation applies. Excerpts from the referenced California policies and legislations are in Appendix D and aligned to the various technology areas.

Table 29: Agriculture Technical Area Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms												
State Policy or Legislation	**Food and Agriculture Reduction Technologies**											
	Electricity-Intensive Agriculture			**Irrigation**				**Food and Beverage Processing**				
	Dryeration	Water-cooled plate cooler	Smart irrigation scheduling	Micro-irrigation	Controls and smart systems	Regulated deficit irrigation	Advanced CO_2 recovery systems	Blowers to replace compressed air systems in soft drink production	Improved refrigeration systems in wineries	Mechanical vapor recompression evaporators in whey drying	*Ambient temperature sanitization	*Smarter sensors for waste water composition for BOD^ and COD^ prediction
California Codes												
Warren Alquist Act	X	X	X	X	X	X	X	X	X	X	X	X
Public Resources Code 25620	X	X	X	X	X	X	X	X	X	X	X	X
California Energy Commission												
Energy Action Plan	X	X					X	X	X	X	X	X
Integrated Energy Policy Report	X	X	X	X	X	X	X	X	X	X	X	X
Energy Commission Energy Innovations Small Grant (EISG) Program	X		X	X	X	X	X	X	X	X	X	X
Executive Orders												
Clean Energy Jobs Plan	X	X	X	X	X		X	X	X	X	X	X

State Policies and Legislation: Relevance to Technology Platforms												
Executive Order S-3-05	X	X	X	X	X	X	X	X	X	X	X	X
Executive Order B-30-15	X	X	X	X	X	X	X	X	X	X	X	X
Executive Order B-37-16			X	X	X	X						
Executive Order B-40-17			X	X	X	X						
Senate Bills												
SB 32	X	X	X	X	X	X	X	X	X	X	X	X
SB 350	X	X		X	X		X	X	X	X	X	
SB X1-2	X	X					X	X	X	X	X	X
SB X7-7			X	X	X	X						
Assembly Bills												
AB 32	X	X	X	X	X	X	X	X	X	X	X	X
California Air Resources Board												
California's 2017 Climate Change Scoping Plan	X	X	X	X	X	X	X	X	X	X	X	X
CARB AB 32 Scoping Plan	X	X	X	X	X	X	X					
California Public Utilities Commission												
Energy Efficiency Strategic Plan	X	X	X	X	X	X	X	X	X	X	X	X
Other												
Western Regional Climate Action Initiative	X	X	X	X	X	X	X	X	X	X	X	X

Source: Biochemical and chemical oxygen demand (BOD and COD)

CHAPTER 8: Water and Wastewater State-of-the-Art Opportunities

Water and Wastewater

The total energy consumption for sewage treatment and water supply facilities in California was estimated using federal data. The Census Bureau CBP survey data provides the total number of employees and firms by sector in California. The ASM provides the total energy consumption per value of shipments and services by sector in California. The CBP and ASM surveys were broken down by their respective NAICS codes and multiplied by the MECS consumption rates. The two estimation approaches were averaged to estimate the total and electrical energy consumption in sewage treatment facilities in California, 1.4 trillion Btu (TBtu) and 1,673 million kWh, respectively. The water supply data was combined with irrigation systems which are part of the agriculture/irrigation tech area presented earlier. Sewage and water supply treatment facilities sector statistics are in Table 30.

Table 30: Sewage Treatment Facilities Sector Statistics in California, 2014

Sector	NAICS Code [1]	Natural Gas Consumption (TBtu, estimated) [2]	Electricity Consumption (million kWh, estimated) [2]	Number of Facilities [3]	Number of Employees [3]
Sewage Treatment Facilities	221320	1.4	1,673	43	375
Water Supply and Irrigation Systems*	221310	0*	1,229*	419*	4,337*

* Note – irrigation systems is more relevant to the agriculture/irrigation tech area, it is combined here with water supply as the data sources do not allow for this separation.

Sources: [1] USCB 2014; [2] 2014 IOU supplied data via Energy Commission Demand Analysis office; [3] CBP Surveys 2014

Water and Wastewater Technical Assessment

The assessment identified 10 priority technologies for electricity savings. These are listed below with a brief description. Further details on the researched technology impacts and development status, and the references consulted, are available in the assessment report.

State-of-the-Art Technologies from the Technical Assessment

- **Microfiltration** – A filtration process that uses membranes to separate suspended particles and microorganisms from contaminated water. This is typically used as a pre-treatment before other separation processes.
  - Process(es) affected: membrane separation

    - Impact: relatively low energy consumption (0.1 kWh/kgal of water treated) due to lower feed pressure; increased productivity and lower operational cost due to reduced fouling of the pretreatment membrane; membrane fouling remains a challenge.
- **Reverse osmosis** – Use of semi-permeable membranes for water purification.
    - Process(es) affected: water treatment, depending on feed water salinity and total dissolved solids (TDS)
    - Impact: up to 40 percent reduced electricity consumption for seawater desalination and up to 90 percent reduction for brackish water desalination facilities; concentrate discharge can have significant environmental impact because of higher salinities and membrane fouling.
- **Ultraviolet (UV) disinfection** – Optimizing energy use of ultraviolet disinfection systems used for wastewater treatment through various control strategies.
    - Process(es) affected: plant wide measures, primarily water post-treatment
    - Impact: potential short term energy savings of 50 percent; chemical free process with no transport or storage and produces no disinfection by products; could be wasting energy if not operated at full flow; additional pre-treatment might be needed to remove compounds that absorb UV light.
- **Advanced aeration** – Use of advanced aeration technologies, such as high-speed turbo blowers, to reduce energy use in wastewater treatment.
    - Process(es) affected: plant wide energy efficiency/management and demand response
    - Impact: optimized blower and process air controls will help reduce blower operating costs (50 to 82 percent nominal blower efficiency); fewer moving parts result in lower maintenance; quiet operation and small footprint.
- **Information technology** – Use of information technology solutions for data processing and system control to reduce energy consumption and peak demand in water supply and wastewater treatment.
    - Process(es) affected: plant wide energy efficiency/management and demand response
    - Impact: electric energy savings potential of at least 5 to 10 percent for water loss/leakage detection; advanced metering infrastructure and sensors can be used for operational optimization, system health monitoring (prognostics), and automation of various processes through real-time controls.
- **Load shifting** – Rescheduling the time of electricity demand to off-peak hours.
    - Process(es) affected: plant wide energy efficiency/management and demand response
    - Impact: 10 to 15 percent electricity cost savings for wastewater treatment facilities; untreated wastewater can be stored and then processed (i.e. bio-solids thickening/dewatering and anaerobic digestion) during off-peak hours.
- **Optimized head loss and friction loss in distributed piping systems** - Optimizing pipe size to reduce pumping energy needs in a distribution system.
    - Process(es) affected: plant wide measures, primarily distribution pipe networks

- Impact: reduced energy requirements to pump water through optimization of the entire water distribution system (pipes, storage, valves, etc.) by reducing the number of pumps or size of pumps needed as well as overcoming head loss and friction loss in pipes; challenge is high cost of replacing existing in-ground infrastructure.

A number of technology areas were identified in water supply and wastewater treatment through literature search, including physical, chemical, and biological treatments, electrical and mechanical system improvements, and information technology applications. The full list of technologies identified and prioritized is in the assessment report.

Variable frequency drives and ozone treatment were later dropped from the list. Representatives from the Energy Commission IAW clarified that these technologies were already being addressed.

Water and Wastewater Roadmapping

During the roadmapping portion, water and wastewater, academia, and federal/state/local government industry representatives provided opinions on promising technologies, commercialization status, barriers to implementation, and ideas for improving market entry. Feedback was received from 50 individuals on the three surveys. Representatives from American Water, Suez North America, American Water Works Association, Water Environment Research Foundation, water treatment and electric utilities, universities, consultants and national laboratory representatives joined the three webinars.

During the first round of outreach, the technologies were vetted. Participants confirmed all but one of the eight technologies on the list without any suggested changes to technology descriptions. Pressure reducing valves from in-line turbines was removed from the technical assessment listing. Information technologies and load shifting were suggested as technologies with the highest potential for electricity savings. Information technologies were further refined into:

- Data standards: collection, organization, management, mining, sensitivity, and accuracy.
- Water loss/leakage detection, condition assessment, and monitoring systems.
- Automation and real-time control system.
- Advanced metering infrastructure.

Additional technology areas suggested from the survey feedback included, microbial electrochemical technologies, advanced oxidation (included in the assessment under R&D), deionization, shortcut nitrogen removal or annamox (included in the assessment under R&D), hydrothermal liquefaction (discussed in the R&D webinar), granular sludge, anaerobic membranes, and alternative disinfectants. With exception of those listed under R&D, there was no further input on any of these technologies from webinar participants so these technologies are not included.

The only technology from the assessment that the participants indicated did not present the same level of electricity saving opportunities was pressure reducing valves and in-line turbines. Energy Commission IAW representatives agreed so the technology was removed from the list.

Technology Barriers

The main technology specific barriers for information technology were cyber security, interconnectivity and data availability. Access to data and permission to use it were the main concerns for cybersecurity. For interconnectivity, advanced metering infrastructure and Industrial Internet of Things require data standardization to ensure widespread adoption. The question of how to incentivize systems which have already invested in different technologies to automate/convert/translate their own outputs to (standardized networkable date) was discussed in detail. More integrated information technology would result from using the information for system automation and data collection history (ability to monitor and quantify extensive data and adjustments). Aggregated and analyzed data is valuable to understand energy usage and peak loading periods. It is crucial to realizing energy and water savings for the overall industry.

The barrier identified for load shifting was that water and wastewater utilities do not have access to the wholesale market (for electricity not water) and are responding to retail rates. While the retail market is changing, participants said the access to wholesale market would help reduce costs.

Collaboration from both water and electric utilities was also identified as a barrier. Electric utilities seem to be more advanced than the water ones in funding new technology development and adoption. Participants identified the need for third party-testing to ensure verifiable and repeatable results. Lack of case studies for several of the identified state-of-the-art technologies was also identified as a barrier. From a financial perspective, adoption incentives were mentioned as a barrier several times, especially for capital-intensive technology deployments.

The return on investment ultimately predicts the market and the ability to capture water (capturing money from a demand response program) and access to cap-and-trade funds were identified as barriers. Reducing energy with water can reduce GHG emissions but current policies only allow that for hot water, not cold.

There were no barriers discussed for commercialized treatment technologies.

General Barriers

Barriers that were identified by participants in the water and wastewater roadmapping effort were typical, and in line with feedback from other technology areas. Policy-related barriers included California regulations and policies and regulatory integration of energy and water. Cost-related barriers mentioned were water and power pricing structures, the capital cost of technology, incentives for new technologies, and demonstration funding. Additional barriers were the conservative business culture of the water sector, the organizational mission being treatment of water at all costs (redundancy is often included), lack of education and awareness as well as multi-stakeholder engagement, and demonstration of effective use of information technologies (i.e. Industrial Internet of Things and advanced metering infrastructure).

Path to Market

When asked to identify actions that the Energy Commission can take to support the market entry of technologies in the water and wastewater sector in California, suggestions from participants included the following:

- Project-based actions:
  - Pilot demonstrations and case studies
  - Funding for demonstration with clear follow-ons about uptake and implementation
  - IOUs, the Energy Commission and CPUC to work together to allow technology demonstration and accounting for savings as part of the state's goals to doubling energy efficiency without increasing the energy efficiency budget
- Multi-stakeholder engagement and continued support of innovation clusters to foster technology development
- Financial incentives:
  - Incentivize reductions in energy intensity of water
  - Better power pricing and incentives for load shifting and on-site power generation and storage
  - Strategies that address concerns of raising rates, while also allowing systems greater revenue to reinvest into critical system maintenance

Pilot demonstration needs were emphasized for load shifting and information technology. Having a well-defined use case and quantifying the cost and benefits is very important. From an investment perspective, participants agreed that implementing policies that allow greater geographic area to invest into water beyond the utility territory and access to CARB-managed cap and trade funds for investing in water would be important.

Participants said the methodology for energy efficiency rebates for water and wastewater is complex. While there is payment for gas and electricity savings, additional support to help with the calculation preparation for cold-water technologies would be beneficial. Data and planning constraints were mentioned, as well as a need for technical assistance. Regulatory bodies presenting standardized use and types of data would help open up different opportunities. A potential public surcharge for water and gas was also mentioned, which is used for electricity in the EPIC program and the utilities to help technologies get to the marketplace.

When asked to identify success indicators, there was a range of responses including general ones: realization of cost savings and lower GHG emissions, energy savings from load shifting and increased coordination between the water and energy sectors, and shaved peaks can be compared to a baseline with energy and cost savings for water providers, water customers, energy grid managers, and energy customers. More specific indicators included elimination of ballast or no energy losses across it for UV disinfection, elimination or greatly reducing pressure differential for optimizing head and friction losses in piping, and reverse osmosis energy requirements and attractiveness for utilities.

Participants emphasized that lowering GHG emissions is based on joint savings of water and energy, and establishing ways to do that is crucial, especially for carbon. Tracking investments in energy, water, and carbon savings was also mentioned. Another indicator was the ability to automate water system or working towards it (interoperability would be a key measure). Per capita overall water use over time and percentage use and recycling were also suggested as additional success indicators.

Water and Wastewater Relevant Policies and Legislation

The seven technologies identified are listed in Table 30, with indication of which state policy or legislation is applicable. Excerpts from the referenced California policies and legislations are in Appendix D, and aligned to the various technology areas.

Table 31: Water and Wastewater Relevant Policies and Legislation

State Policies and Legislation: Relevance to Technology Platforms							
	Water and Wastewater Technologies						
State Policy or Legislation	Microfiltration	Reverse Osmosis	UV Disinfection	Advanced Aeration	Optimized Head and Friction Loss in Piping	Information Technology	Load Shifting
California Codes							
Warren-Alquist Act					X	X	X
California Energy Commission							
Energy Action Plan						X	X
Integrated Energy Policy Report							X
Executive Orders							
Executive Order B-29-15	X	X	X	X			
Senate Bills							
SB 1250					X	X	X
SB 350					X	X	X
SB 1389						X	X
SB X7-7	X	X	X	X	X	X	X
SB 966	X	X	X	X			
Assembly Bills							
AB 2717	X	X			X	X	X
California Public Utilities Commission (CPUC)							
California Energy Efficiency Strategic Plan	X	X	X	X	X		X
California Air Resources Board (CARB)							
California's 2017 Climate Change Scoping Plan: California Water Action Plan	X	X	X	X	X	X	X

CHAPTER 9: Research and Development Opportunities

Overview of Research and Development Technologies

Identifying the number of R&D technologies was secondary in focus to state-of-the-art in the scope of the roadmapping project, although equally important for future program planning efforts. The initial target was to have an 80 percent focus on state-of-the art technologies and 20 percent focus on R&D.

A separate round of surveys and webinars addressed technology opportunities not yet commercially proven. An initial list of technologies was gathered through research and presented in the technical assessment. These technologies identified through literature search are noted with "TA" in the descriptions below. Industry experts in the surveys and webinars helped finalize the list. All technologies are categorized to the same areas identified in

Table 1.

The R&D technologies discussed during roadmapping outreach activities were identified in broad terms. Examples include advanced sensors and monitoring, Internet of Things and cloud-based monitoring and control, integration of renewable energy, onsite energy storage, and waste heat capture and reuse. The scope of research and outreach for R&D technologies was not specific and detailed. The target timeframe to deploy these R&D technologies is three to five years.

The roadmap identified 81 state-of-the-art technologies and 42 R&D technologies, accounting for 66 percent and 34 percent, respectively. However, the project team identified a subset of 12 R&D technologies for possible further investigation and/or support by the Energy Commission. When considering only those R&D technologies, the technologies identified are 87 percent state-of-the-art and 13 percent R&D.

When considering R&D opportunities, there is less justification for excluding technologies. Without specific performance qualifications, almost all the R&D technologies identified were considered candidates for consideration. The 12 technologies identified were considered the most applicable to current IAW sector needs and scalable for future benefits to California.

These 12 technologies are noted in the following descriptions with italicized titles. Further detail is provided on this subset of promising R&D technologies at the end of this chapter.

Glass Manufacturing

- **Oxy-fuel furnaces** - The addition of oxygen at specific points in the melting process lowers the energy intensity of glass melting by either increasing output or reducing fuel input. Using oxygen instead of air helps reduce the energy required for combustion and prevents the formation of NO_x. (TA)[3]
- **New grinding technology** (such as fine grinding of glass with centrifugal ball mill) - Efficient grinding technology combines energy-efficient comminution and classification technologies to achieve an even, reproducible particle size distribution at low energy costs. (TA)
- **Preheating of fuel stream -** Overall process energy consumption is reduced because of the reuse of heat recovered from flue gases to preheat oxygen and natural gas in crosscurrent heat exchangers before they are injected into the furnace.

Metals Manufacturing

- **Hydraulic pump of strip steel cutting system controlled by a converter** - New technology can reduce the hydraulic energy usage of strip steel cutting systems by 90 percent (Siemens 2014). (TA)

[3] All technologies noted (TA) were identified through literature search. More information is in the assessment report.

- **Wetted drained cathodes** – Using inert titanium diboride (TiB_2) cathodes (also called wetted cathodes), when used with new inert anodes, reduces the anode–cathode distance and reduces electricity consumption. (TA)
- **Iron slag heat recovery** - Technologies to recover the heat contained in blast furnace slag (which has a temperature of approximately 1450˚C) could reuse this lost energy. (TA)
- **Inter-electrode insulation for pickling line** – Using an insulation that covers a significant percentage of the electrolyte cross-section area between the anode and cathode electrode groups could dramatically improve the current efficiency of the pickling process. (TA)
- **EAF electrode technology** - Advances in electrode technology (e.g., increased toughness, more efficient carbon dispersion) could increase furnace productivity and reduce electricity consumption.

Chemicals Manufacturing

- **New high-temperature, low-cost ceramic media for natural gas combustion burners** - Multiple technologies are combined into a single radiant burner package that functions as a burner and a catalyst support. Elimination of the flame from the combustion reaction greatly reduces NO_x emissions. (TA)
- **High-temperature chillers for cooling water** - For plastics and chemicals, high-efficiency cooling technologies could supply about 65ºF water and use natural refrigerants instead of traditional refrigerants that have a much higher global warming potential.

Plastics Manufacturing

- ***Large-scale microwave processing*** [4]- Microwave technology, in which the load is heated directly, can be applied to the heating, drying, and curing of plastic polymers, lowering energy use and processing time. (TA)
- **Computational fluid dynamics to optimize cooling unit designs** - Computational fluid dynamics can improve the design of cooling processes, resulting in large efficiency gains in compressed air systems used in plastics molding. (TA)
- **Advanced additive manufacturing -** Advances in additive manufacturing as it relates to plastics production could increase throughput more than tenfold, improve product quality, and reduce cycle time, all of which saves energy.

Pulp and Paper Manufacturing

- **Liquid-free chemical pulping (LFCP) method** – In the process, he pulping reactions occur only inside the woodchips (where reaction chemicals have been pre-loaded). The total amount of the chemical consumption is significantly lower than traditional Kraft pulping. (TA)
- **Dehumidification/drying using heat pipe and heat pumps -** Drying heat pumps are more energy efficient than conventional hot-air convective drying and can operate independent of

[4] More detail is available for this R&D technology at the end of this chapter.

outside ambient air conditions. No water vapor and polluted and/or toxic gases are discharged into the atmosphere.

Industrial Facilities and Power

- **Continuous liquid interface production (CLIP)** - Continuous liquid interface production can be used to manufacture parts with fine resolution without layer-to-layer interface. (TA)
- **Wide-bandgap materials for power electronics** - Silicon carbide (SiC) and gallium nitride (GaN), both wide bandgap semiconductors, have roughly 10 times better conduction and switching properties than silicon and can be used to create new power electronics devices with greater power density and energy efficiency.
- **Transactive peer-to-peer enabling energy technologies** - Blockchain and other technology advances could allow utility customers who own renewable energy resources to sell their power directly to their neighbors. This can enable an industrial operation to share its energy system costs and benefits with neighbors, and, perhaps, also meet local, state or utility energy-environment goals including grid improvements.

Data Centers

- ***Data center water reduction*** - Water is continually required from a public water source to support data center cooling. Technologies that enable a sustainable strategy for water use will help ensure the sustainability of data centers.
- ***Onsite microgeneration at data centers*** - Reliable microgeneration technologies (e.g., CHP and fuel cells) that can supply power to the smart grid based on price signals are key to encouraging data centers to participate in demand response programs, which will reduce electricity demand from the grid.
- **High-voltage DC power** - Recent studies have shown that high-voltage DC power distribution systems (380 volt [V] nominal/400 V peak) can substantially reduce electricity consumption in data centers. Added benefits include no source synchronization, no phase balancing or harmonic issues, longer battery backup, smaller footprint, and lower total cost of ownership.
- **Consolidating workload onto servers** - By consolidating small and large data centers into smaller ones or renting space in a colocation facility that has newer and more efficient infrastructure, companies can save energy and real estate costs.

Bioenergy

- ***Alkali pretreatment for anaerobic digestion*** - Alkali pretreatment for anaerobic digestion generates high-quality feedstock (e.g., clean, homogeneous cellulose) for use in a biomass gasification combined-cycle system. (TA)
- ***Biogas upgrading to renewable natural gas (RNG)*** - Improved technologies to reliably upgrade biogas from modest methane levels (typically 40 to 60 percent) to 99 percent methane while also meeting CO_2, nitrogen, and H_2S specifications will accelerate the acceptance of this energy resource by utilities by enabling biogas to go into pipelines and displace (indirectly, but at high efficiency electricity generation via large combined cycle

power plants) natural gas that would otherwise be a fossil carbon emission source at a power plant.

- ***Pyrolysis/gasification*** - Novel reactor designs for biomass pyrolysis/gasification with improved thermal conversion efficiency and environmental performance could help secure sustainable energy generation.
- **Biochar applications** - Further development and demonstration of biochar production and utilization technologies at larger scale can accelerate this carbon-capturing resource.
- **Microbial electrochemical cells** - Microbial electrochemical cells (MECs) are emerging biotechnologies that marry microbial metabolism with electrochemical cells. Microbial fuel cells can be used to derive energy and products from biomass and organic waste with the high efficiency advantage of fuel cell electrochemistry compared to combustion cycles.

Irrigation

- ***Low-energy drip systems*** - Ultra-low-pressure drip irrigation systems could reduce pumping energy by 50 percent.

Food and Beverage Processing

- **Sequential infrared and freeze-drying (SIRFD)** - SIRFD is a dry-blanching and drying system for fruits or vegetables that uses about 40 percent less energy than traditional freeze-drying. (TA)
- **Simultaneous infrared dry-blanching and dehydration (SIRDBD)** - SIRDBD eliminates the water or steam used in traditional blanching and reduces energy use. (TA)
- ***More efficient chilling and refrigeration techniques*** (replace Freon with refrigerants) - Newer designs involving natural refrigerants (e.g., ammonia, CO_2, and hydrocarbons) and cryogenic chillers (using either CO_2 or nitrogen gas) are low-global-warming potential alternatives to conventional technology.
- **Onsite water purification** - Advanced technologies such as membrane bioreactors capable of cleaning process wastewater to the quality of municipal drinking water will encourage reusing food processing wastewaters.

Water and Wastewater

- **Advanced oxidation process** - Advanced oxidation processes for removing contaminants from wastewater can improve the efficiency of wastewater effluent treatment and solids separation. (TA)
- ***Shortcut nitrogen removal or anaerobic ammonia oxidation (Anammox)*** - Anammox is a wastewater de-ammonification process that can save more than half of the oxygen demand (energy) compared to conventional nitrification/denitrification. (TA)
- **Ultrafine bubble diffusers** - This technology uses ultrafine bubbles to diffuse undesirable species in wastewater. The high oxygen transfer efficiency of the membrane panel diffusers means smaller blowers and motors can be used. (TA)

- ***Carbon nanotube reverse-osmosis (RO) membrane*** - A carbon nanotube reverse-osmosis membrane system is expected to offer a tenfold permeability increase over conventional saltwater RO-based desalination, resulting in 30 to 50 percent energy savings. (TA)
- **Biomimetic membranes** - New membranes that emulate biological water channels (such as those in human cell walls) are more permeable by up to an order of magnitude than conventional desalination membranes. (TA)
- **Concentrated solar desalination** - Solar thermal desalination can achieve lower costs than current reverse osmosis systems by lowering the cost of collecting and storing solar thermal energy and increasing the efficiency of thermal desalination technologies.
- **Anaerobic membrane bioreactors (AN-MBR)** - These systems combine anaerobic digestion with physical separation membranes, resulting in maximum organic load removal and biogas production.
- ***Partial nitrification over anammox (PN/A)*** - More operating data will accelerate the advancement of the PN/A process, a more sustainable alternative for nitrogen removal than conventional nitrification-denitrification over nitrate since it requires almost two-thirds less aeration energy, does not require adding an external carbon source, and produces very little sludge and CO_2 emissions.
- **Ceramic membranes** - New high-quality ceramic membranes have great potential for recovery and reuse of wastewater. Advanced filtration systems using these membranes have higher filtration efficiency, reduced maintenance downtime, and lower energy consumption.
- ***Membrane aerated bioreactors (MABRs)*** - MABR systems have an oxygen utilization efficiency that is essentially about 100 percent due to the growth of a biofilm on the membrane surface that allows the oxygen to go into the biomass.

Barriers

The technologies classified as R&D technologies all have some technological issues yet to be resolved before these technologies can reach all of their intended markets. In addition, they all face institutional barriers similar to those described earlier for the state-of-the-art technologies.

Institutional Barriers

Institutional barriers that are common to most of the R&D technologies include:

- permitting issues
- stringent environmental standards (e.g., the inability of biomass combustion technologies, even including gasification and biogas power technologies, to meet low NO_x standards)
- lack of incentives to innovate (e.g., policy changes, funds for pilot testing and communicating success stories)
- lack of performance data including third-party verification efforts
- lack of consumer awareness of new technologies, and education and training for stakeholders on new technologies and/or new applications

Institutional barriers specific to carbon-reducing technologies include:

- lack of a price – particularly a stable price - on carbon, that would drive the economy toward technology investment.

Institutional barriers specific to biogas upgrading to renewable natural gas (RNG):

- lack of uniform federal or state specifications for gas acceptance
- absence of a national quality standard for RNG injected into the pipeline system,
- unresolved issues related to California's Renewables Portfolio Standard grid power credit, and other regulatory policy barriers.

Institutional barriers specific to use of onsite microgeneration in data centers:

- Although providing demand response via shifting workload can be more cost-effective than using a backup generator (the most common data center response to peak warnings), there is significant risk associated with ensuring that service level agreements (e.g., completion deadlines) remain satisfied even with uncertainties in coincident peak and warning patterns, workload demand, and renewable generation. This would require highly accurate load forecasting with tightly automated and safe operational procedures to manage dynamic workload migration.

Technology Barriers

Technological barriers impeding further development and deployment of new technologies are specific to the technologies themselves, but some general aggregation is possible. Membrane technologies require an understanding of the materials properties and their transport mechanisms, as well as the realization of innovative functional materials with improved properties. Developers of new membrane technologies also face concerns over membrane life, fouling, cost, and performance under industrial conditions. Similarly, ceramic burners require more evaluation and testing in long-term experiments and under industrial conditions. Technologies for the food and beverage industry must be further optimized and tested to ensure they meet or exceed product quality and safety standards.

Path to Market

General suggestions on path to market for the R&D technologies identified are applicable across the most of the sectors in this report and are similar to strategies identified for the state-of-the-art technologies. Some examples include promoting demonstration, deployment, and industrial-scale projects where appropriate; providing R&D funding for technologies facing technological barriers; developing case studies for successful demonstrations and publicizing successes; and partnering with other organizations who represent stakeholders in technologies of interest.

Additional Detail for Promising Research and Development Technologies

The 12 R&D technologies thought to have the greatest potential for scalable impact in California are listed with additional details on the technology application and status.

Plastics Manufacturing

- ***Large-scale microwave processing*** (U.S. Department of Energy 2007; Ku & Yusaf 2008) – Microwave technology, in which the load is heated directly, can be applied to heating, drying, and curing plastic polymers, lowering energy use and processing time. Microwave processing of materials is a relatively new technology that provides new approaches to improve the physical properties of materials, alternatives for processing materials that are hard to process, reduces the environmental impact of materials processing, economic advantages through energy savings, space, and time, and an opportunity to produce new materials and microstructures that cannot be achieved by other methods. Microwave systems have lower energy requirements and reduced processing times compared to conventional process heating. (TA)
    - *Process(es) affected*: Thermoplastics processing
    - *Technology status*: There have been numerous studies for fixed and variable frequency microwave processing technologies. Fixed frequency microwave technology uses a constant flux of microwaves to process materials, which causes "hot spots" from non-uniform heating (similar to kitchen microwaves). Variable frequency microwave (VFM) technology is a new technique for microwave processing introduced to solve the problems brought about by fixed frequency microwave processing. It offers rapid, uniform and selective heating over a large volume and at a high energy coupling efficiency. This is accomplished using preselected bandwidth sweeping around a central frequency employing tunable sources such as travelling wave tubes as the microwave power amplifier. Although variable frequency microwave technologies provide higher quality products, fixed frequency technologies are cheaper at this time.
    - *R&D needs/issues*: While this process could contribute to achieving the practical minimum energy consumption, actual energy savings of this emerging technology as applied to plastics and rubber processing are unclear. In addition, uniform heating of materials in microwave systems operating on a single frequency is difficult due to standing waves in the cavity, which generate local hot spots. To avoid interference with other equipment, proper shielding of the equipment is required.
    - *Potential impacts*: Microwave technology can be applied to lower processing time, and by extension energy use, for thermoplastics. Both fixed and variable frequency technologies have demonstrated high efficiency, high energy density, reasonably good control, and a small footprint for the equipment.

Data Centers

- ***Data center water reduction*** (Hume 2017; McFarlane n.d.; Microsoft. n.d.; Nortek Air Solutions 2015; Sverdlik 2016) - Water is continually required from a public water source to support data center cooling. Technologies that enable a sustainable strategy for water use will help ensure the sustainability of data centers. Most efficiency improvements to data center cooling systems reduce water use. More significant water reduction can be achieved through technologies that eliminate reliance on a public water source, such as various free cooling systems or underwater data centers. Free cooling systems can use cool air or free water sources, such as sea, lake, or river water.

- Process(es) affected: Data center cooling
- Technology status: Different free cooling systems using either cool air or another water source besides a public water supply have been implemented at different locations and are market-ready in many ways, but there is room for improvement for the systems to become more common and accepted cooling solutions in the industry. Underwater data centers fully submerged in an ocean or another body of water are in the early development phase. Microsoft's Project Natick deployed a small experimental underwater data center pod off the California coast in late 2015. The company is looking to develop a larger underwater data center for further experimentation.
- R&D needs/issues: Many free cooling solutions cannot provide needed cooling at all times. A traditional mechanical cooling system is still needed. One must find a way to maximize the benefit from the free cooling system, but not change between the mechanical cooling system and free system too often. Incorporating water-based free cooling systems are easier than air systems because traditional cooling systems use chilled water. Air quality, filtering, and humidity control are challenges with air-based free cooling systems.

  Installing and maintaining a data center located underwater is a challenge. The center must be fully sealed, yet accessible when needed. Biofouling is a problem that impacts heat transfer and reduces the effectiveness of the heat exchangers. Providing electrical power to underwater centers is also more complicated. There is an opportunity to use renewable energy sources, such as tidal or wave energy systems and offshore wind. Large-scale underwater centers would require large power generating systems. There are no marine renewable projects that have been deployed at such scale. A challenge for free cooling and underwater data centers is that free cooling sources are not available in all locations.
- Potential impacts: Free cooling technologies and underwater data centers can eliminate or significantly reduce use of public water sources. The technologies can also save significant energy. Free cooling systems that do not fully replace a traditional system have produced up to 70 percent in energy savings. Even systems that can utilize 100 percent free cooling use some energy for fans, pumping, and other system operations. Underwater centers save energy and can be deployed in a short time. An underwater center could be deployed in three months compared to the two years for a traditional large data center. Leasing underwater "land" for data centers would be much cheaper than on land.

- ***Onsite microgeneration at data centers*** (U.S. Department of Energy 2017a; U.S. Department of Energy 2017b; U.S. Department of Energy 2018a; U.S. Department of Energy 2018b; U.S. Department of Energy 2018c) - Reliable microgeneration technologies (for example fuel cells and other CHP technologies) that can supply power to the smart grid based on price signals are key to encouraging data centers to participate in demand response programs, thereby reducing their demand for electricity. Waste heat generated by these systems can also be utilized to provide additional cooling capacity for the data center.

    - Process(es) affected: Data center power supply and cooling
    - Technology status: The prime mover technologies typically used for small-scale onsite power generation—such as fuel cells, reciprocating engines, and microturbines—are relatively mature. At this time, technologies are not available to seamlessly integrate these distributed power generation technologies with the electric grid and enable automated response to price signals and other requests from power system operators. Absorption chillers to provide additional cooling capacity from produced waste heat are readily available in the market.
    - R&D needs/issues: In order for the microgeneration systems to be able to respond automatically to price signals and other requests from the power system operator, power electronics to enable seamless integration with the electric grid must be developed. These technologies will need to automatically monitor and predict data center power needs as well as grid conditions, receive price signals and other requests from the power system operator, and control the microgeneration system. For the prime mover technologies to respond to grid needs, they must also have fast ramp-up times and good efficiency at partial loads. Even though small-scale power generation technologies are relatively mature, additional research and development efforts to increase system efficiency and reduce system costs will improve their cost competitiveness and enhance market adoption.
    - Potential impacts: Cost-effective microgeneration technologies that can respond to price signals and other requests from power system operators can potentially produce significant energy cost savings for data center owners and operators. Cost savings and additional revenues generated by the systems will vary depending on multiple factors, including price of electricity, price of the microgeneration system, fuel cost, type of electricity market, and available utility and/or market incentives. Widespread adoption of such grid-responsive generation technologies would also have a positive impact on the electric grid, including reduced grid congestion, reduced transmission and distribution losses, decreased need for new central power generating units, and availability of flexible generating resources to supplement intermittent renewable resources.

Bioenergy

- ***Alkali pretreatment for anaerobic digestion*** (Torres 2008; Montgomery & Bochmann 2014; He et al. 2008; Liew et al. 2011) - For wastes with complex organics and high solids content, such as the organic fraction of municipal solid wastes and woody wastes (lignocellulose-rich wastes), the hydrolysis of the complex organic matter to soluble particles is often the rate-limiting step in anaerobic digestion (Torres 2008). Pretreating complex organic waste with high solids content before anaerobic digestion increases the global rate of anaerobic digestion. Pretreatment processes increase the solubilization of organic waste and improve the efficiency of the anaerobic decomposition of the waste by breaking down complex polymeric organics into simpler molecules. Pretreatment of the organic waste with alkali compounds such as lime addition calcium hydroxide (Ca(OH)2) enhances chemical oxygen demand solubilization of the complex molecules so they can be converted efficiently during the anaerobic digestion process.

    - Process(es) affected: Anaerobic digestion of organic wastes
    - Technology status: Alkali pretreatment is not currently carried out at large scale for biogas production from anaerobic digestion (Montgomery & Bochmann 2014). There have been several reports of alkali treatment being effective in pretreating recalcitrant organic wastes in anaerobic digestion. Rice straw (a significant California waste stream) alkali pretreatment showed a significant increase in biogas yield in batch tests using 6 percent solid sodium hydroxide (NaOH) (He et al. 2008). Liew et al. (2011) carried out simultaneous pretreatment and methanisation using 3.5 percent NaOH on tree leaves, increasing the methane yield by 20 percent during batch tests. These studies demonstrated that alkali pretreatment can increase gas yield from lignocellulose-rich substrates. However, alkali pretreated substrates have high pH values, and studies were carried out using small-scale batch tests. During continuous fermentation, alkali pretreatment could lead to excessive salt build up and increased pH in the digester system. The excessive salt concentration and the resulting effect on the ammonium-ammonia balance inhibits the methanisation cycle in the anaerobic digestion process (Chen et al., 2008).

      The high costs of alkalis used for pretreatment may make this technology uneconomical for anaerobic digestion. But, it could be useful for lignocellulosic-rich organic wastes.
    - R&D needs/issues: Greater insight into the economic cost-benefit of alkali pretreatment in anaerobic digestion. R&D is also needed in anaerobic digestor reactor design to be able to handle very fibrous substrates (such as many ligno-cellulosics are) as current continuously stirred-tank systems are best suited for traditional substrates such as manure, sludge, and easily digestible food wastes. Pretreatment also needs to be integrated in the digester system rather than as a separate system.
    - Potential impacts: The potential conversion of recalcitrant organic wastes, such as lignocellulosic (woody) wastes, by anaerobic digestion would allow much greater use

of urban green waste (such as tree and shrub trimmings, grass clippings, etc.), which is abundant in California.[5]

- ***Biogas upgrading to renewable natural gas (RNG)*** (University of California, Davis 2014; Black & Veatch 2016) - Biogas generated from anaerobic digestion or landfills consists mainly of methane (a.k.a. biomethane) and carbon dioxide that can be used as a renewable energy source in combined heat and power plants, as a vehicle fuel, or as a substitute for natural gas. The methane in the biogas can also be used in industrial processes. Depending on the end use, different biogas treatment steps are necessary. In some applications, such as use of biomethane as a transportation fuel or injection into the natural gas transmission/distribution pipeline (for subsequent withdrawal for transportation fuel or combustion in an electrical power plant), it is important to have a high energy content in the gas (Btu/cubic foot) and the biogas needs substantial upgrading. The energy content of biogas is direct proportionate to the methane concentration. Removing carbon dioxide in the upgrading process increases the energy content of the gas. Improved technologies to reliably upgrade biogas from modest methane levels (typically 40 to 60 percent) to 99 percent-plus biomethane while also meeting CO_2, nitrogen, and H2S specifications to further mimic traditional fossil-based natural gas will accelerate electric and gas utilities accept this energy resource.
    - Process(es) affected: Anaerobic digestion produced biogas upgrading to biomethane
    - Technology status: Several existing biogas upgrading techniques exist and are continually being improved. New techniques are being developed. These new developments, both for new and more traditional biogas cleaning and upgrading technologies, can lower investment costs and operational costs. The developments can also lower methane emissions to the atmosphere, which is important from both an economical and environmental perspective.

      Current technologies being used for biogas upgrading to biomethane include:
      - Pressure swing adsorption – CO_2 is separated from the biogas by adsorption on a surface under elevated pressure
      - Absorption uses water scrubbing, organic physical scrubbing (organic solvents), and chemical scrubbing (amine solutions) to remove the CO_2
      - Membranes – dry membranes made of material that are permeable to CO_2, water, and ammonia, but not to methane
      - Cryogenic distillation – biogas is compressed and cooled until CO_2 becomes liquefied and can then be easily separated from methane

      Emerging technologies for biogas upgrading to methane include:

      - Supersonic separation uses a compact tubular device that combines expansion, cyclonic gas and liquid separation, and then recompression to simultaneously

[5] Green waste will be available in ever-increasing volumes, as Assembly Bill 1594 (2014) stipulates that, effective January 1, 2020, green waste used as alternative daily cover will no longer receive diversion credits.

condense and separate the water and non-methane hydrocarbons. Additional R&D is underway to allow for bulk removal of the $CO_2$and hydrogen sulfide (U.C. Davis, 2014)

    - Industrial lung is a bioengineered process using carbonic anhydrase (an enzyme present in human blood which aids in the dissolution of carbon dioxide formed from cellular metabolism) to pull biogas CO_2 into an aqueous phase where it can be picked up by an absorbent.

  - R&D needs/issues: Although biogas upgrading to biomethane technologies are in the commercial marketplace, the cost of the biomethane production is markedly different for small anaerobid digestion systems. Biomethane from 400 cubic foot per minute anaerobic digestion system has a levelized cost of $14 to $15 per million Btu, while large systems (1,000 cubic feet per minute or higher) can produce biomethane in the $7 to $9 per million Btu range, according to estimates (Black & Veatch, 2016). Continuing R&D is needed to lower the biomethane production costs for smaller systems.
  - Potential impacts: The production of biomethane from anaerobic digestion biogas has several environmental benefits including the following:

    - It can be used as a substitute for fossil fuels, which reduces GHG emissions.
    - It reduces the release of methane to the atmosphere when compared to traditional livestock manure management or disposal of organic wastes in landfills.
    - It is a renewable energy source that helps solve waste management issues;
    - A high-quality digestate that can be used as a fertilizer is a byproduct of anaerobic digestion. However, higher biomethane production costs for smaller anaerobic digestion systems severely limit their ability to upgrade produced biogas to the biomethane quality needed for injection into the natural gas transmission system pipeline.

- ***Pyrolysis/gasification*** - Pyrolysis is the thermal decomposition of the volatile components of an organic substance, such as woody biomass, in the temperature range of 400 to 1,400°F (200 to 760°C), and in the absence of air or oxygen, forming syngas and/or liquids. An indirect source of heat is used. A mixture of un-reacted carbon char (the non-volatile components) and ash remains as a residual. Gasification takes this to the next step. It occurs in a higher temperature range of 900 to 3,000°F (480 to 1,650°C) with very little air or oxygen. In addition to the thermal decomposition of the volatile components of the feedstock, the non-volatile carbon char from pyrolysis is converted to additional syngas. Steam may also be added to the gasifier to convert the carbon to syngas. Gasification uses only a fraction of the oxygen needed to burn the material. Heat is supplied directly by partial oxidation of the carbon in the feedstock.

  Woody biomass stores chemical energy in the form of carbohydrates by combining solar energy and carbon dioxide using the photosynthesis process. It is available in different forms such as agricultural and forestry residues and urban green waste. Its most common conversion route to electricity has been direct combustion. The heat produced by direct biomass combustion in a boiler can generate electricity via a steam turbine or engine. The electrical efficiency of the steam cycle is not high but it has historically been the cheapest and most reliable route to produce electric power from biomass in standalone applications. Gasification efficiency for creating electricity is higher as such systems can use gas-fired internal combustion engine generator sets and combined cycle systems at large scale. The gases produced by gasification can also be used for electricity generation via fuel cells, but only if cleaned and methane-concentrated to meet the purity standard for fuel cells.

- Process(es) affected: Woody biomass gasification
- Technology status: There are several gasification technologies categories, which include:
  - Fixed/moving bed – Downdraft and updraft gasifiers
  - Fluidized bed – Bubbling and circulating
  - Entrained flow

  In the case of woody biomass gasification, most small-scale gasifiers are downdraft technology because they produce the least amount of tars, while most medium/large scale gasifiers are of the fluidized bed type. There are also very few gasification systems operating in the United States. Nearly all biomass gasification systems are found in Europe and Asia.
- R&D needs/issues: The principal area of continued R&D for biomass gasification technology is syngas cleanup processes. Tars in syngas continue to inhibit the use of gasifiers to produce electricity via internal combustion generator sets. This is even more so in fuel cells or production of biofuels for transportation, as the syngas in these latter applications. More R&D is necessary for gasifier systems to be more feedstock flexible with improved performance.
- Potential impacts: Positive impacts of woody biomass gasification include:
  - Renewable baseload energy
  - More efficient in electricity generation than direct combustion steam cycle
  - Safer than steam cycle power systems
  - Fewer emissions from internal combustion engine gensets, almost zero emissions if fuel cells used.

  Negative impacts include:
  - Syngas cleaning systems are may not adequately clean gas used in internal combustion engines
  - Woody biomass feedstock must usually be dried before being fed to the gasifier system
  - Fuel size, shape, and moisture of woody biomass have large impacts on performance
  - Condensate and recovered tars can be toxic and must be handled accordingly.

Irrigation

- ***Low-energy drip systems*** (Shamshery and Winter, V 2014; Taylor, et al. 2015; Rowell & Jacobsen 2017; Shamshery, et al. 2017) – Drip irrigationis a promising alternative to flooding. It is one of the most common irrigation practices particularly in developing countries. Drip irrigation reduces water consumption, increases crop yields, and decreases fertilizer consumption costs by as much as 30 to 70 percent, 20 to 90 percent, and 30 to 40 percent respectively. Ultra-low-pressure drip irrigation systems could reduce pumping energy by 50 percent. Using low-pressure forms of irrigation is that requires less energy from pumps and less fuel.

    - Process(es) affected: Conventional irrigation systems (such as flood irrigation), particularly pumping
    - Technology status: Drip irrigation technologies have been extensively studied. There are also numerous manufacturers for drip irrigation system parts such as tubing, pumps, delivery pipes, and fittings. These manufacturers suggested drip irrigation operating pressures of 8 to 15 pounds per square inch (psi). Ultra-low drip irrigation systems demonstrated operating pressures as low as 1 to 3 psi for small plots up to 0.25 acres. However, low- and ultra-low pressure drip irrigation systems are expensive and difficult to scale up, which means their use is limited to small farms. In addition, hundreds of field tests have been carried out for this technology in the United States (especially in Kentucky and Colorado) and Southeast Asia.
    - *R&D needs/issues*: Cautions involving such low pressures include that the uniformity of watering can be reduced considerably by small changes in elevation within the field to be irrigated, so ultra-low pressure drip systems are most suited to level fields and high tunnels. In addition, large-scale drip irrigation systems are very expensive to implement. Costs are estimated to be $1,500/acre for the drip irrigation system, plus an additional $1,500 if a solar emitter system is incorporated. There may also be a policy issue about time-of-day electricity demand because the water supply to irrigate a particular set of fields may not be flexible enough to enable good electric load management (PG&E 2016).
        - *Potential impacts*: Low-pressure drip irrigation systems have significant implications for new irrigation systems in the United States. Drip irrigation allows for the cultivation of higher value crops, which are more sensitive to water and fertilizer application rates. They have lower water and energy consumption requirements and the use of more saline (lower quality) water. The slow and regulated water application reduces the salt concentration in the root zone and allows for micro-leaching to keep salts away from the root zone.

Food and Beverage Processing

- ***More efficient chilling and refrigeration techniques (replace Freon with refrigerants)*** (Goetzler, et al. 2014; The Linde Group 2014; Gluckman Consulting 2015) – Newer designs involving natural refrigerants (e.g., ammonia, CO_2, and hydrocarbons) and cryogenic chillers (using either CO_2 or nitrogen gas) are low-global-warming potential alternatives to conventional technology. Conventional refrigerants are predominantly high-global warming potential hydrofluorocarbons (HFCs). Global industries have begun developing equipment that use alternative refrigerants in response to HFC being phased down. Cryogenic processes are any cold processing that uses either CO_2 or liquid N_2. Cryogenic chillers can be used to speed up production in limited space while improving product quality. Cryogenic gases freeze or chill food products quicker, which enables higher throughput, quicker changeover rates, and smaller land footprint for the required equipment.

- *Process(es) affected*: Conventional freezing, chilling, and refrigerating
- *Technology status*: More efficient freezing, chilling, and refrigeration techniques have been extensively studied. Some natural refrigerants, such as hydrocarbons and CO_2, are already used in aerosols, small refrigeration systems, foams, and fire protection systems. Other natural refrigerants, such as ammonia and hydrofluoroolefins (HFOs), have extensive large refrigeration applications but are toxic and flammable. These natural refrigerants have global warming potential between 0 and 9, versus 1,430 to 2,107 for conventional HFC refrigerants like R-134a, R-407F, and R-407A. In addition, numerous cryogenic chillers have been designed and tested, including but limited to tunnel freezers, individually quick freezing freezers, immersion freezers, and spiral freezers. Because cryogenic chillers and freezers operate at lower temperatures than mechanical freezers and chillers, the food freezes faster, preserving food product quality.
- *R&D needs/issues*: For each new installation using these techniques, safety is a primary concern. Most new low-alternatives have at least one undesirable characteristic, such as greater flammability, toxicity, or lower volumetric capacity, than conventional HFC refrigerants. In addition, cryogenic chiller equipment operators must use protective eyewear and gloves rated for handling cryogens. Prolonged exposure to high levels of inert cryogenic gases can be harmful or fatal, so proper operating and maintenance procedures must be followed. Like all food processors, cryogenic chillers also must comply with food safety standards, and strictly control temperature and hygienic conditions. Cryogenic processing many not kill all pathogens completely, but it can defend against Salmonella, E. coli, and other pathogens.
- *Potential impacts*: While efficiency is inherently higher than conventional freezing, chilling, and refrigerating processes, the energy consumption impact for these technologies is unclear at this time. Implementing new low refrigerants can provide a viable alternative as high HFCs refrigerants are gradually phased down. Cryogenic solutions can often significantly save processors money per line, while preserving food product quality.

Water and Wastewater

- ***Shortcut nitrogen removal or anaerobic ammonia oxidation (anammox)*** - Shortcut nitrogen removal is biological nitrogen removal that avoids complete oxidation of ammonia to nitrate but stops at nitrite to shortcut the conventional nitrification/denitrification process. It is a wastewater deammonification process that can save more than half of the oxygen demand (energy) compared to conventional nitrification/denitrification since aeration is not required. With shortcut nitrogen removal, anaerobic ammonia oxidation bacteria are used instead of nitrite oxidizing bacteria to convert nitrite to nitrate by converting ammonia (NH_3) into nitrogen (N_2) in two biological steps. Nitration converts about half of the ammonia into nitrite. Anaerobic deammonification converts almost 90 percent of inorganic nitrogen into N_2 gas.

- Process(es) affected: Municipal wastewater treatment
- Technology status: Since anammox bacteria was discovered in 1995, several variations on shortcut nitrogen removal have been developed to optimize performance and overcome challenges. Various configurations include granular sludge reactors, suspended growth sequencing batch reactors, and moving-bed biofilm reactors (MBBRs) which are done to better grow and retain the bacteria. Many research projects were conducted over the past 20 years. The first-large scale anammox reactor was built in Rotterdam, Netherlands in 2007.
- R&D needs/issues: The major shortcoming of the deammonification technology is a long start-up period for slow-growing anammox bacteria compared to ammonia oxidizing bacteria. The long times associated with shortcut nitrogen removal, typically eight to 10 months, can be reduced with MBBRs to four months. Doubling time is slow, taking between 10 and 14 days (Jimemez n.d.; Neethling et al. 2015). The recovery time after the loss of sludge by accident is longer than in conventional systems. The main challenges are bacteria growth and retention, control of ordinary heterotrophic organism activity, and limiting nitrite oxidizing bacteria growth. The bacteria is highly sensitive to oxygen concentration and nitrite accumulation. Process performance optimization for both side-stream and full-scale wastewater treatment is an area of additional improvement. Large-scale treatment with the anammox process is very complex in design, operation, and maintenance.
- Potential impacts: Compared to conventional nitrification/denitrification the benefits include (Jimemez n.d.; Neethling et al. 2015):
  - 55 to 60 percent reduction in aeration energy requirement
  - No carbon requirement (or 90 percent reduction if carbon is used to eliminate leftover nitrate)
  - Net consumption of carbon dioxide (CO_2) versus CO_2 release from carbon oxidation
  - 45 percent reduction in alkalinity demand
  - Reduced sludge production

- ***Carbon nanotube RO membrane*** (Das 2014; Lee 2015; Rizzuto 2018) – A carbon nanotube reverse-osmosis membrane system offers a tenfold permeability increase over conventional saltwater RO-based desalination, producing energy savings of 30 to 50 percent. The rise of nanotechnology and the beneficial properties of various nanostructured materials have created new opportunities to purify water. The hollow carbon nanotube (CNT) structure in these new membranes provides frictionless transport of water molecules suitable for high-flux applications. A carbon nanotube reverse-osmosis membrane system is expected to offer a tenfold permeability increase over conventional saltwater RO-based desalination. CNT-based membranes have remarkable accomplishments in terms of water permeability, desalination capacity, solute selectivity, robustness, antifouling, energy savings, and scalability. These new membranes could be used from point-of-generation to point-of use-treatment, potentially providing potable water instantly.

- Process(es) affected: Water desalination and decontamination
- Technology status: The high energy requirement of conventional pressure-driven membrane technologies has led scientists to look for novel membranes such as carbon nanotubes for cost-effective, commercial water purification and desalination technologies. Scientists have performed molecular modeling and experiments on CNT membrane fabrication and functionalization for desalinizing both sea and brackish water. Simulation of tubes with characteristics closer to the real material have been performed, providing insights in the water flux to tube structure relationship. In the past five years, laboratory-scale experiments have been conducted to create CNT membranes and measure their properties.
- R&D needs/issues: The commercial availability of CNT membranes depends on their ability to meet certain criteria such as water permeability, desalination capacity, solute selectivity, robustness, antifouling, costs targets, scalability, and compatibility with industrial environments. More understanding is needed on how changing the number of walls can affect the performance of the membrane at the molecular level. Other hurdles include the complicated methods for the synthesis of CNTs with uniform pore size and distribution, ensuring proper tube alignment during growth as irregularities in membrane shape might produce deleterious effects on water passage and salt rejections, the sensitivity of the atomic structures of the nanotube networks to various wet chemical treatments, which could change the membrane's structural properties, and the cost of single-walled carbon nanotubes.
- Potential impacts: The increase in permeability over conventional RO-based desalination results in up to 50 percent energy savings. Other advantage of these new membranes over conventional ones include antifouling and self-cleaning functions.

- ***Partial nitrification over anammox (PN/A)*** (Miao et al. 2018) - Anaerobic ammonium oxidation (anammox) is a relatively new method to cost-effectively reduce nitrogen in ammonium-rich wastewater without aeration. One of the most innovative developments in biological wastewater treatment is combining anammox with partial nitrification, known as PN/A. PN/A systems are attractive for wastewater with high ammonium concentration and low carbon-to-nitrogen ratio. The process can take place in one reactor or two (one for the partial nitrification and one for removing nitrogen through annamox). The two-reactor system has a higher reaction rate but costs more upfront.
    - Process(es) affected: Municipal wastewater treatment

- Technology status: Approximately 100 PN/A systems using a variety of reactor configurations (including sequencing batch reactors, granular reactors, and moving bed biofilm reactors) have been developed and implemented at full scale (mainly in Europe) over the past decade.
- R&D needs/issues: The effect of chemical oxygen demand (COD) on mainstream anammox processes is not fully understood. PN/A systems have more complex combinations of microbial processes compared to conventional biological nitrogen removal processes. These microbial processes - the very features of PN/A systems that lead to energy savings - are still not always under control. More robust on-line monitoring and control systems are needed to enable the operator to run a PN/A system with as little manual manipulation as possible. According to a survey by Lackner et al. (2014), the major issues reported with PN/A systems include mechanical failures and accumulation of nitrogen species, foaming, scaling, and solids retention. The overall environmental performance of specific PN/A configurations should be assessed in order to determine the systems' true environmental benefits.
- Potential impacts: Conventional nitrogen removal processes that rely on nitrification-denitrification over nitrate are energy intensive, mainly due to aeration costs. PN/A represents a more sustainable alternative for nitrogen removal since it requires almost two-thirds less aeration energy, does not require adding an external carbon source, and produces very little sludge and CO_2 emissions. Depending on the local conditions, the required manpower to run and maintain a PN/A system is estimated between one and four hours per day for normal operation, which is higher than a conventional system. One study showed the reduction in life-cycle nitrogen emissions from using a two-reactor anammox technique decreased the marine eutrophication potential of 16 percent for the total wastewater treatment plant (Hauck et al. 2016). However, the reduction in nitrogen increased the cost of electricity use in the two-reactor process studied.

- ***Membrane aerated bioreactor (MABR)*** – The MABR system has an oxygen utilization efficiency that is essentially 100 percent due to the growth of a biofilm on the membrane surface that allows the oxygen to go into the biomass.
    - Process(es) affected: Wastewater treatment (both municipal and industrial)
    - Technology status: The MABR concept has existed for decades. Several technologies have been commercialized, but few full-scale installations exist.
    - R&D needs/issues: Membrane systems cost more than simple fine bubble diffuser aeration (FBDA) systems and also more than advanced high-shear aeration devices. Not enough data is available on membrane life, which is critical given their high replacement cost. MABR is not as effective as FBDA in limiting the collection of solids at the base of the aeration tank. Using a membrane for aeration means there is no membrane-based biomass separation. An additional membrane separation

stage may be required to produce a clarified effluent. The biofilm cannot be allowed to grow uncontrolled since it would clog the membrane channels. A stable biofilm thickness must be maintained.

- Potential impacts: The oxygen utilization efficiency of about 100 percent (versus the 10-40 percent efficiency of conventional FBDA) saves up to 90 percent of the energy associated with aeration compared to conventional plants. This efficiency means MABR modules can be powered by solar arrays, bringing treatment to locations not previously possible. MABR generates half as much sludge as conventional activate sludge treatment.

CHAPTER 10: Summary

Cross-Cutting Technology Areas

When identifying potential high-impact technologies for the IAW sectors, the project team sought to capture a wide range of technologies. Some technologies do not fit neatly under one of the specific technology areas included in Chapters 3 to 9. Among such crosscutting topic areas were smart manufacturing and sustainability design. These areas were given their own sections in the assessment. Other crosscutting technologies that applied to several topic areas or economic sectors were compressors, pumps, sensors and controls, and DER (distributed energy resources, which includes renewable generation, electricity storage, and interconnections in the grid and in microgrids).

As technologies under these crosscutting areas were further analyzed, most of them were not ranked as high-priority technologies. Some were moved to the most applicable technology study areas for further analysis and consideration. For example, the additive manufacturing technologies identified in the smart manufacturing analysis were moved to the metals manufacturing topic area, where the same additive manufacturing solutions were brought up by webinar participants. Under sustainability design, direct capture of CO_2 from atmosphere to produce limestone for cement manufacture was initially identified as a potential high-impact technology. Because the technology is related to cement manufacturing, it was further discussed and evaluated by the cement manufacturing stakeholder group.

Identified Technologies

At the conclusion of the two phases of this project (technical assessment and roadmapping), Energetics is recommending 123 energy-saving technologies in six technology areas. Of these 123 technologies, 81 are state-of-the-art and 42 are R&D. Appendix A has the full list of recommendations, sorted by technology area. Figure 4 provides a diagram of the project phases and number of technologies identified in each phase.

Figure 4: IAW Roadmap Technology Identification Steps

Explanation of the state-of-the-art technologies are in Chapters 3 through 8, along with how these technologies align with relevant California policies and legislation. Chapter 9 provides a summary of identified R&D technologies. The full list of identified technologies is in Appendix A.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AB	Assembly Bill
AHSS	Advanced High-Strength Steel
AI	Artificial Intelligence
AISI	American Iron and Steel Institute
ASM	Annual Survey of Manufacturers
BOD	Biochemical Oxygen Demand
BPA	Bonneville Power Administration
CAL FIRE	California Department of Forestry and Fire Protection
CalRecycle	California Department of Resources Recycling and Recovery
CAPEX	Capital Expenses
CARB	California Air Resources Board
CBP	County Business Patterns
CDFA	California Department of Food and Agriculture
CHP	Combined Heat and Power
CIMIS	California Irrigation and Management Information System
COD	Chemical Oxygen Demand
CPUC	California Public Utilities Commission
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EIA	U.S. Energy Information Administration
EISG	Energy Innovations Small Grant (Program)
EPIC	Electric Program Investment Charge
ET	Evapotranspiration
IAW	Industrial, Agricultural, and Water
IEPR	Integrated Energy Policy Report
IOU	Investor-Owned Utility
IT	Information Technology
LBNL	Lawrence Berkeley National Laboratory

Acronym or Abbreviation	Definition
LEED	Leadership in Energy and Environmental Design
LEPA	Low-Energy Precision Application
MECS	Manufacturing Energy Consumption Survey
MMBtu	Million Btu
MVR	Mechanical Vapor Recompression
NAICS	North American Industry Classification System
NRCS	National Resources Conservation Service
OPEX	Operating Expenses
ORC	Organic Rankine Cycle
PG&E	Pacific Gas and Electric Company
R&D	Research, & Development
RDD&D	Research, Development, Demonstration, and Deployment
RDI	Regulated Deficit Irrigation
ROI	Return On Investment
SB	Senate Bill
SCFM	Standard Cubic Feet Per Minute
SGMA	Sustainable Groundwater Management Act
SMR	Steam Methane Reforming
SOA	State-of-the-Art
TA	Technical Assessment
TBtu	Trillion Btu
TCR	Thermochemical Regenerator
TDS	Total Dissolved Solids
UC Davis	University of California, Davis
UPS	Uninterruptible Power System
UV	Ultraviolet
VFD	Variable Frequency Drive
VOC	Volatile Organic Compound
VSD	Variable Speed Drive
VSEP	Vibratory Shear Enhanced Processing

APPENDIX A: Technology Listing

During the technical assessment, 325 technologies were identified in the literature review. This list was later prioritized to 91 technologies based on the methodology in Chapter 1. The assessment report includes technology briefs written to further describe their impacts for implementation in California. During the first and second webinars in the roadmapping process (Chapter 1), additional technologies were considered based on participant feedback, while some were eliminated. Table lists all the technologies identified in the assessment and roadmapping steps, with notation for short-term state-of-the-art (SOA) versus long-term R&D impacts.

The cells with a white background were identified during the assessment and remained after feedback from the surveys and webinars. The cells in light grey background were added during the webinars and surveys, based on input from experts. For the 12 R&D technologies identified for further investigation, the R&D label in the fourth column is italicized.

Table A-1: Technologies Recommended, Sorted by Technology Area

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Industrial Processing	Glass Manufacturing	Electric melting	SOA
Industrial Processing	Glass Manufacturing	Increased cullet rate	SOA
Industrial Processing	Glass Manufacturing	Thermochemical regenerator (TCR) system	SOA
Industrial Processing	Glass Manufacturing	Capturing waste heat for electricity generation using organic rankine cycle (ORC)	SOA
Industrial Processing	Glass Manufacturing	Advanced sensors and controls	SOA
Industrial Processing	Glass Manufacturing	Oxy-fuel furnaces	R&D
Industrial Processing	Glass Manufacturing	New grinding technology	R&D
Industrial Processing	Glass Manufacturing	Preheating of fuel stream	R&D
Industrial Processing	Cement Manufacturing	Horomill	SOA
Industrial Processing	Cement Manufacturing	Gravity-fed homogenizing silos	SOA
Industrial Processing	Cement Manufacturing	Waste heat recovery	SOA
Industrial Processing	Cement Manufacturing	High-efficiency vertical roller mill	SOA
Industrial Processing	Cement Manufacturing	Appropriate sizing and most efficient motors for crushing and grinding	SOA
Industrial Processing	Metals Manufacturing	Use of pre-baked anodes	SOA
Industrial Processing	Metals Manufacturing	Optimized point feeding system with computer control	SOA

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Industrial Processing	Metals Manufacturing	Minimizing losses from rectifiers, auxiliaries and pollution control	SOA
Industrial Processing	Metals Manufacturing	Direct casting with aluminum transferred hot to alloying furnace	SOA
Industrial Processing	Metals Manufacturing	Oxy-fuel burners/lancing	SOA
Industrial Processing	Metals Manufacturing	Natural-gas-based Midrex process with CO_2 removal system	SOA
Industrial Processing	Metals Manufacturing	Hot charging of slab reheat furnaces	SOA
Industrial Processing	Metals Manufacturing	Continuous annealing	SOA
Industrial Processing	Metals Manufacturing	High-pressure grinding rolls	SOA
Industrial Processing	Metals Manufacturing	Recycling gold	SOA
Industrial Processing	Metals Manufacturing	Smart sensors and control systems for integrated steel mills and electric arc furnace (EAF) steelmaking	SOA
Industrial Processing	Metals Manufacturing	New forming methods for next-generation advanced high-strength steel (AHSS)	SOA
Industrial Processing	Metals Manufacturing	Improved recycling of other metals	SOA
Industrial Processing	Metals Manufacturing	Advanced sensors and controls	SOA
Industrial Processing	Metals Manufacturing	Heat recovery in metals production	SOA
Industrial Processing	Metals Manufacturing	Hydraulic pump of strip steel cutting system controlled by a converter	R&D
Industrial Processing	Metals Manufacturing	Wetted drained cathodes	R&D
Industrial Processing	Metals Manufacturing	Iron slag heat recovery	R&D
Industrial Processing	Metals Manufacturing	Inter-electrode insulation for pickling line	R&D
Industrial Processing	Metals Manufacturing	EAF electrode technology	R&D
Industrial Processing	Chemicals Manufacturing	New high-temperature, low-cost ceramic media for natural gas combustion burners	R&D
Industrial Processing	Chemicals Manufacturing	High-temperature chillers for cooling water	R&D
Industrial Processing	Plastics Manufacturing	Extrusion barrel heating using electrically heated thermal oil and insulation	SOA
Industrial Processing	Plastics Manufacturing	Extruding polymer directly after drying	SOA
Industrial Processing	Plastics Manufacturing	Variable speed drive (VSD) on chilled water pump	SOA
Industrial Processing	Plastics Manufacturing	Insulation on barrel heaters	SOA

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Industrial Processing	Plastics Manufacturing	Switching from hydraulic to all-electric injection molding machines	SOA
Industrial Processing	Plastics Manufacturing	Radiant heater bands for plastic extrusion	SOA
Industrial Processing	Plastics Manufacturing	Low–pressure drying	SOA
Industrial Processing	Plastics Manufacturing	High-efficiency motors for extruder drive system	SOA
Industrial Processing	Plastics Manufacturing	Specific process control strategy using one VSD for multiple parallel motors	SOA
Industrial Processing	Plastics Manufacturing	More effective separation of plastics recycling	SOA
Industrial Processing	Plastics Manufacturing	Foam-blowing agents	SOA
Industrial Processing	Plastics Manufacturing	Large-scale microwave processing	*R&D*
Industrial Processing	Plastics Manufacturing	Computational fluid dynamics to optimize cooling unit designs	R&D
Industrial Processing	Plastics Manufacturing	Advanced additive manufacturing	R&D
Industrial Processing	Pulp and Paper Manufacturing	High-consistency forming	SOA
Industrial Processing	Pulp and Paper Manufacturing	Efficient washing of pulp	SOA
Industrial Processing	Pulp and Paper Manufacturing	Higher-efficiency boilers and turbines	SOA
Industrial Processing	Pulp and Paper Manufacturing	Vibratory shear-enhanced processing (VSEP)	SOA
Industrial Processing	Pulp and Paper Manufacturing	Liquid-free chemical pulping (LFCP) method	R&D
Industrial Processing	Pulp and Paper Manufacturing	Dehumidification/drying using heat pipe and heat pumps	R&D
Industrial Processing	Petroleum Refining	Fiber optics sensors	SOA
Industrial Processing	Petroleum Refining	Advanced distillation techniques	SOA
Industrial Processing	Petroleum Refining	Integrate increased natural gas into refining	SOA
Industrial Processing	Petroleum Refining	In-furnace cameras for oil refineries	SOA
Industrial Facilities and Power		Large batteries	SOA
Industrial Facilities and Power		Industrial uninterruptible power systems (UPSs)	SOA

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Industrial Facilities and Power		Solid-state power transformers	SOA
Industrial Facilities and Power		Advanced combined heat and power (CHP) systems	SOA
Industrial Facilities and Power		Ice storage	SOA
Industrial Facilities and Power		Flywheels	SOA
Industrial Facilities and Power		Continuous liquid interface production (CLIP)	R&D
Industrial Facilities and Power		Wide-bandgap materials for power electronics	R&D
Industrial Facilities and Power		Transactive peer-to-peer enabling energy technologies	R&D
Data Centers		Close-coupled cooling	SOA
Data Centers		Liquid immersion cooling	SOA
Data Centers		Direct-to-chip liquid cooling	SOA
Data Centers		Dynamic cooling management	SOA
Data Centers		Direct and indirect evaporative cooling	SOA
Data Centers		Data center water reduction	*R&D*
Data Centers		Onsite microgeneration at data centers	*R&D*
Data Centers		High-voltage DC power	R&D
Data Centers		Consolidating workload onto servers	R&D
Bioenergy	Anaerobic Digestion	Gas cleanup	SOA
Bioenergy	Anaerobic Digestion	Enhanced anaerobic digester biogas production using enzymes	SOA
Bioenergy	Anaerobic Digestion	Fixed film anaerobic digestion of dilute waste streams such as livestock and dairy manure	SOA
Bioenergy	Anaerobic Digestion	Codigestion	SOA
Bioenergy	Anaerobic Digestion	Dry fermentation anaerobic digestion	SOA
Bioenergy	Gasification	Sierra Energy FastOx®	SOA
Bioenergy	Gasification	Gasification with Organic Rankine Cycle (ORC) engine	SOA
Bioenergy	Anaerobic Digestion	Alkali pretreatment for anaerobic digestion	*R&D*

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Bioenergy	Anaerobic Digestion	Biogas upgrading to renewable natural gas (RNG)	*R&D*
Bioenergy	Gasification	Pyrolysis/gasification	*R&D*
Bioenergy	Gasification	Biochar applications	R&D
Bioenergy	Anaerobic Digestion	Microbial electrochemical cells	R&D
Agriculture	Electricity-Intensive Agriculture	Dryeration	SOA
Agriculture	Electricity-Intensive Agriculture	Water-cooled plate cooler	SOA
Agriculture	Irrigation	Smart irrigation scheduling	SOA
Agriculture	Irrigation	Micro-irrigation	SOA
Agriculture	Irrigation	Controls and smart systems	SOA
Agriculture	Irrigation	Regulated deficit irrigation (RDI)	SOA
Agriculture	Irrigation	Low-energy drip systems	*R&D*
Agriculture	Food and Beverage Processing	Advanced carbon dioxide (CO2) recovery systems	SOA
Agriculture	Food and Beverage Processing	Blowers in compressed air systems	SOA
Agriculture	Food and Beverage Processing	Refrigeration improvements in wineries (and other applications)	SOA
Agriculture	Food and Beverage Processing	Mechanical vapor recompression (MVR) evaporators in whey drying	SOA
Agriculture	Food and Beverage Processing	Ambient temperature sanitization vs. steam and hot water	SOA
Agriculture	Food and Beverage Processing	Smarter use of jacket cooling in batch systems	SOA
Agriculture	Food and Beverage Processing	Sequential infrared and freeze-drying (SIRFD)	R&D
Agriculture	Food and Beverage Processing	Simultaneous infrared dry-blanching and dehydration (SIRDBD)	R&D
Agriculture	Food and Beverage Processing	More efficient chilling and refrigeration techniques	*R&D*
Agriculture	Food and Beverage Processing	Onsite water purification	R&D
Water and Wastewater		Microfiltration	SOA

Technology Area	Technology Subareas	Technology Innovation Title	SOA or R&D
Water and Wastewater		Reverse osmosis	SOA
Water and Wastewater		Ultraviolet (UV) disinfection	SOA
Water and Wastewater		Advanced aeration	SOA
Water and Wastewater		Information technology	SOA
Water and Wastewater		Load shifting	SOA
Water and Wastewater		Optimized head loss and friction loss in distributed piping systems	SOA
Water and Wastewater		Advanced oxidation process	R&D
Water and Wastewater		Shortcut nitrogen removal or anaerobic ammonia oxidation (anammox)	*R&D*
Water and Wastewater		Ultrafine bubble diffusers	R&D
Water and Wastewater		Carbon nanotube reverse-osmosis (RO) membrane	*R&D*
Water and Wastewater		Biomimetic membranes	R&D
Water and Wastewater		Concentrated solar desalination	R&D
Water and Wastewater		Anaerobic membrane bioreactors (AN-MBRs)	R&D
Water and Wastewater		Partial nitrification over anammox (PN/A)	*R&D*
Water and Wastewater		Ceramic membranes	R&D
Water and Wastewater		Membrane aerated bioreactors (MABRs)	*R&D*

APPENDIX B: California Policies

Table B-1: Summary of California Policies and Legislation that Affect Technological Development within the Proposed Task Areas

State Policy or Legislation	Function
	Air Resources Board
California's 2017 Climate Change Scoping Plan	Set up by AB 32, which created a program to reduce GHG emissions in California. In 2016, SB 32 set new 2030 GHG goals. AB 197 further directed development on the scoping plan. CARB administers this plan, which reflects the 2030 target set by SB 32 and EO B-30-15.
Short-Lived Climate Pollutant Reduction Strategy	CARB is developing a comprehensive strategy in coordination with other state agencies and air quality districts to reduce emissions of SLCPs. The strategy contains numerous policies to promote dairy biomethane and other renewable gas projects to reduce methane emissions.
	Assembly Bills
AB 32	Original bill passed in 2006 that set GHG reduction levels to 15 percent of 1990 levels by 2020. SB 32 expanded on this mandate.
AB 221	Bill alters specifications clarifying the definition of recycled concrete as defined in the California Green Building Standards Code. The original code allowed for recycled concrete materials to be used if the user has been fully informed.
AB 262	California looks to lower the amount of lifecycle GHGs emitted by materials used in construction of state-owned buildings. Emission reductions will be based on established baselines.
AB 324	Expands on bill limiting arsenic and lead content in manufactured beads by changing detection methods and ability to monitor manufacturing process.
AB 758	Establishes regulatory proceeding to develop a program to achieve greater energy savings in residential and non-residential buildings. Resulted in the Existing Buildings Energy Efficiency Action Plan.
AB 1158	Increases goal of state to reach a 24 percent recycling rate for post-consumer carpet by 2020.
AB 1594	Eliminates the diversion credit for using organic material as landfill alternative daily cover (ADC). This diversion credit incentivized the use of organics in the landfill. Removing this diversion credit does not prohibit the use of organics as ADC. However, without the diversion credit, landfill operators are incentivized to find alternative uses for organic materials to achieve diversion requirements.
AB 1613	States intent to lower natural gas use by capturing unused waste heat to reduce wasteful consumption and support CHP systems. Electrical power produced on site has to be purchased by electric utilities.
AB 1826	Requires commercial generators to subscribe to composting or anaerobic digestion service for their organic waste.

State Policy or Legislation	Function
AB 1923	Amends SB 1122 (BioMAT) to allow a nameplate generation capacity of 5 MW if only 3 MW are exported to the grid.
AB 2717	The Cobey-Porter Saline Water Conversion Law authorizes the California Department of Water Resources, either independently or in cooperation with public or private entities, to conduct a program of investigation, study, and evaluation in the field of saline water conversion, to provide assistance to persons or entities seeking to construct desalination facilities, and after submission of a written report and upon appropriation from the Legislature, to finance, construct, and operate saline water conversion facilities.
CA Department of Food and Agriculture (CDFA)	
Dairy Digester Research and Development Program	Provides financial assistance for the installation of dairy digesters in California, which will result in reduced greenhouse gas emissions. CDFA receives funds from the California Greenhouse Gas Reduction Fund for methane emissions reductions from dairy and livestock operations. CDFA allocates between 65 to 80 percent of the funds as incentives to support digester projects on California dairy operations through an annual grant program.
CA Department of Forestry and Fire Protection (CAL FIRE)	
Forest Climate Action Team	In preparation of the California Forest Carbon Plan, includes the use of forest biomass to produce electricity. The plan also serves as the mechanism in addressing black carbon emissions from forest sources such as wildfire.
CA Department of Resources Recycling and Recovery (CalRecycle)	
Greenhouse Gas Reduction Grant and Loan Programs	CalRecycle established the Greenhouse Gas Reduction Grant and Loan Programs to provide financial incentives for capital investments in infrastructure for aerobic composting, anaerobic digestion and recycling and manufacturing facilities that will reduce greenhouse gas emissions. These grants promote California infrastructure developments that achieve greenhouse gas emission reductions by diverting more materials from landfills and producing beneficial products such as soil amendments, renewable fuels or recycled-content products. Grants are targeted to build or expand organics infrastructure, such as anaerobic digestion of food and organic waste to electricity.
California Codes	
Public Resources Code 25601	Gives priority to research and development in energy supply, consumption, and conservation.
Public Resources Code 25620	It is in California's interest to promote environmentally positive energy technologies. The state should undertake RD&D on these energy projects. Should economically benefit the state. Encourages investment to meet energy growth needs while optimizing energy conservation and resource efficiency.

State Policy or Legislation	Function
Warren Alquist Act	Calls for public interest energy research not adequately provided for by energy markets. Calls for environmentally sound, reliable, and affordable energy services and products. Funds RD&D in energy conservation and efficiency, fuel substitution, alternative sources of energy, and other areas. Recommends a range of measures to reduce wasteful, uneconomical, and unnecessary uses of energy, thereby reducing the rate of growth of energy consumption. Provides loans and other financial incentives for energy projects, and encourages use of alternative energy resources.
California Public Utilities Commission (CPUC)	
Energy Efficiency Strategic Plan	Last updated in 2011, the plan looks to reach California's energy efficiency and GHG reduction goals from an approach from the utilities side. Collaborative process with California’s utilities.
California Energy Commission	
Bioenergy Action Plan	Identifies barriers to bioenergy utilization and recommends actions to address them, so that the state can meet its clean energy, waste reduction and climate protection goals. · Increase environmentally and economically sustainable energy production from biomass waste. · Encourage development of diverse bioenergy technologies that increase local electricity generation, CHP, renewable natural gas, and renewable liquid fuels for transportation and fuel cell applications. · Create jobs and stimulate economic development, especially in rural regions of the state. · Reduce fire danger, improve air and water quality, and reduce waste.
Building Energy Efficiency Standards	The measure includes new prescriptive requirements and new modeling rules. One could argue that it also includes new mandatory requirements since it makes it clear that the existing mandatory requirements apply to computer rooms, which have commonly been interpreted as exempt from Title 24.
Energy Action Plan	Encourages investment to meet energy growth needs while optimizing energy conservation and resource efficiency.
Energy Commission Energy Innovations Small Grant (EISG) Program	Funds $150,000 for hardware projects and $75,000 for modeling projects to small businesses, non-profits, individuals, or academic institutions. Devices that improve end use energy efficiency are included as a potential funding area.
Integrated Energy Policy Report	Provides policy recommendations to conserve resources; protect the environment; ensure reliable, secure, and diverse energy supplies.
Executive Orders	
Clean Energy Jobs Plan	Eight-point plan designed to make half a million new clean energy jobs in the state over a decade.
Executive Order B-18-12	Calls for reductions in state agency energy purchases and GHG emissions. Included a Green Building Action Plan, which gave additional details.
Executive Order B-29-15	In response to droughts, the order set up a restriction on water usage throughout the state.

State Policy or Legislation	Function
Executive Order B-30-15	Set GHG emissions targets for 2030 at 40 percent below 1990 levels.
Executive Order B-37-16	In response to droughts, points 11 to 13 require Ag Water Management Plans and water conservation actions.
Executive Order B-40-17	In response to droughts, point 8 requires actions by ag water users.
Executive Order S-03-05	Established GHG emission reduction targets and created a Climate Action Team.
Executive Order S-06-06	EO-S-06-06 directs Secretary of Cal/EPA to participate in the Bio-Energy Interagency Working Group and addresses biofuels and bioenergy from renewable resources.
Governor's Proclamation of State of Emergency, 10/31/2015	This proclamation is in response to the very high amount of tree mortality due to drought induced bark beetle infestations. The proclamation has several orders to assist and enhance the use of bioenergy in dealing with woody biomass from forest trees killed by the bark beetle infestations.
Other	
Western Regional Climate Action Initiative	Started in February 2007 by governors of five Western states (Arizona, California, New Mexico, Oregon, and Washing) with the goal of creating a market-based program across multiple sectors to lower GHG emissions. More states and Canadian provinces have signed on since. In 2011, every U.S. state except California left the agreement.
Senate Bills	
SB 32	Bill that officially set 2030 emissions target of 40 percent below 1990 levels) for California.
SB 71	Sets safety standards for petroleum refining and related industries.
SB 332	Decreases the amount of recycled glass required in manufactured glass food, drink, and beverage containers if manufacturer properly utilizes mixed color cullet glass.
SB 350	Increases the amount of renewable energy sold to retail customers to 50 percent by 2030. Increases renewable generation in the state to 33 percent by 2020 (from 2015 levels).
SB 966	This bill would, on or before December 1, 2022, requires the state board, in consultation with the California Building Standards Commission, to adopt regulations for risk-based water quality standards for the onsite treatment and reuse of non-potable water, as provided.
SB 1106	The amount of postconsumer products in materials sold to the state must be published including for flat glass and glass containers. Recycled glass must contain up to 10 percent postconsumer glass.

State Policy or Legislation	Function
SB 1122	Established a Bioenergy Feed-in Tariff (a.k.a. BioMAT) requiring the three largest investor owned utilities procure 250 MW from small-scale bioenergy projects (3 MW or less) that commence operation after June 1, 2013. The bill specified that the CPUC should allocated the 250 MW in the following manner: · 110 MW for biogas from wastewater treatment, municipal organic waste diversion, food processing, and co-digestion · 90 MW for dairy and other agricultural bioenergy · 50 MW for bioenergy using byproducts of sustainable forest management
SB 1250	Public Goods Utilities surcharge to support public interest R&D for energy efficiency and renewable, conservation activities.
SB 1300	Refinery turnaround (planned, periodic shutdown) regulations and processes.
SB 1383	Created goals for short-lived climate pollutant reductions in various industry sectors, including reduction goals for black carbon, fluorinated gases, and methane. Organic materials comprise two-thirds of the waste stream. This bill aims for a 75 percent reduction in the level of statewide disposal of organic waste from 2014 levels by 2025.
SB 1389	The bill requires the State Energy Resources Conservation and Development Commission to manage a data collection system for obtaining the information necessary to develop specified energy policy reports and analyses, and energy shortage contingency planning efforts, and to support other duties of the commission, as prescribed. The bill would authorize the commission to impose a civil penalty to ensure timely and accurate compliance with the data collection system. The bill would include certain requirements relating to the confidentiality of the data.
SB X1-2	Sets the Renewables Portfolio Standard (RPS) at 33 percent by 2020 (of 2010 totals).
SB X7-7	This bill requires the state to achieve a 20 percent reduction in urban per capita water use in California by December 31, 2020. The state would be required to make incremental progress towards this goal by reducing per capita water use by at least 10 percent on or before December 31, 2015. The bill would require each urban retail water supplier to develop urban water use targets and an interim urban water use target, in accordance with specified requirements. The bill would require agricultural water suppliers to implement efficient water management practices.

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APPENDIX C: Excerpts from Relevant Energy Commission Policies and Legislation

Table C-1: Excerpts from Relevant Energy Commission Policies and Legislation

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Air Resources Board							
California's 2017 Climate Change Scoping Plan	x	x	x	x	x	x	x
"Double energy efficiency savings" "The plan is a package of economically viable and technologically feasible actions to not just keep California on track to achieve its 2030 target but stay on track for a low- to zero-carbon economy by involving every part of the state." "The administration will also continue to collaborate with water and wastewater agencies and energy utilities to educate consumers on the water-energy nexus. The administration will work with the Legislature to eliminate barriers to co-funding projects with water and energy benefits and expand and prioritize funding and technical support for water and wastewater agencies that achieve energy efficiency co-benefits and greenhouse gas reductions." "The state will adopt uniform water recycling criteria for indirect potable reuse of recycled water for groundwater recharge." "Accelerate Clean-up of Contaminated Groundwater and Prevent Future Contamination: ... The State Water Resources Control Board and the Department of Toxic Substances Control will develop recommendations and take action to prevent the spread of 15 contaminations, accelerate cleanup, and protect drinking water in urban areas. The State Water Resources Control Board will continue to implement appropriate control measures to address these sources through its water quality permitting authority."							
CARB AB 32 Scoping Plan					x	x	
"…Unleash opportunity in the agricultural sector by improving manure management, boosting soil health, generating renewable power, electrifying operations, utilizing waste biomass…" "…Implementation will include policy and program pathways, with activities related to land protection; enhanced carbon sequestration; and innovative biomass utilization." "…Excess materials generated by commercial agricultural and forestry operations, biomass and wood harvested through forest health and restoration treatments, and material that is generated in response to Tree Mortality Emergency activities, should be used in a manner that minimizes GHG and black carbon emissions…" "…Providing incentives for expand and new facilities to organics… to meet 2020 and 2030 goals." "…Supporting existing and new clean technologies… for excess woody biomass from urban areas, forests, and agriculture."							

<table>
<tr><th>State Policy or Legislation Excerpts</th><th>Industrial (Non-metals)</th><th>Industrial (Metals)</th><th>Industrial Power</th><th>Industrial Facilities</th><th>Bioenergy</th><th>Agriculture</th><th>Water and Wastewater</th></tr>
<tr><td>Short-Lived Climate Pollutant Reduction Strategy</td><td></td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td colspan="8">"…State agencies and the air districts are committed to continuing to work together to ensure concept outlined in this SLCP Strategy are implemented in a coordinated and synergistic way."</td></tr>
<tr><td colspan="8">Assembly Bills</td></tr>
<tr><td>AB 32</td><td>x</td><td>X</td><td></td><td></td><td>x</td><td>x</td><td></td></tr>
<tr><td colspan="8">Part 4
"38561 (b) The plan shall identify and make recommendations on direct emission reduction measures, alternative compliance mechanisms, market-based compliance mechanisms, and potential monetary and nonmonetary incentives for sources and categories of sources that the state board finds are necessary or desirable to facilitate the achievement of the maximum feasible and cost-effective reductions of greenhouse gas emissions by 2020."</td></tr>
<tr><td>AB 221</td><td>x</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Section 1
"16000 (b) Facilitating recycling of concrete materials in concrete production reduces waste, truck trips, and emissions, while advancing sustainable practices in concrete manufacture."
"16000 (e) Recycling of returned fresh concrete maximizes the reuse of the natural resources of aggregates, water, and cement and conserves embodied energy from concrete production."</td></tr>
<tr><td>AB 262</td><td>x</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Digest
"This bill, the Buy Clean California Act, would, by January 1, 2019, require the Department of General Services to establish, and publish in the State Contracting Manual, a maximum acceptable global warming potential for each category of eligible materials, in accordance with requirements set out in the bill."
Section 2
"3501 (c) "Eligible materials" means any of the following: … Flat glass"</td></tr>
<tr><td>AB 324</td><td>x</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Section 1
"25258 (a) A person shall not manufacture, sell, offer for sale, or offer for promotional purposes in this state glass beads that contain 75 parts per million (ppm) or more of arsenic or 100 ppm or more of lead by weight, if those glass beads will be used with pressure, suction, or wet- or dry-type blasting equipment."</td></tr>
<tr><td>AB 758</td><td>x</td><td>x</td><td>x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Section 2
"(a) the commission shall establish a regulatory proceeding to develop and implement a comprehensive program to achieve greater energy savings in California's existing residential and nonresidential building stock. This program shall comprise a complementary portfolio of techniques, applications, and practices that will achieve greater energy efficiency in existing residential and nonresidential structures that fall significantly below the current standard"</td></tr>
</table>

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
AB 1158	x						
"The bill would prohibit a carpet stewardship organization from expending funds from the carpet stewardship assessment for specified costs and penalties, including for engineered solid waste conversion, as defined, the use of cement kilns to burn carpet, or transformation, as defined."							
AB 1594					x		
Section 2 "Commencing January 1, 2020, the use of green material as alternative daily cover does not constitute diversion through recycling and shall be considered disposal for purposes of this division."							
AB 1613	x	x	x				
Section 1 "2840.6 (b) It is the intent of the Legislature to reduce wasteful consumption of energy through improved residential, commercial, institutional, industrial, and manufacturer utilization of waste heat whenever it is cost effective, technologically feasible, and environmentally beneficial, particularly when this reduces emissions of carbon dioxide and other carbon-based greenhouse gases."							
AB 1826					x		
Section 1 "…Existing solid waste and organic waste recycling facilities within the jurisdiction that may be suitable for potential expansion or colocation of organic waste processing or recycling facilities."							
AB 1923					x		
Section 1 "…Direct the electrical corporations to authorize a bioenergy electric generation facility with an effective capacity of up to five megawatts to participate in the tariff made available pursuant to this paragraph"							
AB 2717							x
Section 2 "...The need for research, development and demonstration projects for more cost effective and technologically efficient desalination processes."							
CA Department of Food and Agriculture (CDFA)							
Dairy Digester Research and Development Program					x		
Greenhouse Gas Reduction Fund "CDFA received $99 million from the Greenhouse Gas Reduction Fund in 2017 (AB 109 - Budget Act of 2017) for methane emissions reductions from dairy and livestock operations. CDFA plans to allocate between 65-80 percent of the funds as incentives to support digester projects on California dairy operations"							

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
CA Department of Forestry and Fire Protection (CAL FIRE)							
Forest Climate Action Team					x		
California Forest Carbon Plan (Draft 2017) "…Build out the 50 MW of small scale, wood-fired bioenergy facilities mandated through SB1122. Continue public investment in this build-out through the California Energy Commission's EPIC program. Expedite contracting and interconnection for facilities fueled by feedstock from tree mortality High Hazard Zones…"							
CA Department of Resources Recycling and Recovery (CalRecycle)							
Greenhouse Gas Reduction Grant and Loan Programs	x				x		
Organics Grant Programs "The purpose of this competitive grant program is to lower overall greenhouse gas emissions by expanding existing capacity or establishing new facilities in California to reduce the amount of California-generated green materials, food materials, and/or Alternative Daily Cover being sent to landfills"							
Recycled Fiber, Plastic, and Glass Grant Program	x						
"The Department of Resources Recycling and Recovery (CalRecycle) offers the Recycled Fiber, Plastic, and Glass Grant Program pursuant to Public Resources Code section 42999. The purpose of this competitive grant program is to lower overall greenhouse gas emissions by expanding existing capacity or establishing new facilities in California that use California-generated postconsumer recycled fiber (paper, textiles, carpet, or wood), plastic, or glass to manufacture products."							
California Codes							
Public Resources Code 25601		x	x	x			
25601 "The commission shall develop and coordinate a program of research and development in energy supply, consumption, and conservation and the technology of siting facilities and shall give priority to those forms of research and development which are of particular importance to the state ..."							
Public Resources Code 25620	x	x	x	x	x	x	
25620 (b) "To improve the quality of life of this state's citizens, it is proper and appropriate for the state to undertake public interest energy research, development, and demonstration projects that are not adequately provided for by competitive and regulated energy markets."							

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Warren-Alquist Act	x	x	x	x	x	x	x
25007. State Policy Reduction in uses of energy — “...policy of the state ...to employ a range of measures to reduce wasteful, uneconomical, and unnecessary uses of energy, ...reducing rate of growth of energy consumption ...” **25008. State policy; energy and water conservation; alternate supply sources; energy or water facilities at state-owned sites** "It is further the policy of the state and the intent of the Legislature to promote all feasible means of energy and water conservation and all feasible uses of alternative energy and water supply sources...which may be use to substitute for traditional energy… including biomass…” **25216. Duties, research, and development** “...The commission shall ...(c) Carry out... research and development into alternative sources of energy, improvements in energy generation, ...fuel substitution, and other topics related to energy supply, demand, ...and conservation which are of particular statewide importance.” **25401 Continuous studies, projects** …The commission shall… carry out studies, technical assessments **25402. Reduction of wasteful, uneconomic, inefficient or unnecessary consumption of energy** "The commission shall ... reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy, including the energy associated with the use of water" **25602. Technical assessment studies** "The commission shall carry out technical assessment studies on all forms of energy and energy-related problems, in order to influence federal research and development priorities and to be informed on future energy options and their impacts, including, in addition to those problems specified in Section 25601, but not limited to, the following: (f) Measures to reduce wasteful and inefficient uses of energy ... (j) Implications of government subsidies and taxation and ratesetting policies."							
California Public Utilities Commission (CPUC)							
Energy Efficiency Strategic Plan	x					x	x
"Last updated in 2011, the Energy Efficiency Strategic Plan looks to reach California's energy efficiency and GHG reduction goals from an approach from the utilities side. Collaborative process with the State's utilities.” "Expected reductions in surface water supplies due to climate change that will increase demand for energy-intensive groundwater pumping, making energy efficiency both critical and cost-compelling." "Integrated Resource Management: Setting up a common framework for resource management that can better leverage and “piggyback” multiple resource management programs to support increased adoption of energy efficiency, demand response and onsite generation opportunities integrated with efforts to attain air, water, and solid waste objectives."							
Renewables Portfolio Standard					x		

<table>
<tr><th>State Policy or Legislation Excerpts</th><th>Industrial (Non-metals)</th><th>Industrial (Metals)</th><th>Industrial Power</th><th>Industrial Facilities</th><th>Bioenergy</th><th>Agriculture</th><th>Water and Wastewater</th></tr>
<tr><td colspan="8">2017 RPS Report, page 23
“… A Feed-in Tariff (FIT) program is a policy mechanism designed to accelerate investment in small, distributed renewable technologies. The goal of Feed-in Tariff programs is to offer long-term contracts and price certainty that aid in financing renewable energy investments. The RPS program has two FIT programs, Renewable Market Adjusting Tariff (ReMAT) and Bioenergy Market Adjusting Tariff (BioMAT).”</td></tr>
<tr><td>Self-Generation Incentive Program</td><td></td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td colspan="8">CPUC SGIP Webpage
“The CPUC's Self-Generation Incentive Program (SGIP) provides incentives to support existing, new, and emerging distributed energy resources. SGIP provides rebates for qualifying distributed energy systems installed on the customer's side of the utility meter. Qualifying technologies include wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems.”</td></tr>
<tr><td colspan="8">California Energy Commission</td></tr>
<tr><td>Bioenergy Action Plan</td><td></td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td colspan="8">Principal Actions
“The increased production and use of sustainable bioenergy can provide a range of economic and environmental benefits. Bioenergy can reduce the state’s dependence on foreign oil and imported natural gas, while diversifying the state’s energy supply and improving energy security. Bioenergy creates green jobs, enhances rural economic development, and promotes local economic stability. Using biomass from wildfire fuel reduction activities and agriculture residues can reduce the occurrence of large costly wildfires, protect watershed and ecosystem, provide an alternative to open field burning, and increase the efficiency and profitability of forestry and farming.”</td></tr>
<tr><td>Building Energy Efficiency Standards</td><td></td><td></td><td></td><td>x</td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Section 120.2
“Required controls for space-conditioned systems”</td></tr>
<tr><td>Energy Action Plan</td><td>x</td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="8">Specific Action Areas
“In addition, partnerships with industry in California will become increasingly important. Although most state industrial production is dominated by relatively light industry, some energy-intensive industries still remain, including cement and glass production, as well as agricultural processing and petroleum refining. By encouraging utilities to partner with these types of energy consumers, we can increase our chances of meeting our greenhouse gas goals together.”
“…Develop and implement forestry, agriculture, and waste management policies to encourage the generation of electricity from landfills, biomass, and biogas”
"… adopt load-management standards to establish a demand-response infrastructure"
"programs that utilize advanced metering, tariff, and other automated demand response infrastructure"
“The most important tool for addressing greenhouse gas emissions in the energy sector is energy efficiency.”</td></tr>
</table>

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Energy Commission Energy Innovation Small Grant (EISG) Program	x					x	

What project subject areas are eligible for funding?

"Building End-use Efficiency: (a) reduce the energy input requirements per unit of energy output or service of end-use devices or systems; (b) conserve energy by reducing demand for energy goods and services; or (c) reduce energy-related expenditures by facilitating load management techniques."

"The Energy Innovations Small Grant (EISG) Program provides up to $150,000 for hardware projects and $75,000 for modeling projects to small businesses, non-profits, individuals and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts"

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Integrated Energy Policy Report	x	x	x	x	x	x	x

General

Time-of-Use Rates: "… The redesign of TOU periods has significant potential to encourage shifts in electricity-use patterns, but unlocking the greatest benefits will require adaptation and investment by customers, many of who have planned operations around TOU periods that have not changed in decades... Shifts in the pumping schedule from evening to afternoon is an opportunity to use excess renewable generation and help avoid curtailment.... A constraint is that water managers are reluctant to make investments to shift their electricity usage without some stability in TOU rates over a multiyear time horizon."

"Desalination also offers an opportunity to productively use excess energy"

Pub. Res. Code 25301 (a)

" ...to develop energy policies that conserve resources, protect the environment, ensure energy reliability, enhance the state's economy, and protect public health and safety."

Executive Orders

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Energy Jobs Plan	x	x	x	x		x	

"1. Build 12,000 megawatts of localized electricity generation"

"4. Create New Efficiency Standards for new Buildings"

"5. Make Existing Buildings more Efficient"

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Executive Order B-29-15							x

Point 2

"The State Water Resources Control Board (Water Board) shall impose restrictions to achieve a statewide 25 percent reduction in potable urban water usage"

Point 5

"require that commercial, industrial, and institutional properties, such as campuses, golf courses, and cemeteries, immediately implement water efficiency measures to reduce potable water usage"

Point 8

"The Water Board shall direct urban water suppliers to develop rate structures and other pricing mechanisms, including but not limited to surcharges, fees, and penalties, to maximize water conservation consistent with statewide water restrictions."

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
Executive Order B-30-15	x	x			x	x	
Point 1 “A new interim statewide greenhouse gas emission reduction target to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030 is established in order to ensure California meets its target of reducing greenhouse gas emissions to 80 percent below 1990 levels by 2050.” **Point 6** “State agencies shall take climate change into account in their planning and investment decisions, and employ full life-cycle cost accounting to evaluate and compare infrastructure investments and alternatives.”							
Executive Order B-37-16						x	
Point 12 “The department (DWR) shall permanently require the completion of Agricultural Water Management Plans by water suppliers with over 10,000 irrigated acres of land.”							
Executive Order B-40-17						x	
Point 8 “The Water Board and the Department shall continue to take actions to direct urban and agricultural water suppliers to accelerate their data collection, improve water system management, and prioritize capital projects to reduce water waste.”							
Executive Order S-03-05	x	x			x	x	
Point 1 “That the following greenhouse gas emission reduction targets are hereby established for California: by 2010, reduce GHG emissions to 2000 levels; by 2020, reduce GHG emissions to 1990 levels; by 2050, reduce GHG emissions to 80 percent below 1990 levels.”							
Executive Order S-06-06					x		
Point 1 “The following targets to increase the production and use of bioenergy, …, are established for California: Regarding the use of biomass for electricity, the state met a 20 percent target within the established state goals for renewable generation for 2010 and 2020;” **Point 2** “The Secretary for the California Resources Agency and the Chair of the Energy Resources Conservation and Development Commission ("Energy Commission") shall coordinate oversight of efforts made by state agencies to promote the use of biomass resources;” **Point 4** “The Energy Commission shall coordinate with other responsible state agencies to identify and secure federal and state funding for research, development and demonstration projects to advance the use of biomass resources for electricity generation…”							

<table>
<tr><th>State Policy or Legislation Excerpts</th><th>Industrial (Non-metals)</th><th>Industrial (Metals)</th><th>Industrial Power</th><th>Industrial Facilities</th><th>Bioenergy</th><th>Agriculture</th><th>Water and Wastewater</th></tr>
<tr><td>Executive Order S-18-12</td><td>x</td><td>x</td><td>x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Point 7
“That new and existing buildings incorporate building commissioning to facilitate improved and efficient building operation.”
Point 12
“...incorporate environmentally preferable products,”</td></tr>
<tr><td>Governor's Proclamation of State of Emergency 10/31/15</td><td></td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td colspan="8">Point 11
"The California Energy Commission shall prioritize grant funding from the Electric Program Investment Charge for woody biomass-to-energy technology development and deployment…"
Point 13
"…work with bioenergy facilities that accept forest biomass from high hazard zones to identify potential funds to help offset higher feedstock costs."</td></tr>
<tr><td colspan="8">Other</td></tr>
<tr><td>Western Regional Climate Action Initiative</td><td>x</td><td></td><td></td><td></td><td></td><td>x</td><td></td></tr>
<tr><td colspan="8">“Started in Feb 2007 by governors of five western states (AZ, CA, NM, OR, and WA) with the goal of creating a market-based program across multiple sectors to lower GHG emissions. More states and Canadian provinces have signed on since. In 2011, every U.S. state except CA left the agreement.”</td></tr>
<tr><td colspan="8">Senate Bills</td></tr>
<tr><td>SB 32</td><td>x</td><td>x</td><td></td><td></td><td>x</td><td>x</td><td></td></tr>
<tr><td colspan="8">Section 1.
“(a) The California Global Warming Solutions Act of 2006 (Division 25.5 (commencing with Section 38500) of the Health and Safety Code) authorizes the State Air Resources Board to adopt regulations to achieve the maximum technologically feasible and cost-effective greenhouse gas emissions reductions.”
“(b) The California Global Warming Solutions Act of 2006 (Division 25.5 (commencing with Section 38500) of the Health and Safety Code) requires the State Air Resources Board to reduce statewide emissions of greenhouse gases to at least the 1990 emissions level by 2020 and to maintain and continue reductions thereafter.”

Section 2
“…the state (Air Resources) board shall ensure that statewide greenhouse gas emissions are reduced to at least 40 percent below the statewide greenhouse gas emissions limit no later than December 31, 2030.”</td></tr>
</table>

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
SB 71	x						
Section 42 "7852. (a) It is the intent of the Legislature, in enacting this part, that the Occupational Safety and Health Standards Board and the Division of Occupational Health and Safety (OSHA) promote worker safety through implementation of training and process safety management practices in petroleum refineries and chemical plants and other facilities deemed appropriate."							
SB 332	x						
Digest "Existing law requires each glass container manufacturer to use a 35 percent minimum percentage of California postfilled glass in the manufacturing of glass food, drink, or beverage containers. A manufacturer is authorized to seek a reduction or waiver of this requirement from the department...This bill would reduce the minimum percentage of postfilled glass to 25 percent if the glass container manufacturer makes a specified demonstration to the department with regard to its use of mixed color cullet, as defined."							
SB 350	x	x	x	x	x	x	x
Introduction "This bill would require the State Energy Resources Conservation and Development Commission to establish annual targets for statewide energy efficiency savings and demand reduction that will achieve a cumulative doubling of statewide energy efficiency savings in electricity and natural gas final end uses of retail customers by January 1, 2030" **Section 1** "To increase from 33 percent to 50 percent, the procurement of our electricity from renewable sources." **Section 2** "(2) To double the energy efficiency savings in electricity and natural gas final end uses of retail customers through energy efficiency and conservation." **Section 30** "…encourage the diversity of energy sources through improvements in energy efficiency, development of renewable energy resources, such as wind, solar, biomass, and geothermal energy, and widespread transportation electrification."							
SB 966							x
Digest "require the state board, … to adopt regulations for risk-based water quality standards for the onsite treatment and reuse of nonpotable water … to ... adopt ... a local program that includes the risk-based water quality standards established by the state board."							
SB 1106	x						
Section 31 "12209. For purposes of this article, the following minimum content requirements apply: … (d) For recycled glass, the total weight shall consist of at least 10 percent postconsumer material."							

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
SB 1122					x		
Section 1 "(A) Allocate the 250 megawatts identified in this paragraph among the electrical corporations based on the following categories:" "(i) For biogas from wastewater treatment, municipal organic waste diversion, food processing, and codigestion, 110 megawatts." "(ii) For dairy and other agricultural bioenergy, 90 megawatts." "(iii) For bioenergy using byproducts of sustainable forest management, 50 megawatts. Allocations under this category shall be determined based on the proportion of bioenergy that sustainable forest management providers derive from sustainable forest management in fire threat treatment areas, as designated by the Department of Forestry and Fire Protection." "…Coordinate, to the maximum extent feasible, any incentive or subsidy programs for bioenergy with the agencies listed in subparagraph (A) of paragraph (3) in order to provide maximum benefits to ratepayers and to ensure that incentives are used to reduce contract prices." "…The commission shall encourage gas and electrical corporations to develop and offer programs and services to facilitate development of in-state biogas for a broad range of purposes."							
SB 1250							x
Section 2 "25620.1 ... (4) Advanced electricity technologies that reduce or eliminate consumption of water or other finite resources, increase use of renewable energy resources, or improve transmission or distribution of electricity generated from renewable energy resources. (c) To achieve the goals established in subdivision (b), the commission shall adopt a portfolio approach for the program that does all of the following: (1) Effectively balances the risks, benefits, and time horizons for various activities and investments that will provide tangible energy or environmental benefits for California electricity customers. (2) Emphasizes innovative energy supply and end use technologies, focusing on their reliability, affordability, and environmental attributes. (3) Includes projects that have the potential to enhance transmission and distribution capabilities. (4) Includes projects that have the potential to enhance the reliability, peaking power, and storage capabilities of renewable energy."							
SB 1300	x						
"This bill would require every petroleum refinery employer to, every September 15, submit to the division a full schedule for the following calendar year of planned turnarounds, meaning a planned, periodic shutdown of a refinery process unit or plant to perform maintenance, overhaul, and repair operations and to inspect, test, and replace process materials and equipment, as specified. "							

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
SB 1383					x		

Section 5

"The energy commission, in consultation with the state board and the commission, shall develop recommendations for the development and use of renewable gas, including biomethane and biogas, as a part of its 2017 Integrated Energy Policy Report prepared pursuant to Section 25302 of the Public Resources Code. In developing the recommendations, the energy commission shall identify cost-effective strategies that are consistent with existing state policies and climate change goals by considering priority end uses of renewable gas, including biomethane and biogas, and their interactions with state policies, including biomethane and all of the following:"

"(1) The Renewables Portfolio Standard program (Article 16 (commencing with Section 399.11) of Chapter 2.3 of Part 1 of Division 1 of the Public Utilities Code)"

"(3) Waste diversion goals established pursuant to Division 30 (commencing with Section 40000) of the Public Resources Code."

"Based on the recommendations developed pursuant to subdivision (b), and to meet the state's climate change, renewable energy, low-carbon fuel, and short-lived climate pollutants goals, including black carbon, landfill diversion, and dairy methane targets identified in the strategy, state agencies shall consider and, as appropriate, adopt policies and incentives to significantly increase the sustainable production and use of renewable gas, including biomethane and biogas."

"Based on the recommendations developed pursuant to subdivision (b), the commission, in consultation with the energy commission and the state board, shall consider additional policies to support the development and use in the state of renewable gas, including biomethane and biogas, that reduce short-lived climate pollutants in the state."

Section 6

"Achieving organic waste disposal reduction targets requires significant investment to develop organics recycling capacity.,"

"More robust state and local funding mechanisms are needed to support the expansion of organics recycling capacity,"

"(1) The status of new organics recycling infrastructure development, including the commitment of state funding and appropriate rate increases for solid waste and recycling services to support infrastructure expansion."

"(2) The progress in reducing regulatory barriers to the siting of organics recycling facilities and the timing and effectiveness of policies that will facilitate the permitting of organics recycling infrastructure."

"(3) The status of markets for the products generated by organics recycling facilities, including cost-effective electrical interconnection and common carrier pipeline injection of digester biomethane and the status of markets for compost, biomethane, and other products from the recycling of organic waste."

"(b) If the department determines that significant progress has not been made on the items analyzed pursuant to subdivision (a), the department may include incentives or additional requirements in the regulations described in Section 42652 to facilitate progress towards achieving the organic waste reduction goals for 2020 and 2025"

State Policy or Legislation Excerpts	Industrial (Non-metals)	Industrial (Metals)	Industrial Power	Industrial Facilities	Bioenergy	Agriculture	Water and Wastewater
SB1389							x
Chapter 4 "25300...(b) The Legislature further finds and declares that government has an essential role to ensure that a reliable supply of energy is provided consistent with protection of public health and safety, promotion of the general welfare, maintenance of a sound economy, conservation of resources, and preservation of environmental quality." "(d) The Legislature further finds and declares that timely reporting, assessment, forecasting, and data collection activities are essential to serve the information and policy development needs of the Governor, the Legislature, public agencies, market participants, and the public."							
SB X1-2	x				x	x	
Section 5 “The commission shall optimize public investment…, …Production incentives for reducing fuel costs, that are confirmed to the satisfaction of the commission, at solid fuel biomass energy facilities in order to provide demonstrable environmental and public benefits, including improved air quality.” **Section 31** “The electrical corporation shall first meet its unmet resource needs through all available energy efficiency and demand reduction resources that are cost effective, reliable, and feasible.”							
SB X7-7						x	x
Digest Point 1 "… require the state to achieve a 20 percent reduction in urban per capita water use" ".. require agricultural water suppliers to implement efficient water management practices" **Section 1, Chapter 1** " Improvements in technology and management practices offer the potential for increasing water efficiency in California over time, providing an essential water management tool to meet the need for water for urban, agricultural, and environmental uses." 10608.4 (d) "Establish a method or methods for urban retail water suppliers to determine targets for achieving increased water use efficiency" **Chapter 4, Chapter 5** “Requires agricultural water suppliers to prepare and adopt agricultural water management plans with specified components on or before December 31, 2012, and update those plans on or before December 31, 2015, and on or before December 31 every 5 years thereafter. Provides for increased funding for research, feasibility studies and project construction.”							