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# PIER INDUSTRIAL, AGRICULTURAL, AND WATER ENERGY EFFICIENCY PROGRAM RD&D TARGETS: CONSOLIDATED ROADMAP

CONSULTANT REPORT

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# PREFACE

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*PIER Industrial, Agricultural and Water Energy Efficiency Program RD&D Targets: Consolidated Roadmap* is the final report for the Indentify RD&D Targets for PIER Industrial, Agricultural and Water Energy Efficiency Program project (Contract Number NCI-06-032-P-R, conducted by Navigant Consulting, Inc.). The information from this report contributes to PIER's Industrial, Agricultural, and Water End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

# ABSTRACT

In 2009, the California Energy Commission's Public Interest Energy Research Industrial, Agricultural, and Water Program consolidated nine roadmaps, which were developed between 2003 and 2009 to promote cross-team knowledge and enhance uniformity and usability. The Industrial, Agricultural, and Water program uses roadmaps to identify promising areas of research and to justify future research initiatives. The roadmaps cover a wide area of sectors, including data centers, the California food industry, petroleum refining, and water/wastewater. The consolidation process identified data, policies, and other content that needed updating.

**Keywords:** California Energy Commission, data centers, food processing, petroleum refining, natural gas, beverage industry, water and wastewater, energy efficiency, industrial natural gas efficiency, electronics, Public Interest Energy Research cross-cutting, Industrial, Agricultural, and Water Program

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# EXECUTIVE SUMMARY

From 2003 to 2009, the California Energy Commission's Public Interest Energy Research (PIER) Industrial, Agricultural, and Water (IAW) Program engaged stakeholders from various industries to help develop research, development, and demonstration (RD&D) roadmaps to guide research funding priorities. From these discussions, the IAW program produced nine roadmap documents:

1. *Industrial Agriculture & Water Energy Efficiency RD&D Program Overview (2007)*
2. *Technology for Reducing Natural Gas Use in California Industry (2007)*
3. *Energy Efficiency Roadmap for Petroleum Refineries in California (2006)*
4. *Data Center Energy Research & Deployment Roadmap (2003)*
5. *RD&D Plan and Roadmap for Enhancing Energy Efficiency and Supply Reliability for California's Electronics Industry (2003)*
6. *Energy Efficiency Roadmap for the California Food Processing & Beverage Industry (2009)*
7. *Energy Efficiency in California's Food Industry (2006)*
8. *PIER Water-Energy Strategic Plan and Technology Roadmap (2008)*
9. *Water and Wastewater Industry Energy Efficiency: A Research Roadmap (2004)*

This report is a consolidation of those roadmaps. The consolidation served several purposes, including:

- Organizing roadmap documents, particularly in cases where multiple roadmaps existed for a single sector.
- Streamlining content and presentation styles to improve cohesiveness of consolidated document.
- Identifying data, policies, and other content that needed updating.
- Identifying gaps in information and analysis and addressing these gaps wherever possible.
- Providing the IAW program with a specific plan for expanding or updating roadmapping efforts in the future.

Content and intent of each original roadmap were largely preserved with data, policy, and content updates constituting the bulk of the revisions. Some content pertaining to method ranking priorities was removed from these documents. The original documents with full descriptions of methods can be referenced as needed. The original roadmaps will also be updated in the future to reflect changing RD&D needs and initiatives.

The consolidated roadmap consists of eight chapters covering the following topics:

1. General & Miscellaneous Industrial
2. Natural Gas
3. Petroleum Refineries
4. Data Centers
5. Electronics
6. Food Processing
7. Water-Energy
8. PIER Cross-cutting

Note: All tables and figures in this report were produced by the authors, unless otherwise noted.

# 1.0 General & Miscellaneous Industrial

## 1.1. Introduction

This chapter summarizes core content from the *Industrial End-Use Energy Efficiency RD&D and Implementation Plan* published in 2007. The purpose of the *RD&D and Implementation Plan* document was to provide an overview of research, development, and demonstration (RD&D) opportunities that cut across various sectors in the California Energy Commission's Public Interest Energy Research (PIER) Industrial, Agricultural, and Water (IAW) program. The document provides a starting point for evaluating opportunities within the sectors covered by the IAW program, particularly within the industrial sector.

References to natural gas, petroleum refineries, food processing and water sector opportunities have been removed because full roadmaps have since been completed for these sectors. The remaining content has been refocused on other industrial sectors that do not currently have full roadmaps.

The *RD&D and Implementation Plan* roadmapping process involved interviews and workshops with nearly 80 participants including 22 interviewees, 26 Webex participants, and 30 public workshop participants representing various industry stakeholders including utilities, industrial end-users, and research organizations.

Over forty research opportunities were identified and prioritized from four priority research areas.

**Table 1-1: Cross-cutting Priority Research Areas**

| Priority Research Area | High Priority Initiatives |
|---|---|
| Industrial Energy Systems | Steam and Related Processes<br>Advanced Refrigeration, Air Conditioning (HVAC) and Cooling<br>Boilers<br>Advanced Heat Generation<br>Heat Recovery |
| Energy and Greenhouse Gas (GHG)/Emissions Optimization | GHG/Emission Support<br>Flexible Fuels |
| Process Measurement, Diagnostics and Optimization | Energy Management Systems (EMS)<br>Optimized Pumps, Fans, Compressed Air<br>Advanced Sensors and Controls |
| Market Mechanisms | Best Practices<br>Peak Load Management/Demand Response Program Opportunities |

## 1.2. Industry Overview

As the single largest economy within the United States, and one of the most significant on a global scale, California is home to a wide range of industrial sectors. While some of these sectors have received individual consideration in the form of sector-specific RD&D roadmaps, many smaller industrial sectors have not been considered at this level of detail. This chapter provides an introduction to some of these smaller industrial sectors and broadly outlines some of the energy efficiency opportunities that may be available. Although these sectors consume less energy than the most energy intensive sectors, there is potential for realizing substantial energy efficiency gains. In particular, the development of technologies with broader application—without the sector specificity of many technologies aimed at larger and more energy intensive sectors—may yield additional energy efficiency savings and make a compelling case for investing in RD&D projects.

This chapter references the cement and concrete, glass, and primary and fabricated metals industries because these were specifically mentioned in the original roadmapping documents. Additionally, this chapter provides an introduction to several other industrial sectors that may offer RD&D opportunities for PIER. These sectors include chemicals, plastics & rubber, paper, machinery, printing, apparel, furniture, and textile mills. Figure 1-1 illustrates the annual electricity and natural gas consumption for these sectors. Figure 1-2 includes an economic comparison of these industries and the other manufacturing sectors covered in subsequent chapters. A brief summary of each sector is also included below for reference.

**Figure 1-1: 2008 Electricity and Natural Gas Consumption by Industrial Sector in California**

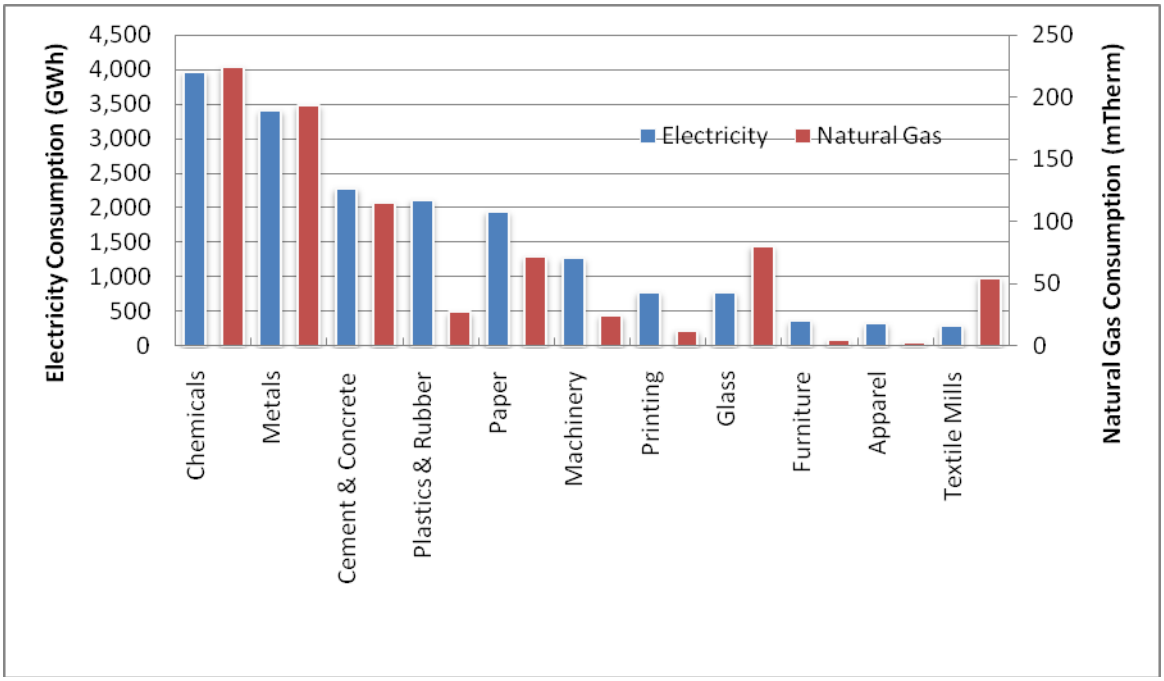
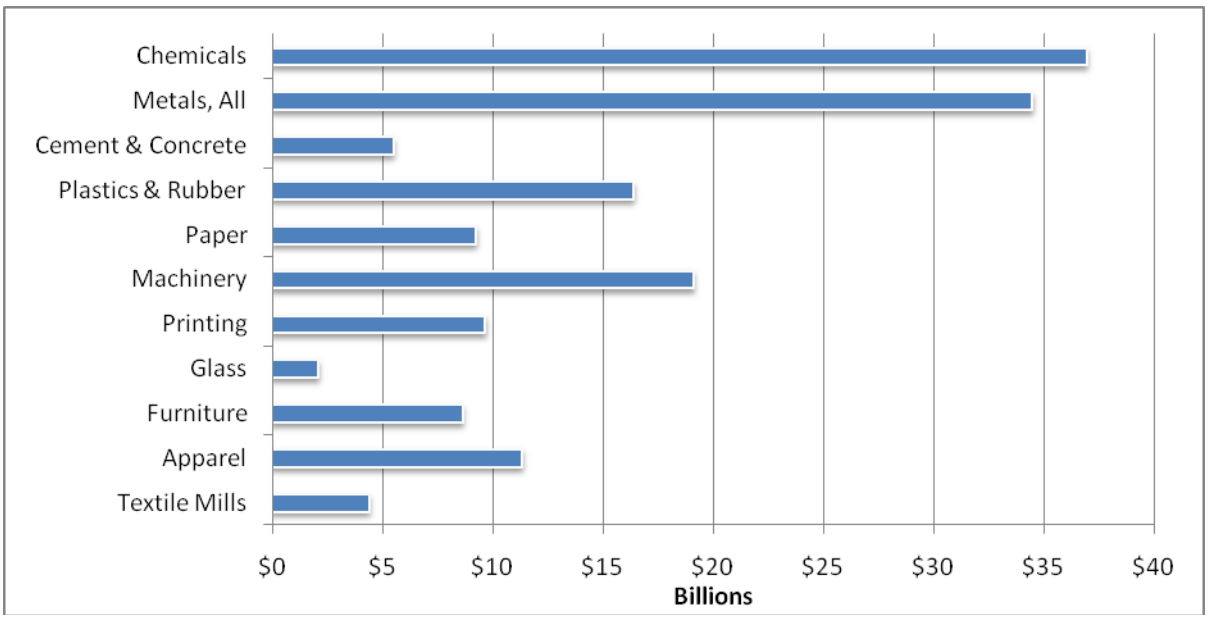


**Figure 1-2: Annual Shipments by Industrial Sector**




Other sectors for PIER to consider may include the following:

**Chemicals**[1]

Over 67,000 California residents are employed by the chemical industry (North American Industry Classification System (NAICS) code 325), which produces $36.9 billion in annual shipments across a broad range of subsectors including raw chemical compounds, fertilizers, pharmaceuticals, paints, cleaning agents and explosives. In 2008, the sector used 3,964 GWh of electricity and 224 million therms of natural gas, making it the most natural gas intensive sector in the state. Major chemical companies in California include Clorox, Invitrogen, Genetech, Bayer, Novartis, Roche, NBTY, Teva Pharmaceuticals, ICI Dulux Paints, Coit Cleaning & Restoration and Ampac Fine Chemicals.

**Metals**

Metals manufacturing in California encompasses both the primary metals and fabricated metals (NAICS codes 331 and 332) industries, and includes the smelting of raw ores and the manufacture of metals into intermediate or end products not included in the other sectors. In 2008, the metal industry used 3,404 GWh of electricity and 193 million therms of natural gas. In 2006, the industry shipped $34.5 billion in products. The industry employs approximately 166,000 state residents and major manufacturers include USS-Posco Industries, California Steel Industries and Aluminum Precision Products.

[1] Data on employment and value of shipments from US Census Bureau, Annual Survey of Manufacturers, 2006; data on Energy and natural gas usage from California Energy Commission, 2008; data on companies from California Employment Development Department.

**Cement & Concrete**
The cement industry (NAICS code 3273) includes the manufacture of cement, ready-mix concrete, and pipe, brick, and block materials. In 2007, the industry consumed approximately 1,500 GWh of electricity and 32 million therms of natural gas.[2] Energy use attributed to particular sectors of the cement industry was not available.

California's cement production accounts for 12 percent of the national total. The production of portland, natural, masonry, pozzalanic and other hydraulic cements employs approximately 2,000 state residents and had $1 billion in shipments in 2007. Although the cement industry consists of around 25 to 30 manufacturing sites, just eleven undertake full-scale cement production. These 11 sites account for 90 percent of the electricity use and 80 percent of the natural gas use attributed to cement production in California. The other sites are involved more in grinding and mixing.

Cement is a key ingredient in concrete products, an energy intensive subsector within the industry. The production of concrete products, including ready-mix concrete and pipe, brick, and block, employs approximately 20,000 residents through over 600 businesses and accounted for $4.4 billion in shipments in 2007.

**Plastics & Rubber**
With an annual product of $16.4 billion, plastics and rubber manufacturing in California (NAICS code 326) employs 75,000 residents. This industry uses 2,111 GWh of electricity annually and 27 million therms of gas for plastics compression, extrusion and injection molding machinery and equipment, and tire building and recapping machinery and equipment. Major plastic and rubber manufactures within California include Rehrig Pacific, Jacuzzi Whirlpool Bath and Esterine Kirkhill Elastomers.

**Paper**
The paper industry (NAICS code 322), responsible for the manufacturer of pulp, paper, and paper products, produces $9.2 billion in shipments and employs over 23,000 residents statewide. The sector uses 1,942 GWh of electricity and 72 million therms of natural gas each year. Companies with significant paper manufacturing operations in California include International Paper and Pactiv Corporation.

**Machinery**
California's machinery manufacturing sector (NAICS code 333) is a $19.1 billion industry that employs over 68,000 residents. Machinery manufacturing creates products that perform work for a variety of other industries and end-uses. This sector includes equipment for the agriculture industry, construction, mining, HVAC units, commercial refrigeration, metalwork, turbines and engine machines. As such, potential opportunities to engineer more energy and water efficient equipment could involve the participation of this sector. In its manufacturing process, this sector uses 1,265 GWh of electricity and 25 million therms of natural gas annually. Major California employers in the machinery

[2]LBNL, 2005, http://ies.lbl.gov/iespubs/59938.pdf.

manufacturing sector include Flextronics International, Hunter Industries, Jonathan Louis International, Brita Products, Northrop Grumman Marine Systems, Solar Turbines, and Potter-Roemer.

**Printing**

The California printing sector (NAICS code 323) is a $9.6 billion industry with more than 61,000 employees in California. This sector uses 774 GWh of electricity and 12 million therms of natural gas annually. Companies with significant printing operations in California include Quebecor Worldwide, Wopschall Printing, Trend Offset Printing and Omega Studios.

**Glass**[3]

Glass manufacturers produce containers, windows, glassware, light bulbs, and fiberglass for use by other industries or direct sales to consumers (NAICS code 3272). The California-based businesses in the industry consumed 771 GWh of electricity and 80 million therms of natural gas in 2008. Approximately 300 businesses employed nearly 10,000 residents and shipped $2.1 billion in products in 2006. The significant waste management strategies in place in California contribute to a lower overall energy consumption profile for the industry. Manufacturers of fiberglass must use at least 30 percent post consumer waste and glass food, drink and beverage containers must use at least 35 percent post consumer waste in their products. The state achieved a 74 percent recycle rate for glass containers in 2008, a waste stream that feeds directly into fiberglass and container production. The production of glass with post consumer waste content is less energy intensive than the production of glass from raw materials. Energy efficiency opportunities may still exist in other facets of the manufacturing process.

**Furniture**

The furniture manufacturing industry (NAICS code 337) is an $8.6 billion industry that employs more than 57,000 Californians. California is responsible for 10 percent of national furniture industry and the largest manufacturer is RB Industries. The furniture sector uses 356 GWh of electricity and 5 million therms of gas each year.

**Apparel**

The apparel sector (NAICS codes 315 and 316), which manufactures clothing and leather goods, is an $11.4 billion industry that employs approximately 73,000 across the state. This sector uses 320 GWh of electricity and 3 million therms of natural gas annually. California accounts for 31.3 percent of the total US production in this sector and major California companies include Guess? Licensing and American Apparel.

**Textile Mills**

Textile mills and textile product mills (NAICS codes 313 and 314) employ 22,000 Californians in a $4.4 billion industry. Textile mills account for 295 GWh of electricity use

[3] California Integrated Waste Management Board, 2009, http://www.ciwmb.ca.gov/glass/SupplyDemand.htm

and 55 million therms of natural gas usage annually. The largest textile mill in California is operated by St. John Knits.

## 1.3. Research Pathways

### *1.3.1. IAW Energy Systems*

**Table 1-2: IAW Energy Systems**

| IAW Energy Systems | | | | |
|---|---|---|---|---|
| | RD&D Opportunity | Description | Applicable Sector | Priority |
| 1 | Heat recovery | Research and development into low temperature heat recovery; improve performance and processing of degradation resistance materials used in heat recovery | Multiple industrial, especially energy intensive industries | High |
| 2 | Boilers | Develop advanced industrial boilers | Multiple industrial | High |
| 3 | Advanced heat generation | Improve heat generation systems; develop next generation of heating methods; develop hybrid gas/electric heating systems | Multiple industrial | High |
| 4 | Steam & related processes | Deploy steam technologies, more efficient steam systems & steam replacement systems | Multiple industrial | High |
| 5 | Air conditioning, cooling, and refrigeration | Develop and disseminate advanced and optimized cooling and refrigeration processes | Data centers<br>Laboratories<br>Clean rooms | High |
| 6 | Motors & adjustable speed drives (ASDs) | Increase implementation of efficient motor systems | Multiple industrial | Medium |
| 7 | Industrial Processes | Optimize evaporation, distillation , drying, sterilization , pasteurization, blanching and comminution | Multiple industrial | Medium |
| 8 | Heat & power integration | Develop innovative ways to supply heat and power to unit operations; demonstrate use of pinch analysis | Any large processing or manufacturing operation<br>Energy intensive industries | Low |
| 9 | Burners | Develop, demonstrate and disseminate high combustion efficiency burners with robust operating controls for harsh environments | Multiple industrial | Low |
| 10 | Furnaces | Design high efficiency furnaces | Multiple industrial | Low |
| 11 | Movement of product & materials | Identify opportunities to reduce energy use | Industrial, manufacturing | Low |

| | | | | |
|---|---|---|---|---|
| 12 | Materials | Research and development to reduce cost of advanced ceramics; field tests of monolithic ceramics | Ceramics | Low |
| 13 | Digital computing & communications equipment | Improve efficiency of high-tech equipment | Data centers | Low |
| 14 | Heat transfer cycle optimization | Optimize heat transfer cycle in batch and continuous and kneeling and heat treating processes | Metal industry | Low |
| 15 | Improve cost effectiveness of cooling devices for superconductors | Research on materials and methods used in pressure-die casting of copper rotors | Metal industry | Low |
| 16 | Improve environmental impacts of welding | Expand use of automation to reduce materials consumption of welding; increase use of alternative energy for welding; develop more environmentally friendly welding processes | Metal industry | Low |
| 17 | Near net shape/strip casting | Need to further demonstrate near net shape casting / strip casting technology at larger scales, improve process control, and develop the technology to apply to all metal products. | Metal industry | Low |

**Description of RD&D Opportunities**

**1. Heat Recovery:**

- RD&D on low-temperature heat recovery (200-300° F). Lower temperature heat recovery is more appropriate for California's industrial applications as the state does not have large steel or glass industries.
- Develop, disseminate and demonstrate cost-effective, compact, and corrosion resistant heat recovery equipment that is low temperature and can withstand high temperature (>500° F). This is a mid-term need (3-10 years).
- RD&D on corrosive flue gas environments.
- Develop low value energy/heat recovery approaches for thermal or electrical energy from difficult fluids (suspensions, contaminated or gummy streams, dehydration of liquid waste streams), from steam (low pressure or temperature steam), and from gases (combustible byproduct gases such as gas separation and recovery and gas cleanup gas treatment technology to enable use of plant gas instead of natural gas, hot gas cleanup, gases generated in metals and non-metallic minerals manufacturing, and industrial processes (the quenching and cooling of metals, lime mud reburning, cement calcining).
- Develop new and alternative heat recovery techniques, including heat pumps, heat transformers, thermo-chemical recuperation technologies for higher-temperature industrial processes (e.g., metals), thermally activated technologies,

innovative working fluids, innovative energy recovery cycles, chillers, and adsorption.

2. **Boilers:**
    - Develop advanced industrial boilers. Near term need to better integrate boilers with "smart" control systems and designs that capture waste heat. Mid-term need to develop design innovations as such gasification and fluidized beds.
    - Demonstrate ultra low-emission high efficiency boilers (e.g., superboilers). Improved boiler insulation and load control will lead to the largest natural gas savings.
3. **Advanced Heat Generation:**
    - Develop improved heat generation systems, such as smart burners, that adjust heat release profiles for process heating (3-5 years). Long-term need to develop the next generation of heating methods and hybrid gas/electric heating systems, including renewable resources.
4. **Steam and Related Processes:**
    - Deploy steam technologies (e.g., BP steam technologies developed by DOE).
    - RD&D to promote the use of more efficient steam systems and to find ways to replace steam (e.g., direct gas firing, electric heating, waste heat use).
    - Focus on steam-traps, as they have been neglected.
    - Develop innovative processing methods to replace or supplement traditional steam based processes, such as distillation, heating, and steam reforming processes.
    - Establish best practices for steam generation, distribution and recovery.
    - Develop and demonstrate reliable advanced steam trap/monitoring/replacement systems.
5. **Air Conditioning (HVAC) and Cooling:**
    - Develop and disseminate advanced and optimized cooling and refrigeration processes (e.g., avoid water cooling, blast freezing air velocity modulation, integrated hybrid refrigeration systems, improved facility design by improving efficient multistate cooling).
    - For data centers, laboratories and clean rooms: improve airflow, efficiency of CRAC units (e.g., more efficient fans, motors, use of variable speed compressors, etc), increase the use of "free cooling," promote the use of highly efficient air delivery systems. RD&D to manage data storage (e.g. backing up less critical data less frequently, consolidating storage locations to reduce consumption, putting less critical data on more efficient servers).
6. **Motors and Adjustable Speed Drives (ASDs):**
    - Increase implementation of efficient motor systems (building from existing national efforts).
    - Improve the efficiency of motors and ASDs, optimize all motor-driven systems (e.g., superconducting motors, single-phase motors, ASDs (100+ hp), and rewind practices) including pumps, compressors, and materials processors (grinders, mixers, crushers, sizers), and promote PM and WP motors.

- Obtain high quality, neutral advice on quality applications and disseminate existing information and software.

7. **Industrial Processes:**
    - Optimize and demonstrate the energy efficiency of energy intensive processes including evaporation, distillation, drying, sterilization, pasteurization, blanching, comminution (of ores/ other feed stocks in the mineral based industries such as cement and glass manufacture), etc.
8. **Heat and Power Integration:**
    - Mid-term need (3-7 years) to develop innovative ways of supplying heat and power to unit operations through more effective integration of unit operations with utility systems (e.g., heat integration analysis, entropic analysis, hydrogen cascading).
    - Demonstrate and disseminate the use of pinch analysis for the design of new processes and plants, including water recovery and efficiency, hydrogen recovery, batch processes.
9. **Burners:**
    - Near term need (0-3 years) to develop, demonstrate, and disseminate high combustion efficiency burners with robust operating controls for harsh environments, that are capable of adjusting operating parameters in real time for system efficiency and emission control (process heating), lower cost and with improved safety, reliability and maintenance.
    - Improve burner designs (e.g., better fuel and air mixing, minimize air volume of convection ovens) and innovative heat exchanger designs and geometries.
    - Mid-term need (3-5 years) for advanced incineration, pyrolysis, and/or gasification technologies for byproduct reuse (e.g., solid waste).
    - Mid-term need (3-5 years) for improved heat transport and transfer systems for gas to gas, gas to liquid, and liquid to liquid heat transfer (e.g., coefficients, lean-premix burners, swirl burners, pulsating burners, and rotary burners).
    - Develop technology and applications for improved energy transport (including waste energy).
10. **Furnaces:**
    - Long-term need (5-10 years) to design high efficiency furnaces (e.g., EAF) and create innovative new furnace design through better fundamental understanding of combustion and scale-up. Improve furnace design through fundamental understanding of heat generation (combustion or other methods), heat transfer, controls, and use of advanced material that would reduce energy use.
11. **Movement of Products and Materials:**
    - Identify opportunities to reduce energy use in the conveyance/transportation of raw materials, in-process product, final product, equipment, staff, and other resources.
    - Educate users on opportunities to reduce the size / improve the proportionality of outdated equipment (e.g., oil/injection pumps and other lifting equipment in the petroleum extraction industry).

12. **Materials:**
    - Mid-term need (3-5 years) to develop, improve the performance of, optimize the processing of, and demonstrate degradation resistant materials that can withstand high-temperature and high corrosion conditions, such as waste streams used in heat recovery systems.
    - RD&D can focus on alloy composites for process heating (e.g., tungsten alloys in reaction vessels, iron chromium alloys).
    - Improve materials to line the gasification reactor and develop cheaper, more efficient, and more reliable construction materials.
    - Near term need (0-3 years) for RD&D that can reduce the cost of advanced ceramics and component field tests to demonstrate that monolithic ceramics increase component life with near or better performance and reliability than metal alloys.
13. **Digital Computing & Communications Equipment:**
    - Improve energy efficiency of high-tech equipment (e.g., servers, networking and telecommunications) through the development of codes, standards, design and analysis tools, and control systems.
    - Develop design guides to improve efficiency of data rooms.
14. **Heat Treating:**

    Optimize the heat transfer cycle in batch and continuous and kneeling and heat treating processes in metal processing.
15. **Superconductor Cooling:**
    - Need to reduce costs, need research on the materials or methods used in pressure-die casting of copper rotors, on the best cooling devices for superconductor motors.
16. **Welding:**
    - Improve material and energy consumption by increasing use of automation/robots, alternative energy, and reduced post-welding processing.
    - Develop new welding processes and filler metals, utilize weldable alloys, environmentally friendly welding processes with low-weld fume emissions and spatter generation, and formulate innovative filler materials.
17. **Near Net Shape / Strip Casting*:***
    - Demonstrate near net shape casting / strip casting technology at larger scales, improve process control, and develop the technology to apply to all metal products.

### *1.3.2. Energy & Greenhouse gas (GHG)/Emissions Optimization*

**Table 1-3: Energy & GHG Emissions Optimization**

| Energy & GHG/Emissions Optimization | | | | |
|---|---|---|---|---|
| | RD&D Opportunity | Description | Applicable Sector | Priority |
| 18 | Flexible fuels | Research, develop, demonstrate and integrate renewables into industrial systems; fuel switching strategies for electricity, natural gas and renewables | Food processing<br>Other energy intensive industries | High |
| 19 | GHG/Emission support | Develop strategies and tools to help GHG emitters comply with mandates and regulations; identify synergies between energy efficiency and emissions reduction; develop best practices for small and medium sized plants | Industries with GHG emissions and regulatory burden (energy intensive industries)<br>Small & medium sized facilities | High |
| 20 | Environmental equipment | Reduce cost of environmental equipment such as higher efficiency compact emission scrubbers | Cement & ceramics industries<br>Metal industry<br>Other point source emissions producing industries | Medium |
| 21 | Low emission combustion | Develop & disseminate combustion technologies that reduce emissions and increase efficiency and heat transfer | Energy intensive industries | Low |
| 22 | Alternative fuel processing | Develop alternative fuel processing technology to meet future low sulfur requirements | Fuel & biofuel processing | Low |

**18. Flexible Fuels:**

- Improve the integration of renewables into industrial systems.
- Demonstrate the application of flexible fuels on industrial applications. Fuel switching strategies for electricity, natural gas and renewables, (e.g., gas turbines that burn multiple fuels (by 2010), feed biomass into pyroprocessing equipment, alternatives to hydrogen production (by 2020)).
- Mid-term need (3-5 years) to improve methods for stabilizing low-emission flames.
- Integrated demonstrations of industrial efficiency, distributed generation, and building efficiency.
- Mid/long-term need (3-10 years) to develop technology that uses biogas and/or solar energy for preheating processes (biogas recovery, solar energy for water or air pretreating, solar industrial process heat).
- Technologies need to have low emissions and a low corrosion rate on the process.
- In cement processing, demonstrate the use of dry-biosolids from wastewater as a fuel substitute and replace coal with alternative fuels (e.g., tires).

**19. GHG/Emissions Support:**

- Identify synergistic opportunities and tradeoffs between energy efficiency and emissions (non-$CO_2$) reduction in the industrial sector.
- Identify GHG emitters, identify issues associated with different manufacturing applications, and develop strategies and tools to comply with greenhouse gas emission reduction mandates and other environmental regulations.
- Conduct analyses to support emissions decision making (e.g. how do various energy efficiency measures compare to buying credits) and develop an emissions (GHG, other) best practices guide for small to medium plants including alternative GHG approaches (e.g. purchasing credits).
- Identify more creative means to reduce GHG from non-energy intensive industries in Silicon Valley.
- Critical need in the short-term to address monitoring & verification (M&V) – How can industry ensure it gets credit for near-term actions? Specialize in offering technical expertise in this area, especially to support other efforts such as ARB's technical advisory committee to identify GHG technology and determine the interplay between efficiency and emissions.

**20. Environmental Equipment:**

- Near term need (0-3 years) to reduce the cost of environmental equipment (e.g., higher-efficiency high-temperature gas clean-up systems to remove sulfur, alkali metals, and dust; compact emission scrubbers and catalytic converters for industry (0-3 years) and $N_2$ filter for combustion air and fuel (by 2020).

**21. Low-Emission Combustion:**

Mid-term need (3-5 years) to develop and disseminate combustion technologies that simultaneously reduce emissions (e.g., CO, $CO_2$, PM, NOx), increase efficiency, and increase heat transfer; should be specific to energy intensive industries.

**22. Alternative Fuel Processing:**

- Develop alternative fuel processing technology to meet future low sulfur fuel requirements.
- Long-term need (5-10 years) for the desulfurization of fuels through less energy intensive biotreatment processes to eliminate hydrotreatment (e.g., develop biofeedstocks, biocatalytic desulfurization, bacteria that can reduce the sulfur content of gasoline).
- Technology needs to withstand process upsets and varied conditions, be capable of handling necessary fuel flow rates, and achieve biocatalyst stability, oil-water separation and product recovery.

### *1.3.3. Process Measurement, Diagnostics & Optimization*

**Table 1-4: Process Measurement, Diagnostics, and Optimization**

| Process Measurement, Diagnostics and Optimization | | | | |
|---|---|---|---|---|
| | RD&D Opportunity | Description | Applicable Sector | Priority |
| 23 | Energy Management Systems (EMS) | Improve monitoring and verification systems to make better use of EMS; optimize existing EMS in facilities; develop, validate and demonstrate cross-sector and industry specific EMS | Any that uses or could use EMS | High |
| 24 | Advanced Sensors & Controls | Improve metering instruments and understanding of energy consumption at facility level; develop inexpensive, reliable and multi-functional integrated sensors and control systems for multiple purposes; improve and promote advanced control and power technologies | Multiple industrial, especially energy intensive industries | High |
| 25 | Optimized Pumps, Fans, Compressed Air | Demonstrate standardized system optimization tool; develop case studies to assess potential efficiency impacts of technologies | Multiple industrial | High |
| 26 | Retro-commissioning | Ensure ongoing operation of new and retrofitted industrial processes and systems | Any that uses EMS, advanced sensors and controls, GHG/emissions monitoring technologies | Medium |
| 27 | Software and Tools for System Optimization | Create California-specific plant-wide tool to assess energy flows (from DOE tool) and certify energy efficiency improvements; develop and improve quality control software and tools | Any industrial or manufacturing plant, especially energy intensive industries | Medium |
| 28 | Automation and Information Processing | Improve automation for maintenance, diagnostics, scheduling and planning technologies; develop data acquisition, analysis and verification technologies | Multiple industrial, especially highly mechanized and automated industries | Medium |
| 29 | Robotics | Integrate sensors, information processing and controls into robotic systems; increase use of energy efficient robotics; develop efficiency standards for robotics | Multiple industrial, especially hazardous environments | Low |

23. **Energy Management Systems (EMS):**
    - Need RD&D to improve M&V systems in order to better monitor EMS savings and understand the potential from EMS systems (utilities need to know these numbers in order to offer comparable incentives for EMS). Optimize existing EMS systems in industrial facilities.
    - Near term need (0-3 years) to develop cross-sector and industry specific Energy Management Systems (EMS) that are user-friendly, simple, and low-cost (e.g., artificial intelligence, neural networks, rule-based systems, total site energy monitoring and management systems).
    - Validate and demonstrate EMS in order to develop the market. Develop a cost-effective sales tool that is more attractive to small and medium sized customers. Integrate EMS with broader Enterprise Asset Management (EAM) systems.
24. **Advanced Sensors and Controls:**
    - Improve instrumentation for better metering of energy use in industrial processes (e.g., development of low-cost meters) in order to monitor energy consumption per unit of production.
    - Help plants understand energy consumption after each shift and the consequences of using too much energy.
    - Opportunity to improve quality measurement systems (e.g., cross-belt analyzers in cement). RD&D must be customized to each plant.
    - Develop new, integrated sensors and control systems for multiple uses (e.g., to detect flames, particle processes, hot liquids, product materials, emissions, process heating, temperature, ventilation, product quality, combustion, part time occupancy) that are inexpensive to install, reliable, and with increased capabilities, including real-time, intelligent, wireless, distributed sensor networks, online, non-intrusive, and resilience against high temperatures and aggressive environments (e.g., optical, ultrasonic, acoustic, and microwave systems.
    - Need training, lab testing, and commercial scale demonstrations in multiple industrial applications.
    - Need to improve advanced control and power technologies (e.g., adopt distributed control systems (DCS), multi-variable controls, variable speed drives (VSD), ASDs, full variable speed controlled areas in refineries) and promote their use through partnerships with companies and institutions, demonstrations, trainings, life-cycle costing techniques, and system oriented control and power standards. Use sensors and controls to achieve peak load management/demand response.
25. **Optimized Pumps, Fans, and Compressed Air:**
    - Need to move toward a standardization of system optimization tools applicable across industries. RD&D should focus on demonstrations.
    - Need to develop the market (e.g., through customer awareness, the promotion of successful applications) for system/plant-wide optimization techniques (e.g., measurement and diagnostics) and industrial energy management systems such as Enterprise Energy Management Systems (EEM) and EAM.

- Need pump system optimization in electric motor-driven systems, new technology developments in pumping (e.g. dry vacuum pumps), power technology (e.g. adjustable speed drivers (ASD) and power electronics) and compressors, as well as case studies, training, and dissemination. Specifically, need case studies to assess the potential energy savings from integrating variable flow pumping to variable flow chillers with hydraulic pumping systems.
- Need optimized fan and compressed air systems.

**26. Retro-Commissioning:**

- Ensure new and retrofitted industrial processes and systems operate, and continue to operate on an ongoing basis, at the design energy performance specification.
- Includes energy performance measurement and management and the development of analytical tools (e.g., software) and best practices to ensure industrial systems are optimized and operating efficiently, and according to original performance specifications.
- Need M&V for quantifying GHG savings from projects.
- Support the California Air Resources Board (ARB), which lacks staff to focus on this, but which is necessary to implement AB 32.

**27. Software and Tools for System Optimization:**

- PIER should build from the Department of Energy's (DOE) plant-wide tool to assess energy flows, to make it specific to California industries. Can develop protocols for system assessment, and work with DOE's program to certify plants for energy efficiency.
- Near term need (0-3 years) to develop quality control software and desktop tools to aid plant staff in identifying, prioritizing, and presenting energy savings opportunities to management (e.g., all-in-one tool for industrial end-users, software to help end-users understand where energy is used, diagnosis software for small/medium facilities, process design optimization tool, process simulation software, software to learn and predict performance, software to reduce waste/reprocessing, allow plants to operate in a narrow range of quality, peak shaving, load management).
- Need to improve the accuracy of these tools through the collection of physical data and model validation (0-3 years).
- Near term need (0-3 years) to develop a component base model to identify and analyze energy efficiency opportunities for common processes (emerging technologies, process heating, heat recovery, etc). Models must quantify the total benefits of energy efficiency projects (e.g., productivity gains, improved system reliability, increases in capacity that could result from implementing advanced control and power technologies, and a reduction in manufacturing costs), including the modeling of payback calculations that includes ancillary savings and production benefits, (e.g., methodology that yields a more comprehensive Cost of Conserved Energy).

28. **Automation and Information Processing:**
    - Need improved automation for maintenance, diagnostics, scheduling, and planning technologies for multiple industries; automate the sense-inter-act loop to achieve operator independent plant optimization.
    - Improve information processing, data mining and machine learning for predictive modeling and anticipatory product quality assurance.
    - Develop means for data acquisition, transformation into useful information, and use the information for improved process design, operation, energy minimization, and quality control (e.g., energy informatics, chemometric methodologies).
    - Need research results on data reconciliation, data rectification, sensor/automated fault detection and diagnosis, etc – anything to ascertain data integrity.
29. **Robotics:**
    - Integrate / incorporate sensors, information processing, and control systems into robotic systems, and use energy efficient robotics to carry out additional production tasks and solve production problems.
    - Develop efficiency standards for robotics (e.g., Energy Star).

### *1.3.4. Market Mechanisms*

**Table 1-5: Market Mechanisms**

| Market Mechanisms | | | | |
|---|---|---|---|---|
| | RD&D Opportunity | Description | Applicable Sector | Priority |
| 30 | Best practices | Tailor best practice guidelines to specific industries and sectors; develop case studies for specific industries and sectors | Multiple industrial | High |
| 31 | Peak Low Management, Demand Response Programs | Improve peak load management and demand response opportunities and costs | Target "second round" of industrial candidates | High |
| 32 | Institutionalize efficiency culture | Develop institutional support for energy efficiency through regular workshops, educational resources and tools; develop methodologies to asses/model decision-making behavior; develop business case for energy efficiency within specific industries and sectors | Target industries with greatest energy savings potential per customer Multiple industrial | Medium |
| 33 | Standards, Benchmarks, ISO14000 | Create industrial systems efficiency and emissions codes, standards and/or benchmarks create a framework that makes energy efficiency an integral part of typical industrial operating practices | Multiple industrial | Medium |
| 34 | Industry & policy analysis | Identify barriers and solutions to achieving energy conservation in | Any industry with significant California presence | Medium |

| | | | | |
|---|---|---|---|---|
| | | California industries; develop case studies and integrated policy framework that reflects multiple stakeholder goals; support development of government incentives | | |

**30. Best Practices:**

- Tailor best practices guidelines to specific industries and areas (e.g., fruit canners, drying processes for forest processing industry). Best practices are currently for generic systems. Develop case studies for specific industries.

**31. Peak Load Management / Demand Response (DR) Program Opportunities:**

- Need to better understand peak load management/DR opportunities and costs for specific energy user groups and how best to package peak load management / DR opportunities in a way that makes them more understandable and compelling to busy energy managers.
- Target the "second round" of candidates for participation.
- Develop an all-in-one tool for industrial end-users. Manage production processes that lend themselves to scale-down (e.g., non-interrupting DR).
- Develop a body of information on compatible instrumentation for industry. Explore the use of different fuels to achieve peak load management and DR.

**32. Institutionalize Efficiency Culture:**

- Develop institutional capacity to support energy efficiency (e.g., through regular exchange of information on energy-efficient practices and technologies). Provide up to date hands-on training workshops for industry professionals and operations and maintenance (O&M) staff, including the development and dissemination of new and existing educational resources and tools (e.g., case studies, guides, software, web-based data) to help users understand the proper application and operation of equipment and use existing energy analysis tools. Efforts should focus on those industries with the greatest energy savings potential per customer effort.
- Enable the sharing of information throughout industry about new technologies (e.g., through targeted energy showcases and expos to connect suppliers, developers, and users).
- Need to develop commonly acceptable methodologies to assess and model decision-making behavior.
- Need to differentiate between the decision-making processes in different industry sub-sectors; to accomplish this, need a better understanding of the decision-making process of business management and the financial benefits of EE, pollution prevention, and enhanced productivity, in order to make a compelling case to business management. This means understanding the interrelationships of various forms of efficiency, and measuring costs and benefits so that the financial ramifications of EE proposals are fully understood and can be communicated to management in terms with which they can identify.

**33. Standards/Benchmarks/ISO14000:**

- Update individual component standards; create industrial system efficiency and emissions standards/codes/benchmarks, e.g., link ISO 9000/14000 quality and environmental management systems and industrial system optimization.
- Create a framework that includes energy efficiency standards, policies, training, and tools that have the net effect of making system optimization for energy efficiency as much as part of typical industrial operating practices as waste reduction and inventory management.
- Need a framework that employs training, implementation of standards for efficient operation of energy systems, and integration of system optimization practices into a company's existing operating paradigm.

**34. Industry and Policy Analysis:**

- Need to identify the barriers in California to achieving energy conservations and strategies to overcome them.
- Develop the analytical database for the industrial sector (e.g., analysis of business cycles, retirement rates, investment policies, age distribution of main energy consuming processes, characterize equipment loads, tools to analyze supply chain efficiency, development of supply curves).
- Need a detailed evaluation of the effects (e.g., competitiveness, diffusion of innovation technologies) and (cost-) effectiveness of industrial energy efficiency policies, including case studies and the development of models that can explicitly model policies and clarify the link between policies and actions.
- Need an integrated policy framework accounting for the different characteristics of decision makers, technologies and sectors.
- Mid-term need (3-10 years) to support strategic thinking by government on incentive spending in a conflicting regulatory environment (e.g., investigate offering financial incentives for state-of-the-art equipment, tax credits) and develop tools to manage policy uncertainty, market risks and energy/emissions price volatility.

# 2.0 Natural Gas

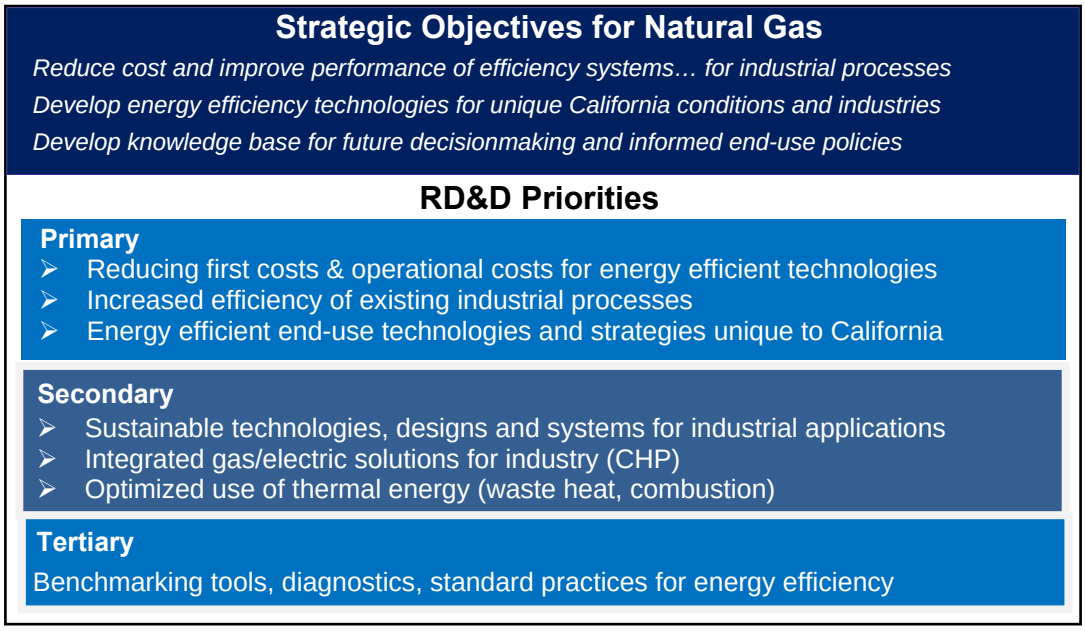
## 2.1. Introduction

Published in 2007, *Technology for Reducing Natural Gas Use in California Industry* sought to respond to higher overall demand and spikes in demand for natural gas. When combined with the constrained supplies of natural gas and growing potential for price volatilities, the need to reduce consumption of natural gas use is a critical challenge requiring innovative solutions.

The PIER IAW program focuses on improving energy efficiency in the natural gas sector and ensuring the availability of reliable energy supplies. The industrial sector in particular is a major energy consumer and one of the largest users of natural gas in the state, accounting for about 23 percent of total use in 2006.[4] Consequently, industry represents a logical target for improving the efficiency of natural gas use through the adoption of new technologies and improved energy management practices.

Recognizing the importance of industrial end-uses in reducing natural gas demand, PIER has defined strategic objectives that directly impact these sectors (Figure 2-1).[5] Preliminary solutions identified by PIER as being relevant to the industrial sector range from reducing first costs and operational costs for energy efficiency technologies to unique and innovative technology development and sustainable processes.

**Figure 2-1: PIER Strategic Objectives for the Natural Gas Relevant to California Industry**




4 California Energy Almanac, 2006.

5 PIER, "2007-2011 Natural Gas Research Investment Plan", CEC-500-2006-CMF. 2006.

To achieve strategic objectives for natural gas and in keeping with PIER priorities, the IAW program identified and evaluated some of the major technology areas that may contribute to improving the efficiency of natural gas use in California's industrial sectors. This report outlines the methods used to identify technologies, key potential areas of application, technical limitations that need to be addressed, and the potential role of government in pursuing RD&D to accelerate adoption within California industries.

## 2.2. Methodology

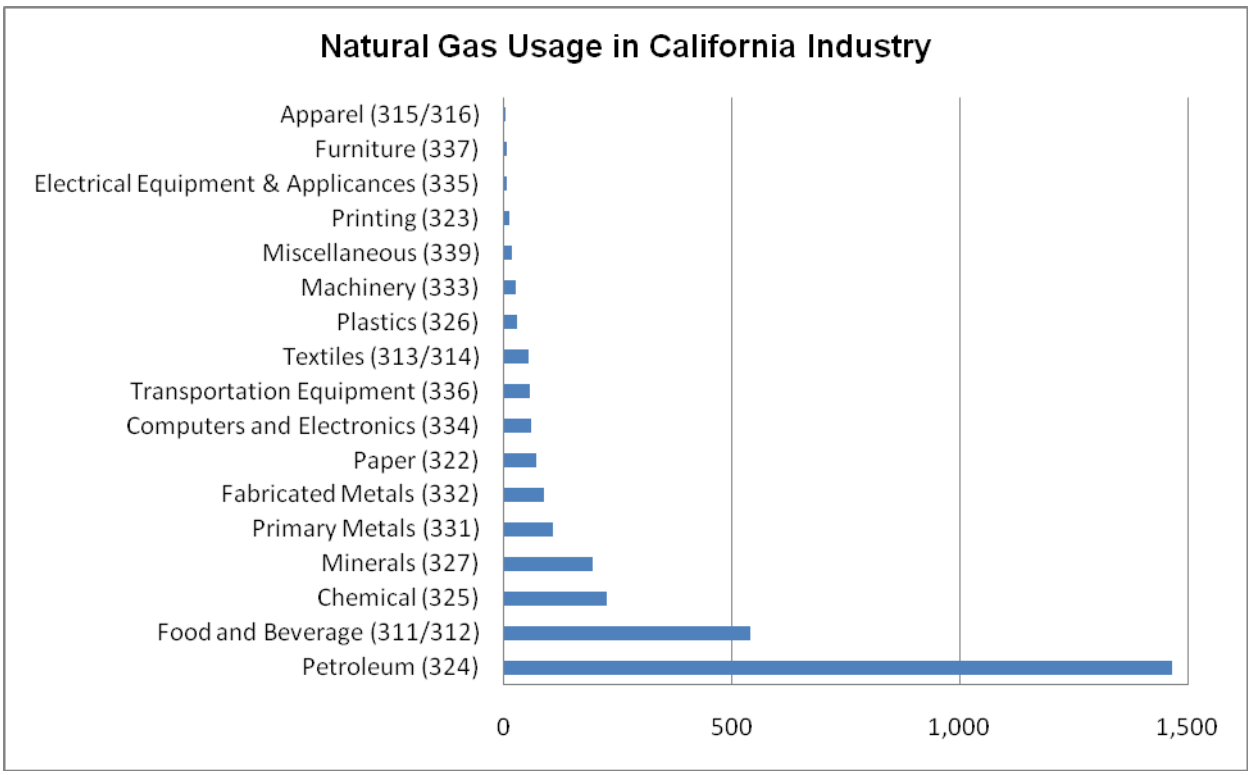
A three-fold approach was used to identify and evaluate the technology platforms with the most promise for reducing natural gas use in California industries:

1. Identify the major natural gas-using industries and industrial processes in California.
2. Review the technology priorities for California industries based on recent studies, industrial technology roadmaps, and other strategic activities.
3. Select the most promising options for reducing natural gas used based on expert opinion, ranking technologies according to energy efficiency, environmental impacts (including reduction in greenhouse gas emissions), economics, government role, and other factors.

### *2.2.1. Role of Natural Gas in California Industries*

Nearly every industrial sector in California relies in some way on natural gas. As shown in Figure 2-2, the use of natural gas in California industry is dominated by a relatively small set of industrial sectors. The largest users include food processing, printing, and manufacture of electronics, transportation equipment, fabricated metals, furniture, chemicals, plastics and machinery. Based strictly on magnitude of consumption, these sectors represent prime areas of opportunity for reducing industrial natural gas use.

**Figure 2-2: 2005 Natural Gas Use in California Industry**[6]




Specific operations and product segments within industries can also be identified as major contributors to natural gas use. Within food processing, for example, canned and dehydrated fruits and vegetables account for a significant share of natural gas use, due to drying and steam processing operations. Paper and paperboard mills account for a large share of natural gas use in the forest products industry, primarily due to heat used for drying and water evaporation.

Understanding how, and not just where, natural gas is used in California industry makes it possible to focus on opportunities and take advantage of ways to expand the potential benefits. While allocations differ across industrial sectors, process heating and steam generation represent the primary uses of natural gas in California industry. Together these two uses account for about 85 percent of industrial natural gas use and represent a significant opportunity for realizing efficiency gains. Boilers (steam generation) account for about half of the natural gas used for process heating. The other half is used in a wide range of process heaters that serve a multitude of functions, from melting to forming to drying.[7]

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[6] California Energy Commission, Analysis Office, 2008.

[7] PG&E, "California Industrial Energy Efficiency Market Characterization Study", 2001. http://www.calmac.org/publications/California%20Ind%20EE%20Mkt%20Characterization.pdf

The major industrial process heating operations are shown in Table 2-1. The technologies in use for process heating are quite diverse and often have characteristics that are unique to the product being manufactured. Food processors and paper manufacturers, for example, both have extensive needs for water removal, and these are met by very different process heating systems designed to fit the unique needs of the product. Separation processes (e.g., distillation, evaporation, drying, extraction, crystallization) are used in many industries and account for a significant portion of process heating needs.

As shown in Table 2-1, the temperature regimes at which process heating takes place are highly diverse even within categories. Despite the characteristics that distinguish these processes, there may also be commonalities (e.g., burners, refractory materials) where technology improvements could benefit multiple industries.

**Table 2-1: Major Process Heating Operations[8]**

| Major Process Heating Operations | | | |
|---|---|---|---|
| **Process** | **Temperature Regime (°F)** | **Description** | **Typical Applications** |
| Fluid Heating | 150-800 | Heating of liquid or gas to raise its temperature without significant vaporization or separation of its constituents | Heating of water, oil and natural gas production, petroleum crude refining (coking, hydrotreating and cracking), chemical feedstock preheating |
| Boiling or Distillation | 300-1000 | Vapor generation from water or other liquid | Steam generation, separation of chemicals or petroleum fractions, steam injected fractionation |
| Drying | 200-700 | Removal of physically mixed water or other liquid from material | Drying of lumber, paper, paint, ore, grain, food products, animal feed, chemicals, rubber, plastic, glass products |
| Curing and Forming | 300-2500 | Heating of material (to promote binding of constituents or changing strength ) for further processing | Heating of plastic, rubber, bricks, ceramics, glass (annealing, tempering), gypsum, refractory firing |
| Metal or Non-Metal Heating | 200-2500 | Raising temperature of the metallic or non-metallic material for further processing | Heating of steel (soaking, reheat, ladle preheating), aluminum, or other materials for rolling, forging |
| Metal Heat Treating | 400-2500 | Heating of material to change its structure and/or composition in air or in presence of special gas mixture (atmosphere) | Heat treating of steel or aluminum to make it soft or hard (annealing, stress relief, tempering, solution heat treating, aging, precipitation hardening) |
| Metal Melting | 800-3000 | Heating of metal to change from solid to liquid form | Melting of steel, aluminum, copper, and other materials in furnaces |

[8]Energetics Inc, "Energy Use, Loss and Opportunities Analysis: U.S. Manufacturing", 2004.

| | | | |
|---|---|---|---|
| Non-Metal Melting | 1500-3000 | Heating of non-metallic material to change from solid to liquid form | Melting of glass, salts, non-metallic minerals |
| Calcining | 1500-2000 | Heating of material (mostly non-metallic) to remove chemically bound water | Lime, ore, cement, soda ash, alumina, gypsum |
| Smelting | >2000 | Heating of material-ore in presence or mixed with other material (carbon) to produce molten metal | Iron ore, copper, lead, and zinc ore smelting |
| Agglomeration - Sintering | >2000 | To heat material to produce material that is fused or "agglomerated" by the effect of high temperature | Powder metal, iron ore palletizing, zinc |
| Other | 200-500 | To heat material for a variety of end-uses or processing | Frying, cooking, baking, textiles (dyeing, setting) |

### *2.2.2. Technology Review and Selection*

To produce a preliminary list of technologies with the potential to reduce natural gas use in California, a number of studies, technology roadmaps and other reports were reviewed. Additionally, technology experts in process heating and steam generation were consulted to provide input on the technical performance characteristics, current status and other aspects of these technologies. Three primary areas for consideration emerged from this process:

- **Industrial Energy Systems** – systems used to generate and supply energy to processes, including steam systems and process heaters (direct and indirect fired)
- **Process Measurement, Diagnostics and Optimization** – equipment, processes and practices to enable better monitoring and management of energy use, as well as process innovations to optimize energy use
- **Renewable Energy for Greenhouse Gas Reduction** – alternative, renewable energy sources for both process heating and on-site electricity generation

Based on a review of the literature and expert inputs, a set of technology areas within each of the areas above was identified for review and relative ranking. The taxonomy of the fifteen technologies selected is shown in Table 2-2, organized by five key technology platforms. The characteristics of these technology platforms, current limitations or challenges, possible industrial applications, and potential role for PIER/IAW are described in detail in the remaining sections of this report.

**Table 2-2: Candidate Technologies for Industrial Natural Gas Reduction**

| Candidate Technologies for Industrial Natural Gas Reduction |
|---|
| **Industrial Energy Systems**<br>Heat Recovery<br>• Very Low Grade (-40 to 250°F) Heat Recovery<br>• Low Grade (250 to 500°F) Heat Recovery<br>• Mid- to High-Grade Heat Recovery (500 to1400°F and higher)<br>• Heat Loss Reduction<br>• Enhanced Heat Transfer<br>• Combustion Systems Improvement<br>• Advanced Natural Gas Burners<br>• Fuel Flexibility |
| **Process Measurement, Diagnostics and Optimization**<br>• Optimization of Energy Management<br>• Energy Metering and Monitoring<br>• Energy Efficiency Assessment and Analysis Tools<br>• Financial Analysis Tools<br>• Process/Product Innovation and Optimization<br>• Advanced Controls<br>• Innovative Processes<br>• Non-thermal Energy Alternatives |
| **Renewable Energy for Greenhouse Gas Reduction**<br>• Renewable Energy Sources<br>• Alternative Fuels<br>• Solar and Other Renewables for Electricity and Heat |

A set of experts knowledgeable with the technologies and applicable industries conducted a technology ranking exercise. Technologies were ranked on a scale of 1 to 5 using the criteria shown in Table 2-3, with the highest possible score for a single technology being 60 points.

**Table 2-3: Technology Relative Ranking Criteria**

| Technology Relative Ranking Criteria | |
|---|---|
| **NATURAL GAS REDUCTION** | |
| Energy Efficiency | Relative potential to improve efficiency of systems using natural gas |
| Alternative Energy Source | Substitution of alternative, waste or byproduct fuels to reduce natural gas use |
| Cross cutting (OR multiple) Industrial Applications | Technology has application to large number of industrial sectors in California |
| Fuel Flexibility | Ability to use multiple fuels |
| **ENVIRONMENTAL IMPACTS** | |
| Climate Change | Reduction in emissions of carbon dioxide, nitrous oxides, methane or other greenhouse gases |
| Criteria Air Pollutants | Reduction in emissions of carbon monoxide, particulates, volatile organic compounds, nitrogen oxides or sulfur oxides |
| **RISK** | |
| Technical Risk | Level of technical barriers to overcome to achieve acceptable performance (5 = High Risk) |
| Timeframe for Development | Near-term (0-2 years) = 1; Mid-term (2-5 years) = 3; Long-term (5 or more years) = 5 |
| Cost/Economics | Range of cost, with the highest cost = 5; or long paybacks > 3 years = 5 |
| **GOVERNMENT ROLE** | |
| Policy Supports | Technology RD&D is supported by existing California energy policies |
| Pre-competitive RD&D | Technology requires precompetitive RD&D that has little likelihood of being funded by a single company |
| Societal/External Benefits | Technology will provide societal or other benefits that are not necessarily attractive to private investors, but serve the public interest |

**Natural gas reduction** was considered a priority for the ranking exercise. This included direct reduction of natural gas through efficiency or other improvements, as well as alternatives to natural gas or capability for substitution of alternatives. Technologies that were considered to be more widely applicable across sectors (cross-cutting) or even more generic in nature were given additional points for potential replication of benefits in more than one industry.

**Environmental** criteria included both the reduction of pollutant emissions that contribute to smog and low-level ozone (those regulated under the Clean Air Act and its Amendments), as well as greenhouse gases related to the combustion of fuels (primarily carbon dioxide). This supports California policies and legislative actions to reduce GHG emissions throughout the state.

**Risk** was considered in the context that it is indicative of a role for government-supported technology RD&D, which can reduce commercial risk. Technology RD&D, for example, can reduce technical risk and increase economic acceptability, paving the way for accelerated movement of the technology into the marketplace. Timeframe for development is also

indicative of risk (e.g., longer term development equates to higher technical and market risk) and suggests a potential role for government support.

**A government role** is an important factor in identifying technology RD&D that could potentially be supported by the PIER/IAW program. A government role can be justified and measured by the existence of supportive government policies, the need for very high risk, pre-competitive RD&D, or the potential for societal benefits that are in the public interest but not necessarily valued by investors.

The results of the ranking exercise are shown in Figures 2-3 (by total score) and Figure 2-4 (in terms of relative impacts on natural gas reduction). Over half of the technologies selected could have a relatively high impact on reducing the use of natural gas in California industries.

**Figure 2-3: Results of Technology Ranking – Total Scores**

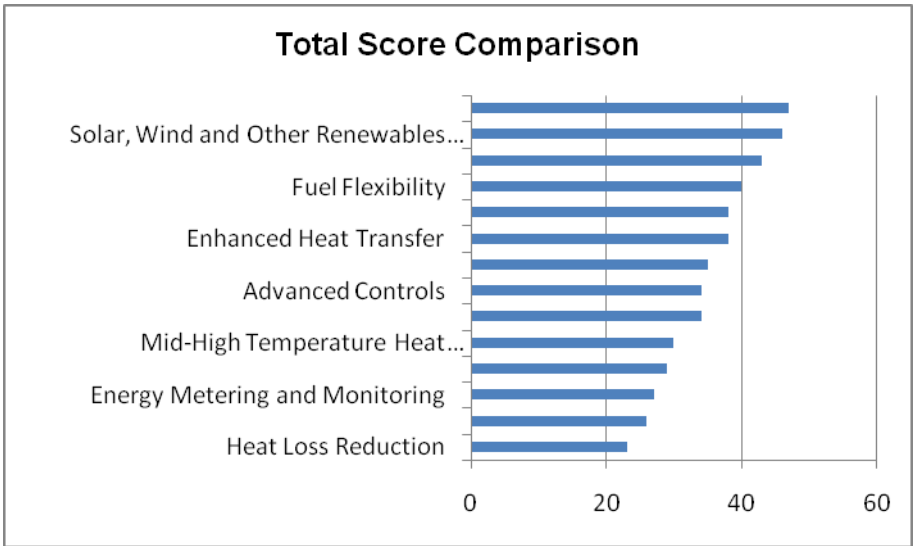
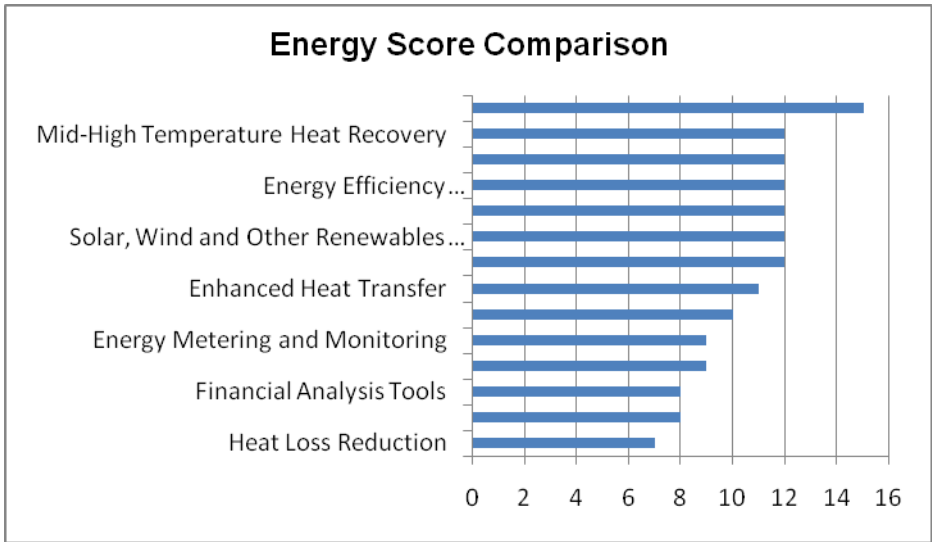



**Figure 2-4: Results of Technology Ranking – Energy Scores**



### *2.2.3. Relevant Government Policies and Programs*

There are a number of major legislative and policy instruments that directly or indirectly support RD&D or provide incentives relevant to the technology platforms described in this report (see Table 2-4). The Warren-Alquist Act, for example, is an overarching piece of legislation that provides support for all PIER IAW activities, and specifically for energy efficiency and renewable energy technologies. Similarly, the Energy Policy Report is a publication required by California law to recommend energy policy and define the issues to be addressed. It is directly relevant to technology development, and is updated every year to reflect new trends and emerging challenges.

Numerous other policies exist to guide and support specific technology RD&D efforts, such as those that reduce emissions of greenhouse gases, or provide targeted incentives for renewable technologies such as solar energy and wind power. Some call for initiatives or programs oriented to energy issues unique to specific regions within California as well as surrounding states.

**Table 2-4: Selected California Policies and Programs Impacting Industrial Natural Gas Reduction Technologies**

| Selected California Policies and Programs Impacting Industrial Natural Gas Reduction Technologies | |
|---|---|
| **Name** | **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. |
| Energy Policy Report | Recommends and defines energy policies for California. Recommends evaluation and monitoring of natural gas efficiency programs, and incorporating results of critical natural gas research into the state's efficiency programs. Endorses the deployment of new technology and guidelines for navigating efficiency programs. Promotes the recycling of waste heat, and potentially recouping energy from industrial off-gases. Encourages technology adoption to reduce greenhouse gas emissions via performance based incentives and policies. |
| Energy Action Plan | Encourages investment to meet energy growth needs while optimizing energy conservation and resource efficiency. Calls for adoption of natural gas efficiency programs and standards to reduce reliance on natural gas for end-uses, and optimizing strategies to increase conservation and resource efficiency of natural gas. Commits energy agencies to continue progress in meeting environmental goals, including minimizing the impact of energy on climate change by developing renewable energy resources to meet the Renewable Portfolio Standard (RPS). |

| Selected California Policies and Programs Impacting Industrial Natural Gas Reduction Technologies | |
|---|---|
| **Name** | **Function** |
| Governor's Executive Order S-3-05 | Establishes GHG reduction goals and encourages tracking of GHG emissions. Greenhouse gas emission reduction targets for California include: 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. Endorses deployment of energy efficiency and other cleaner power sources. |
| Western Regional Climate Action Initiative | Oregon, California, Washington, New Mexico and Arizona will develop regional targets for reducing greenhouse gas emissions, followed by a market-based plan by August 2008. Expected result is expanded deployment and lower cost of renewable energy and energy efficiency technologies. |
| AB 32, Global Warming Solutions Act of 2006 | Adoption of GHG reporting rules and timeline of implementation accomplished through an enforceable statewide cap on emissions. Requires greenhouse gas emissions tracking and reductions. Provides incentives for efficiency and other low GHG projects (e.g., biomass co-firing). Calls for development and implementation of market-based compliance mechanisms. |
| Self-Generation Incentive Program, AB 970, AB 2778 | Provides financial incentives for the first 1.0 MW in capacity of fuel cells, wind turbines and natural gas turbines from 30 kW to 5 MW of generation. Technologies most relevant to the industrial sector include renewable, non-solar fuel cells operating on renewable fuel, wind turbines, microturbines, internal combustion engines, and gas turbines operating on renewable fuel; or microturbines, internal combustion engines and gas turbines operating on non-renewable fuel or waste gas fuel. |
| California Solar Initiative Incentives (2007) | Incentives provided based on expected performance for systems < 100 kW ($2.50 W AC for residential and commercial) and actual performance for systems > 100 kW ($0.39 per kWh for 5 years for all taxable entities) enabling the utilization of solar technology to meet on-site power demand. In addition to residential, includes existing and new commercial, industrial, and agricultural properties. |
| Energy Commission Natural Gas RD&D Program, CPUC R.02-10-001 | Provides funding for RD&D on natural gas technologies in a diversity of areas from supply to demand and environment. PIER/IAW activities are covered under various areas of this resolution. Applicable to industrial RD&D in particular is Research Area 1 – affordable, comfortable and energy-smart choices for daily life and a strong California economy. |
| Energy Commission Public Interest Energy Research Program (PIER) 2007-2011 Natural Gas Research Investment Plan | Sets strategic objectives for natural gas research, including the industrial area. Targeted areas including reducing cost and improving performance of efficiency systems for industrial processes, and developing energy-efficient technologies for unique California conditions and industries. The technology platforms in this report are consistent with these objectives. |
| Energy Commission Energy Innovations Small Grant (EISG) Program | Provides up to $95,000 for hardware projects and $50,000 for modeling projects to businesses, non-profits, individuals, national laboratories, utilities, and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts. Research projects must target one of the six PIER program areas, address a California energy problem and provide a potential benefit to California natural gas ratepayers. |

Table 2-5 illustrates current state policies and legislative actions that support the technology platforms described in this report. Most of these policies are broad directives intended to support energy end-use efficiency and energy supply diversity as a way to strengthen the state economy. These policies are indicative of strong support for energy innovations, especially those with potential to reduce the impacts of energy price and supply volatilities.

With the goal of encouraging diversification of energy supply options for California, renewable energy is a particular focus of some policies. While not specifically directed at the industrial sector, these policies provide universal incentives for using renewable energy that could motivate greater use of biomass, solar or wind energy in industrial applications currently served by fossil fuels.

Alternatively, some of these policies are directed at improving protection of the environment or mitigating potential climate change through the reduction of emissions of greenhouse gases. As energy use is a primary contributor to both criteria pollutant emissions and GHG emissions, these policies directly (or more indirectly, through mandated reductions) support greater efficiency in the way energy is used in California.

**Table 2-5: State Policies and Legislation: Relevance to Technology Platforms**

| State Policies and Legislation: Relevance to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***Warren-Alquist Act*** | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***Energy Policy Report*** | X | X | X | X | X | | | | | | | X | X | X | X |
| ***Energy Action Plan*** | X | X | X | X | X | X | | X | X | X | X | X | X | | |
| ***Governor's Executive Order S-3-05*** | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***Western Regional Climate Action Initiative*** | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***AB 32, Global Warming Solutions Act of 2006*** | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***Self-Generation Incentive Program, AB 970, AB 2778*** | X | X | X | | | | X | | | | | | | X | X |
| ***California Solar Initiative Incentives (2007)*** | | | | | | | | | | | | X | X | | X |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Energy Commission Natural Gas RD&D Program, CPUC R.02-10-001*** | X | X | X | 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 | X | X | X | X |

### *2.2.4. Industrial Resources and Potential Partners*

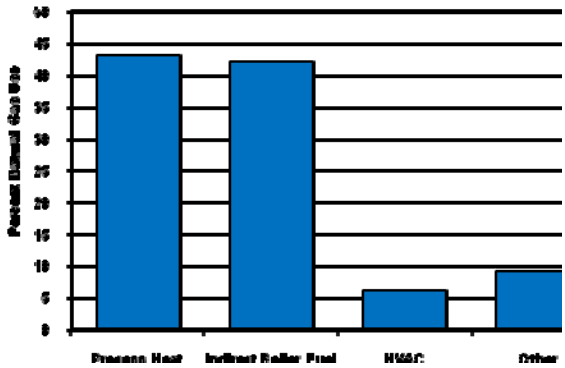
There are a number of industrial organizations, companies, and individuals with the expertise needed to contribute, or partner in some way, in the development of technologies identified in this report. Tapping the capabilities and networks represented by these groups is an important aspect of successfully developing and using these technologies in California industry. Gaining a solid commitment and cost-share agreement from industrial representatives early-on can make a critical impact on whether technologies sit on the drawing table or actually move forward to commercialization and deployment in plant operations. Without deployment, benefits that could be gained do not materialize.

## 2.3. Technology for Reducing Industrial Natural Gas Use

### *2.3.1. Industrial Energy Systems*

Industrial energy systems encompass the equipment used to provide heating, cooling, power and mechanical work to industrial processes. These systems, which include boilers and steam equipment, fired heaters, cooling processes, and motor-driven equipment, play a crucial role in today's manufacturing processes. As shown in Figure 2-5, natural gas is a primary driver for industrial systems in California, and thus represents a significant area of opportunity for reducing use of this energy resource.

**Figure 2-5: Natural Gas End-Use Breakdown for California Manufacturers[9]**



Steam is used to heat raw materials, generate electricity, and provide power for equipment. In the United States, the annual cost of fuels used for steam generation is estimated at

[9] PG&E, 2001.

around $18 billion. Only 55 percent of steam energy is actually delivered to processes while the remaining 45 percent is lost to inefficiencies in boiler equipment, energy distribution, and energy conversion. Steam generation in boilers, with efficiencies ranging from 55-85 percent, accounts for the largest losses. Distribution losses occur in steam traps, valves, and pipes where steam is transported throughout the plant site. Energy conversion losses occur in heat exchangers, steam injectors, and other equipment where steam heat is used to facilitate product conversion.

Fired systems supply heat to produce basic materials and commodities, and cooling systems provide chilling and refrigeration for processes where achieving lower temperatures is essential. Process heaters include direct- and indirect-fired furnaces, dryers, calciners, evaporators, smelters and many others.

Some of the most worthwhile opportunities to reduce natural gas use exist in the reduction and recovery of waste energy from process heaters and other industrial energy systems. Reduction of energy wasted through heat losses, for example, impacts natural gas requirements by improving the thermal efficiency of the process. Recovering and reusing the energy embodied in gaseous and liquid effluents (e.g., flue gases, hot waste streams) reduces natural gas use by supplementing waste energy for virgin energy.

Combustion systems also represent opportunities to reduce natural gas use. The effectiveness with which the fuel is combusted (e.g., completeness of combustion) impacts the overall thermal efficiency of the system, and is affected by the type of burner as well as the control systems that monitor air/fuel ratio and other inputs or parameters. It may be possible to implement energy systems that are capable of switching from one fuel to another, reducing primary use of natural gas in situations where prices are high or supply is constrained. Other areas of improvement include better heat transfer to the process, reduction of losses through the system and improved operating and maintenance practices.

**Technology Limitations**

Implementation of waste heat recovery systems can be hindered by the availability of durable, reliable materials of construction suitable for operation at high temperatures or in corrosive environments. In some cases, the technology does not exist or cannot be applied to cost-effectively capture waste heat (e.g., obtaining usable energy from low temperature heat sources), or has not been demonstrated to perform reliably at the scale of interest. In some cases, heat transfer systems may be over-sized and over-designed because operation at higher temperatures is not possible or heat recovery is not economically feasible – leading to large quantities of waste heat.

For combustion system components, such as burners, there have been considerable improvements over the last two decades, many motivated by a need to improve environmental performance. However, there is still a lack of knowledge base to support continued advances that would enhance efficiency. In addition, many of the advances already made have been based on empirical knowledge. The impacts of burner design on

energy efficiency and environmental emissions must be better understood and incorporated into burner performance through technological and engineering advances.

In terms of fuel flexibility, few burners available operate with flexible fuels, or have been effectively demonstrated to operate with flexible fuels on a continuous basis. It is also possible that use of alternate fuel may result in reduction in production rate without major changes in the process or equipment. The knowledge base that would enable fuel-flexible designs is again limited – and little incentive exists to encourage suppliers to develop this technical expertise.

**Technology Solutions**

Numerous industrial processes generate substantial amounts of waste energy, some of which could be tapped as an energy source. In petroleum refineries, for example, contaminated waste steam from fractionating and stripping processes is a major source of waste heat. Waste gases from boilers, furnaces, vents, flares, and coolers also represent a large source of waste energy. In pulp and paper manufacture, waste steam, hot water, exhaust gases, evaporation of spent liquors, and radiation heat losses are the primary source of energy losses from fluid heating and boiling. In food processing, significant energy is lost in wet corn milling and sugar processing in the form of waste steam, exhaust gases, and radiative heat losses from evaporators, dryers and other key processes.

In metal melting and heating, losses occur in fired systems from hot gases (both contaminated and clean), warm water, and hot products that must be cooled or quenched. Smelting, which produces molten metal, generates energy losses in the form of furnace exit gases. Metal heating and heat treating is accomplished in various types of furnaces and generates losses through exit gases and radiative heat transfer. Calcining (e.g., cement) results in heat losses from exhaust gases (evaporated water, combustion gases, carbon dioxide from calcinations) and via radiation and convection.

The energy content of waste heat depends primarily on temperature and the type of fluid containing the waste heat. Steam at 200˚F, for example, has low energy content and is more difficult to economically recapture as an energy source than steam at 500˚F. This is sometimes referred to as the "quality" of the waste heat. For this report, waste heat is placed into five categories: very low temperature waste streams (-40 to 250˚F); low temperature waste streams (250 to 500˚F); mid to high temperature waste streams (500 to 1400˚F and higher); heat lost during imperfect heat transfer, via thermal conduction, convection, and radiation; and heat losses occurring to the atmosphere/environment through radiation and convection.

### ***Very Low Grade (-40 to 250˚F) Heat Recovery***

Very low temperature waste heat steam is defined as gases or liquids discharged from industrial processes or equipment from about -40˚F to 250˚F. In many cases it is not possible to justify use of waste heat recovery at these temperatures, especially in cases where the waste steam contains contaminates such as particulates or corrosive components. Currently

available technologies such as heat exchanger materials and heat transfer surface configurations limit the amount of heat that can be recovered economically.

**Technology Gaps and Opportunities**

Numerous methods can potentially be used to recover very low temperature heat from industrial heating processes or from relatively clean exhaust gases from prime movers such as gas turbines and natural gas-fired engines. Many of these are also applicable to low grade heat (see Table 2-6). Examples of technology include:

- Direct contact water heating for once-through (open-loop) water use applications such as cleaning and washing of surfaces, or mixing with products such as concrete mixing.
- Indirect water heating by using heat exchangers when the flue gas stream is relatively clean and free of corrosive compounds and particulates. In some cases it is possible to use non-corrosive materials for heat exchangers to avoid acid corrosion associated with gases containing sulfur or chlorine.
- Use of hot gases for desiccant recovery in dehumidification systems.
- Recycling of relatively clean waste exhaust gases from dryers and ovens while maintaining required humidity or lower explosion limit requirements within the dryer/oven.
- High efficiency heat recovery devices such as a "heat-wheel" for make-up air heating.
- Use of waste heat in the form of hot gases or liquids for absorption cooling systems.
- Waste heat for innovative power generation cycles (e.g., Rankin).
- Thermoelectric power generation utilizing waste heat.

Some of the challenges that would need to be addressed by RD&D include (but are not limited to):

- Advanced materials
    - Corrosion-resistant coatings for low temperature applications
    - Heat storage materials with high latent heat and high thermal conductivity
    - Cost-effective thermoelectric or thermo ionic materials capable of producing electricity from heat, with 15 to 20 percent thermal efficiency
- Innovative working fluids and cycles
    - Advanced cycles and working fluids to increase temperature lift in absorption cycles and improve overall heating and cooling performance
    - Innovative heat transfer methods/heat exchanger geometries to reduce heat exchanger size
- Waste heat "boilers" for water and other liquids capable of recovering heat from corrosive streams for use on power generation cycles

- Thermally-activated refrigeration and heat pump systems driven by waste heat to replace or supplement direct gas firing
- Concepts/designs for high efficiency, low cost heat pumps to elevate temperature level of fluids using low temperature waste heat streams
- Sensors and controls to measure and monitor humidity or lower explosion limits in dryers/ovens to allow recycling of exhaust gases and reduce amount of make-up air.

### ***Low Grade (250 to 500˚F) Heat Recovery***

Economically viable methods to recover large amounts of low grade waste heat have been identified as an RD&D priority for California industries. Almost all major industries using steam and process heating systems generate low grade heat (i.e., 250 to 500˚F). In most cases, this heat is not utilized and is discharged as a hot gas or liquid. In some cases, more energy is expended before the process steam can be discharged or reused, as is the case for hot water streams discharged from heating processes. There are at least two reasons for this practice: (1) there is no use for heat at the temperature level of the available waste heat, or (2) available methods or technology for converting the waste heat to a useful form cannot be economically justified. During the last 20 years, a number of technologies and systems have been developed that offer possibilities for converting low grade heat as low as 250˚F into electricity. However, none of these technologies are economically viable at current energy prices. In addition to the cost factor, in many cases the waste stream has contaminants that necessitate an additional cleaning step or may present future performance and maintenance problems if not removed.

**Technology Gaps and Opportunities**

Low grade heat is available in the form of hot gases (flue products from combustion based heating equipment), liquids (hot water or other process liquids), or vapor-gas mixtures (e.g., exhaust air from drying equipment). In most cases, these fluids are discharged at temperatures well below 400˚F. These fluids contain sensible heat as well as the latent heat of vapors that account for a large percentage of the total heat content of the waste stream.

There is a need for high efficiency, low cost, compact equipment or systems that would recover or convert low grade waste heat into usable energy or electricity that can be used in the plant or transmitted outside the plant. It may be necessary to design equipment that can handle the unique characteristics of the waste heat source, such as the presence of contaminants, particulates, condensable materials, or corrosive materials. Available equipment now includes gas to gas, gas to liquid, liquid to liquid or in a few cases, gas to solids heat exchangers. Very few, if any, heat exchangers are designed to recover latent heat of vapors contained in exhaust gases. Examples of technology systems for development include:

- Enhanced heat transfer systems that would increase heat transfer from gases to heat transfer surfaces in gas-liquid heat exchangers.
- Advanced materials with following characteristics:

- Materials that can with stand corrosive components of the waste heat streams. This may include use of non-metallic materials with relatively high thermal conductivity and non-wetting characteristics.
- Low temperature materials with phase change that will absorb and retain relatively large amount of heat between heat transfer stages.
- Relatively moderate or low cost.
- Reusable and ease of maintenance (easy to recover-clean when they are contaminated).

- Chemically reactive systems that involve exothermic-endothermic reactions using waste heat from fluids (gases, liquids, vapors).
- Thermo-electric systems to capture and convert low intensity heat losses into usable energy (e.g., wall losses from heating equipment converted to electrical power).
- Novel concepts for heat pumps or pressure/temperature elevation systems using supplementary sources of energy (solar, electricity). Systems to capture air cooler effluent and apply as warm make-up air for dryers.
- Innovative working fluids to capture low-quality heat.
- Thermal energy storage systems. Novel concepts for compact heat storage systems that can be used to store large amounts of low grade heat for recovery at the appropriate time of a day.
- Power generation systems using novel working fluids that allow use of low grade heat.
- Improved energy transport systems.

Selected application areas are given in Table 2-6. Note that many of these would also be applicable to very low grade heat recovery.

**Table 2-6: Opportunities for Low Temperature Waste Heat Recovery**

| Opportunities for Low Temperature Waste Heat Recovery | |
|---|---|
| **Industry** | **Description** |
| Oil & Gas Extraction | Recovery of heat from fluids (liquids and gases) used in drilling and processing of oil and natural gas. These fluids contain a variety of contaminates such as particulates, condensable, corrosive components, and others. |
| | Power production using low grade (<400°F) waste heat from natural gas processing. |
| Petroleum Refining | Heat recovery from moderate temperature flue gases from process heaters and steam generators. |
| | Use of waste heat from steam and low temperature condensate from distillation columns, process heating equipment and condensate generated in steam heated systems. |
| Glass & Cement Residual | Reuse of medium temperature exhaust gases from glass melting furnaces downstream of the regenerators. These gases contain particulates and corrosive gases and need to be cooled before they enter particulate removal systems (usually bag houses). |

| | |
|---|---|
| Chemical & Allied Products | Heat recovery from moderate temperature flue gases from process heaters and steam generators. |
| | Heat recovery from low heating value gases (e.g., byproducts from chemical processing). |
| Primary Metal Industries | Reuse of low temperature flue gases from heating equipment downstream of combustion air preheaters (recuperators). These gases are at 300 to 800°F and relatively clean (free of particulates or corrosive elements). |
| | Reuse of heat from cooling water used in metal reheat furnaces or electric arc furnaces (EAFs). |
| Fabricated Metal Products | Use of low temperature flue gases from heat treating furnaces used by steel and aluminum fabrication plants. |
| Food Processing | Heat recovery from a variety of low grade heat sources. Specifically includes liquids (condensate, wash water, heated liquid – semi-liquid products that need to cooled before packaging), and exhaust air with large amounts of water vapor from direct fired processes. |
| | Integration of energy systems where low grade heat can be converted to energy for cooling systems required in the plant. These cooling systems include cold or chilled water, cold air, or refrigeration where absorption chilling might be cost-effective. |
| Paper and Allied Secondary Industries | Recovery of heat from drying machines in the form of humid air vented out of pulp and paper dryers. |
| | Heat recovery from condensate from paper drying machines. |
| | Heat recovery from boiler flue gases to heat water used in pulp processing; use of condensing heat exchangers or direct contact water heaters. |

**Government Role**

Taking advantage of opportunities to recoup waste heat available at low temperatures will in many cases require the development and demonstration of new technologies, including operational data to reduce the commercial risk of investment. There is a government role for funding RD&D that is cost-shared with industry early-on. Early industry involvement will help ensure specific industry needs are being addressed, and increase the potential for commercialization and deployment.

## ***Mid to High Grade Heat Recovery (500 to 1400˚F) Heat Recovery***

A number of heating processes using natural gas discharge flue gases at temperature higher than 500˚F. This source of heat is considered to be mid- to high-grade waste heat. These flue gases may contain 20 to 50 percent of the heat supplied to the process and offer an opportunity to reduce the process heat requirement by 10 to 30 percent through energy recovery. The industry has realized the potential for heat recovery from high temperature (usually >1000˚F) flue gases and a few large energy-intensive industries now use flue gas waste heat recovery systems. However, in most cases the amount of energy recovered is relatively low (30 to 50 percent of the heat content of flue gases), leaving as much as 30 percent of the heat still wasted. In smaller facilities, an informal assessment of small to medium size plants in California has shown that they rarely use heat recovery systems.

Heat recovery from medium to high temperature gases present multiple challenges, including: (i) available heat recovery equipment (mostly heat recuperators) requires special design and high temperature materials that necessitate substantial investment, and it has

been difficult for plant engineers to justify the needed expenditures; (ii) higher temperatures and, in many cases, the presence of contaminants, requires frequent maintenance of the equipment; (iii) lack of use for the heat in the available form (usually as hot gases); (iv) concern about increased $NO_x$ emissions when using waste heat to preheat combustion air; and (v) requirement for specialized materials that can withstand higher temperatures and contaminants. In many cases it is necessary to take additional steps to clean the waste stream before the heat can be recovered.

Development of advanced heat recovery technologies and advanced materials has been identified as a priority for RD&D. During the last 20 years, a number of technologies and materials have been developed that offer possibilities of recovering larger percentages (>75 percent) of this heat. However, it is still necessary to develop practical and economically justifiable designs based on these developments.

**Technology Gaps and Opportunities**

Medium to high grade heat is available primarily in the form of hot gases (flue products) from combustion-based heating equipment such as furnaces, melters, process heaters, and thermal oxidizers. In large installations (>20 MM Btu/hr firing rate) with clean, non-contaminated flue gases, the waste heat is used to preheat combustion air or, in a few cases, to raise steam or to produce hot water. As mentioned above, several factors have prevented use of waste heat recovery systems for small to medium size industrial heating applications.

There is a need to develop high efficiency, cost effective compact equipment or systems that would recover or convert waste heat into energy sources that can be used within the plant, stored, or transmitted over the plant fence. At this time, the available equipment or systems includes flue gas to air and flue gas to liquid (water) heat exchangers to recover the waste heat. In many cases, the equipment design is limited by the availability of materials that can withstand high temperatures and challenges such as presence of particulates, condensable vapors, reactive or corrosive gases, and cycling of flow and temperature. In many cases, the available equipment cannot convert the recovered energy into a form of energy that can be transported beyond a short distance from the source of waste heat. As a result, the available technologies can only recover only a small percentage of the waste heat.

Several technologies have been identified recover the waste heat from medium to high temperature flue gases. However, only a few have been attempted at commercial scale and among them, only two systems are widely used where they can be economically justified. It is necessary to develop and demonstrate cost effective systems based on these and other innovative technologies to promote and replicate wide scale use of waste heat recovery.

Examples of technologies that offer substantial heat recovery potential and should be considered for further development and demonstration include:

- High temperature combustion air preheaters
- Low $NO_x$ burners using highly preheated air, operating over a wide range of firing rates and with sustained low $NO_x$ values

- Systems that allow use of waste heat for load preheating and moisture removal prior to thermal processing
- Flue gas recycling and heat cascading systems to recycle heat from higher temperature processes
- Methods to convert sensible heat into storable energy
- Thermo-electrical systems that allow conversion of heat into electricity
- Other methods to convert waste heat into transportable energy source (electricity, high Btu fuel)

Development of many of these technologies would require RD&D efforts in materials, heat transfer equipment, and other areas. Specific areas for research include (but are not limited to):

- New materials resistant to higher temperatures (>1400˚F) in the presence of chemically reactive contaminants and particulates present in flue gases
- Improved heat transfer techniques that would help the reduce size of the waste heat recovery equipment such as recuperators, regenerators, charge preheating system, and drying systems
- Lighter and longer life insulating materials to reduce maintenance problems
- On-line cleaning of heat transfer surfaces in medium to high temperature natural gas fired heating systems
- Combustion – burner technologies that would reduce $NO_x$ formation with the use of highly preheated combustion air
- Advanced materials to enable:
    - Flue gas moisture condensing heat recovery technologies (condensing economizers)
    - Phase change materials with high heat storage capacity for use in regenerative heat recovery and heat storage systems
    - Higher efficiency of thermo-electric systems
    - Catalysts that promote and enhance chemical reactions for conversion of sensible heat into other forms of energy sources (thermo-chemical heat recovery systems)
- Novel concepts for power generation systems that convert sensible heat into electrical energy or can increase efficiency of the current systems
- New concepts for conversion of sensible heat into cooling systems for use in the plants

Primary targets are industries characterized by high temperature processing, including chemicals, petroleum refining, glass manufacture, metals manufacture, pulp and paper. Some of these industries also co-generate heat and power, and advanced materials could improve efficiency in those systems by optimizing operation at higher temperatures. Examples of key industrial opportunities are shown in Table 2-7.

**Table 2-7: Opportunities for Mid- to High-Temperature Waste Heat Recovery**

| Opportunities for Mid- to High-Temperature Waste Heat Recovery | |
|---|---|
| **Industry** | **Description** |
| Oil & Gas Extraction | Recovery of flue gas heat from prime movers such as internal combustion engines and combustion turbines used for on-site power generation in oil and gas wells and production/processes. |
| | Recovery of heat from gas conditioning (e.g., removal of $H_2S$, $CO_2$) plants used in gas exploration and production plants. |
| Petroleum Refining | Recovery of flue gas heat from process heaters, crackers, $H_{2S}$ removal systems. |
| | Recovery of heat generated from flares and thermal oxidizers. |
| Glass & Cement Residual | Heat recovery from furnace/kiln flue gases. |
| | Heat recovery from glass cooling - annealing systems used on float glass lines. |
| | Heat recovery from high temperature ovens or lehrs used for annealing/tempering of glass products. |
| | Heat recovery from hot products. |
| | Heat recovery from thermal oxidizers used in fiber glass production. |
| Chemical & Allied Products | Recovery of flue gas heat from process heaters, chemical reactors and other fired equipment. |
| | Recovery of heat generated from flares and thermal oxidizers. |
| Primary Metal Industries | Heat recovery from aluminum melting furnaces and steel EAFs. |
| | Heat recovery from ladle and tundish heating systems used by steel industry and in other metal melting facilities. |
| | Heat recovery from heated metal products. |
| Fabricated Metal Products | Heat recovery form steel reheating furnaces. |
| | Heat recovery from heat treating furnaces. |
| | Heat recovery from forging furnaces used for aluminum, steel, titanium, other metals. |

**Government Role**

While technology exists that could be applied to some mid- to high-temperature heat recovery applications, for practical use it must be designed and modified for specific industrial uses. There is a government role to support this early RD&D in cooperation with industrial users. In some cases, the cost of the technology and the development aspects are too high risk for single companies to undertake independently. In particular, RD&D in the areas of new materials, novel heat exchange designs and other innovations are generally pre-competitive in nature, high risk and may require extended RD&D effort. These aspects make this RD&D potentially suitable for some measure of government support. For technologies that are readily adaptable and already available on-the-shelf, a government role might be to undertake limited support for demonstration of the technology with an industrial partner to help provide proof of performance for unique or multiple industry applications.

### ***Heat Loss Reduction***

All systems that use natural gas can lose heat by thermal radiation and convection from various areas of the equipment. Specifically, fired equipment such as furnaces, boilers, ovens, and so forth (referred to as heating equipment) loses heat through the walls by radiation-convection and from openings by radiation. The openings also result in leakage of cold air in the furnace when the pressure inside the furnace is lower than the ambient pressure. In some cases, hot flue gases leak through the openings if the pressure is higher than the ambient pressure. In a few cases, the heating equipment uses cooling water or air to maintain a safe operating temperature for structural components. Material handling systems such as conveyors, belts, fixtures, and trays also affect heat losses in the equipment. This results in heat losses that have to be compensated for by additional use of natural gas – typically more than is optimally necessary for the process.

Energy assessments of industrial heating equipment have shown that the radiation – convection losses may account for 2 to 5 percent for the total heat input and can be reduced by 20 to 50 percent of the current values. The heat lost by water cooling could represent 5 to 30 percent of the total heat input and can be reduced significantly, by as much as 75 percent of the current losses. Heat lost in material handling system could account for 5 percent to 25 percent of the total heat input and can be reduced by as much as 50 percent of the current values. Many of the natural gas reduction measures in this category can be retrofitted to existing equipment without affecting the process or requiring major structural changes in the equipment at relatively low cost, and offer attractive paybacks. Factors such as lack of information on how to reduce heat losses and limited data on the benefits and/or performance results are hindering the adoption of new technologies and practices in this area.

**Technology Gaps and Opportunities**

Heat losses from heating equipment depend on design, construction, and operation and maintenance practices. Reduction of heat losses in the various areas described above requires RD&D and demonstration of technologies and design methods for large varieties of heating systems used by California industry. The emphasis is on low cost, retrofit-able compact applications, sometimes with unique functional characteristics that are process-dependent (e.g. drying, metals and non-metals heating, batch versus continuous operation etc.). The following areas of RD&D would be needed to foster the reduction of heat losses from industrial heating equipment.

- Simple software "tools" that help the industry analyze heat losses and their economic value
- Redesigned thermal processes and equipment to reduce air leakage into the system (e.g., direct-fired furnaces, ovens, or dryers)
- Development and demonstration of control systems that maintains safe levels of flammable vapors in paint (organic materials) drying ovens while maintaining the lowest required volume of make-up air
- Optimized insulation system for heat transfer systems

- Sealing systems for openings in heating systems without interrupting material handling requirements
- Development and application training of cost-effective thermography to locate and reduce heat losses through insulation or other means
- Energy conversion systems such as thermo-electric power generation from hot walls of heating systems

Heat loss reduction applies to all industries that rely on large quantities of natural gas for process heating applications. Table 2-8 identifies specific areas of heat losses for major industries using natural gas in California. The equipment includes drying systems (ovens used for moisture reduction, coatings drying), boilers, furnaces used for metal and non-metal heating, aluminum and glass melting, chemical reactors, process heaters, and thermal oxidizers.

**Table 2-8: Opportunities for Heat Loss Reduction**

| Opportunities for Heat Loss Reduction | |
|---|---|
| **Industry** | **Description** |
| Oil & Gas Extraction | Wall loss reduction for high temperature process reactors used in natural gas processing (H2S removal) equipment. |
| | Reduction of air infiltration and draft control. |
| Petroleum Refining | Wall loss reduction from process heaters and other heating equipment. |
| | Seals for fluid heater tubes. |
| | Pressure (draft) control for heating equipment to reduce air leakage into the heater radiation and convection sections. |
| Glass & Cement Residual | Reduction of wall loss and heat recovery from smelter walls, kiln walls and other high temperature areas exposed to ambient conditions. |
| | Sealing of openings and draft control to reduce air leaks in smelting and refining. |
| | Reduction of air infiltration in annealing lehrs and ovens used for finishing operations. |
| | Reduction or elimination of water cooled parts; use of advanced insulation and application methods for longer life and low maintenance. |
| Chemical & Allied Products | Wall loss reduction from process heaters, reactors and other heating equipment. |
| | Insulation of steam and hot fluid transmission pipes. |
| Primary Metal Industries | Wall loss reduction for high temperature metal heating, heat treating and melting furnaces. |
| | Pressure (draft) control at all operating conditions (e.g., high-low fire and variable loading conditions, batch operation) for fired furnaces to reduce ambient air infiltration or discharge of hot gases from furnace openings, doors, and other apertures. |
| | Reduction or elimination of water-cooled parts for steel reheating furnaces. Use of alternate high temperature materials to replace selected water-cooled components. |
| Fabricated Metal | Use of make-up air control while meeting safety requirements in drying of organic coatings (i.e., paint). |

| | |
|---|---|
| Products | Wall loss reduction with use of improved insulation and seals for forging reheating furnaces. |
| Other Industries | Humidity control for dryers used in food, paper, textiles and food processing. |

**Government Role**

In many cases, the natural gas reduction measures in this category have relatively low costs, short payback periods, and can be easily retrofitted, qualities that should make them attractive to industry without government supports. However, industry is often unaware of the attractive cost/benefit ratios of these technologies, or how they might affect performance in the plant. There is a government role to raise awareness of these technologies and help industry understand how to implement them (tool development, training), and to conduct demonstrations to validate their performance and impact on parameters such as product quality in specific industries. Government support for RD&D may be called for in some instances, such as in the integration of technology and processes.

***Enhanced Heat Transfer***

The thermal efficiency of heating and cooling equipment is greatly affected by heat transfer from hot combustion products or cooling medium to the material being heated or cooled. Increased heat transfer in heating equipment would help reduce the size of the equipment and reduce the temperature of exhaust gases; for cooling systems, heat transfer enhancement can reduce the size of heat exchangers and cost of operation. Heat transfer rate or efficiency can be increased by proper design of equipment (furnace, heat exchanger) and use of heat transfer enhancement devices before the equipment is installed. Industry has identified the need to develop technologies and practices to increase heat transfer from the heat source to the process or load in heating and cooling systems.

Heat transfer in equipment can be increased by improving one or more primary heat transfer mechanisms: thermal conduction, convection and radiation. In the past industry has attempted to improve heat transfer by use of higher convection and radiation. However, many factors such as initial cost of equipment, effect on product quality or yield, need for more precise controls, major redesign of equipment with unpredictability of performance has prevented them from making major changes in equipment design. In cases where the equipment has been designed to offer improved heat transfer, it is necessary to maintain the heat transfer efficiency by using proper operating and maintenance practices. Most commonly encountered and ignored practices include operation at off-design capacity, and deposit of scale, dirt, contaminants and so forth on the heat transfer surfaces. Some of these can be addressed by maintaining the equipment. Overall, it is possible to reduce energy use by 2 to 10 percent by improving heat transfer in heating and cooling systems.

**Technology Gaps and Opportunities**

Heat transfer in thermal equipment depends on design, construction, and operation and maintenance practices. Specific actions for heat transfer enhancement depend on the process operating temperature. For example, it is necessary to increase convection heat

transfer for low to medium temperature processes such as drying, cooling, and refrigeration, fluid heating or cooling, metals heat treating, and heat recovery. It is necessary to increase radiation heat transfer for high temperature processes such as metal heating, glass melting, cement manufacturing, chemical reactors, process heaters, and so forth.

The following areas of RD&D and demonstration are needed to assist industry in reduction of heat losses from heating equipment:

- High volume, high efficiency flow recirculating devices such as fans to increase convection heat transfer in low to medium temperature equipment
- Control systems that can maintain heat transfer and reduce energy use in flow recirculation systems
- Jet impingement systems to increase convection heat transfer
- Compact heat transfer devices such as micro-channel systems that promote higher heat transfer on both sides (heat supply and heat demand) of the heat exchanger with the provision of reducing fouling of heat transfer surfaces and/or ease of cleaning the heat transfer surfaces
- Simple mechanism to reduce fouling and corrosion, e.g., testing and mitigation of fouling on heat transfer surface without major interruption of the operation
- Performance improvements for multistage evaporators
- On-line cleaning of heat transfer surfaces (all temperatures)
- Tools and methods to optimize heat transfer at different operating conditions (changes in process temperature, equipment "loading")

The platform applies to all large natural gas-using industries relying heavily on complex heat exchange systems. Primary targets are chemicals, petroleum refining, pulp and paper manufacture; secondary targets include glass and metals manufacture. Key industrial opportunities are shown in Table 2-9.

**Table 2-9: Opportunities for Heat Transfer Enhancement**

| Opportunities for Heat Transfer Enhancement | |
|---|---|
| **Industry** | **Description** |
| Oil & Gas Extraction | Improved heat transfer in heat exchangers used at various stages of gas cleaning, in coolers, fluid heaters, and other processes. |
| | Indication or prediction of fouling or corrosion of heat transfer surfaces, and methods to clean heat transfer surfaces in heat exchangers. |
| Petroleum Refining | Heat transfer optimization for heater tubes in radiant and convection sections. |
| | Indication or prediction of fouling or corrosion of heat transfer surfaces and methods to clean heat transfer surfaces in heat exchangers. |
| Glass & Cement Residual | Optimization of heat transfer in melt and refining section of the glass melter. |
| | Optimization of heat transfer in cement or lime kilns through use of increased heat transfer between hot gases and kiln walls to the material being heated. |
| | Improved heat transfer systems for heat transfer between hot products and combustion air or other fluids that can be used in the plant. |
| Chemical & Allied Products | Optimization of heat transfer in process reactors and process heaters. |
| | Improved heat transfer in heat exchangers used at various stages of production and in heat recovery systems. |
| | Performance improvement for multistage evaporators. |
| Primary Metal Industries | Optimization of heat transfer in metal melting, heating and heat treatment furnaces. |
| | Compact heat exchangers for heat recovery through use of innovative heat exchanger surface configurations and design. |
| Fabricated Metal Products | High volume, high efficiency flow recirculation devices such as fans to increase convection heat transfer in low to medium temperature equipment. |
| | Jet impingement systems to increase convection heat transfer. |

**Government Role**

There is a government role to support RD&D for the longer term, higher risk technologies described in this category, as they have the potential to impact a multitude of industries. These are the innovative, but under-developed technologies that could make a substantial impact on natural gas use as well as productivity and profitability. Much of the development work needed is highly cross-cutting in nature and if successful, results be replicated to extend energy savings across industry sectors. In some cases, these concepts address problems that have been costing industry millions of dollars for decades (e.g., fouling), and innovations could yield great benefits. For low cost operational and maintenance concepts, the government role is in information dissemination, training and potentially design tools. These would increase awareness of gas-reducing concepts and allow industry to better identify the applications, costs and benefits. In some cases, demonstration and testing of existing techniques in new and unique industrial applications

would require government support, as industry might be reluctant to undertake these activities without incentives.

### ***Advanced Natural Gas Burners***

Natural gas combustion is the primary method of delivering heat for all heating processes used by industries in California. The design and proper application of gas burners affects the efficiency of energy use, safety of process operations, emissions of greenhouse gases and criteria pollutants, product quality and productivity. Burners are designed to meet specific process requirements such as amount of heat to be delivered, flame size and shape, turn-down requirements, process temperature and heating requirements, and others. Considerable progress has been made in burner design to meet current and future emission regulations. However most of these developments are based on empirical knowledge and experience rather than fundamental knowledge of the many complex processes such as mixing of air or oxygen and fuel, effect of burner application (process temperature, burner location, turn-down of the burner firing rate, use of preheated air or oxygen enrichment). As a result, it is difficult to design and apply burners that offer the most efficient operation in terms of heat release and heat transfer to the process, and to predict accurate values of emissions even for the most commonly used fuel (natural gas).

Lack of appropriate control systems that monitor and control burner performance in real time prevents optimum use of even the best available burners.

Industry has recognized that in future it will be necessary to make further reductions in regulated emissions and greenhouse gases such as $CO_2$ and free methane. Industry has recognized the need to better understand the link between emissions and efficiency, and believes this information will be helpful in designing improved combustion systems, particularly burners. It is also necessary to develop control systems that would maintain low levels of emissions under the different operating conditions existing in diverse industrial applications.

It is necessary to develop and apply the knowledge base, design methodology and application engineering to enable burner manufacturers, heating equipment suppliers and users to apply burners that best meet current and future emission regulations, including GHG reductions. In addition to RD&D there is a need to educate personnel on the newer, more efficient burners and controls and other combustion design considerations that may improve efficiency. Many plants will be phasing out older burners to comply with new air quality mandates, and need to understand the options that are available.

**Technology Gaps and Opportunities**

Heating systems impacted by advanced burners include steam systems (e.g., boilers), different types of furnaces, direct and indirect-fired process heaters, dryers and ovens, other commonly used industrial heating equipment, and onsite power generators. Technologies that would be associated with advanced burner design include:

- High efficiency with predictable low emission burner designs (industry-specific applications)
- Burners with integrated heat recovery systems such as self-recuperation or regenerative systems with simplified controls. These burners need to be designed for retrofit applications in a variety of size ranges. Current designs are for large installations in the metals industry
- Components such as valves and intelligent cycling system to optimize heat recovery to meet a variety of operating conditions for regenerative or self-recuperating burner systems
- Burner control systems capable of adjusting operating parameters in real time to maintain high combustion efficiency at variable operating conditions
- Retrofit burners and controls that can be applied to currently used/older systems without major equipment modifications or adverse effects on product quality and process performance
- Knowledge base to match appropriate burner and combustion system to specific applications.
- Understanding/communicating the impact of emissions requirements on burner efficiency

All industries that use burners, combustion control systems and auxiliary components of the combustion systems can benefit from the above mentioned development efforts. Primary targets include oil and gas exploration, chemicals, petroleum refining, pulp and paper manufacture, food processing, cement, glass and metals manufacture. Specific opportunities are given in Table 2-10

**Table 2-10: Opportunities for Advanced Natural Gas Burners**

| Opportunities for Advanced Natural Gas Burners | |
|---|---|
| **Industry** | **Description** |
| Petroleum Refining | Hot air burners with predictable low NOx for a variety of known operating conditions. |
| | Burners and associated control systems to maintain optimum $O_2$ and CO in exhaust gases while maintaining desired heat flux to avoid hot spots or undesirable heat flux on tubes in process heaters. |
| Glass & Cement Residual | High temperature regenerative burners that can be used with high $O_2$ air input or oxy-fuel burners for glass melting applications. |
| | Self-recuperative burners or 'raw" gas burners for glass annealing lehrs to allow use of hot exhaust air heat and $O_2$ content. |
| Chemical & Allied Products | Hot air burners with predictable low NOx for a variety of known operating conditions. |
| | Retrofit burners and combustion controls that can be applied to currently used or older systems without major equipment modifications or adverse effects on product quality and process performance. |
| Primary Metal Industries | Small to medium size (< 5 MM Btu/hr capacity) burners with integrated heat recovery systems such as self-recuperation or regenerative systems with simplified controls. These burners need to be designed for retrofit application in a variety of size ranges. |

| | |
|---|---|
| | Burners with high turn-down for batch operations. These burners allow use of optimum air-fuel ratios at all firing rates, preferably with integrated heat recovery systems. |
| Fabricated Metal Products | Burners with high turn-down capability for batch furnaces. These should maintain optimum air-fuel ratio to avoid excess air operation during "soak" or low heating periods. |
| | Small to medium size (< 5 MM Btu/hr capacity) burners with integrated heat recovery systems such as self-recuperation or regenerative systems with simplified controls. These burners need to be designed for retrofit application in a variety of size ranges. |
| Food Processing | Direct fired burners with acceptable minimum generation of NOx to replace use of indirect fired air heaters in drying applications. |
| Paper | Low mass infrared burners for paper drying machines to supplement steam heat to increase production throughput or reduce steam consumption. These require "intelligent" control systems, quick start capability and minimum CO generation during operation. |

**Government Role**

Significant development work is ongoing in the private sector in the development of burners. However, there is a government role to support RD&D on new burner concepts that meet the unique challenges of specific industrial processes, with industry cost-sharing. These activities should be collaborative efforts involving both the industry users and equipment suppliers. To support the transition to more stringent environmental standards and potential greenhouse gas reductions, the government also has a role in educating plant personnel, either through tools, training or other means, in effective selection of burners. The goal would be to effectively match burners with process specifications to gain the most efficient, environmentally sound operation.

***Fuel Flexibility***

California industries use a variety of burners to supply heat to heating equipment and combustion (gas) turbines, and the vast majority of these use natural gas as fuel. Current activities in fuel sources include development of alternatives such as clean coal gasification, bio-fuels, land fill gas and others with very different heating values and combustion characteristics than natural gas. However, few, if any, burners available in the market will operate with alternate fuels and offer the same performance in terms of efficiency and emissions without major modifications. At this time, the burner suppliers have neither sufficient technical knowledge nor incentive to develop new burner equipment that would operate with flexibility of fuel selection. Another barrier is the lack of a knowledge base on critical combustion properties for a variety of fuels that may be available in the future. This makes it extremely difficult to design and test burners that would offer a range of fuel flexibility.

An industry priority is to support the development and demonstration of natural gas-burning equipment capable of firing multiple emerging fuels (hydrogen, byproduct gases, biogas, syngas, and other biofuels). A key element of this activity is incorporating fuel flexibility into system and equipment design, most notably gas turbines, burners and control systems. Improved control systems will be necessary to control emissions within permitted levels, and to be flexible in adjusting firing characteristics as needed for variable fuel properties.

**Technology Gaps and Opportunities**

Some application areas in this platform may include:

- Flexible fuel combustion systems that can use emerging fuels for gas turbines
- Flexible fuel burners that can use emerging fuels for industrial heating applications
- Development of combustion characteristics and safety-related data for a variety of emerging fuels for industrial use in near future (5 to 10 years)
- Development of application data such as available heat, combustion products characteristics and their effect on heating equipment performance (i.e. heat transfer, product quality, heat recovery equipment maintenance and life etc.) for use in flexible fuel equipment
- Specialized combustion systems (fluidized bed, oxy-fuel, flameless combustion) using emerging fuels
- User training and awareness about critical safety issues associated with storage, handling, transmission and use of emerging fuels
- "Intelligent" and on-line control system that assists users in fuel switching, mixing (if necessary) and use without adversely affecting process performance

All large natural gas-using industries would potentially benefit from improved fuel flexibility. Certain industries (petroleum refining, chemical, steel, paper) that use large amounts of self-generated fuels would benefit greatly by the development of gas turbines and steam generators that use flexible fuels. Some industries may benefit more than others, especially those with ready access to fuels other than natural gas, particularly self-generated fuels. Petroleum refineries would achieve significant natural gas savings through the design of flexible fuel gas turbines run on variable-heat content refinery fuel gas. Primary targets are petroleum refining, chemicals, paper manufacture, food processing, and some primary metals. Table 2-11 provides additional information on potential applications and issues.

**Table 2-11: Opportunities for Fuel Flexibility**

| Opportunities for Fuel Flexibility | |
|---|---|
| **Industry** | **Description** |
| Petroleum Refining | Burner that allows use of a variety of fuels produced on-site or purchased. The burner should produce flame size and shape that provides a consistent uniform heat flux along the heater length. |
| | Control system that allows adjustments for fuel composition and associated variables to maintain desired air-fuel ratio or $O_2$ and CO in flue gases. |
| Glass & Cement Residual | Burner and control system that allows use of variable fuel while maintaining desired flame - heat transfer characteristics in glass melting furnaces and cement kilns. The flame emissivity is critical in heat transfer and its variability should be minimized. |
| | Burner design that allows use of flexible fuel with very high air preheat and/or oxygen content without affecting emissions of NOx and other criteria pollutants. |

| | |
|---|---|
| Chemical & Allied Products | Burners with flexibility of fuel use for a variety of process heating systems and boilers, with predictable low NOx at several known operating conditions. |
| | Flexible fuel combustion system that can use emerging fuels for gas turbines and other prime movers used in the plant. |
| Primary Metal Industries | Small to medium size (< 5 MM Btu/hr capacity) burners that allow use of a variety of fuels for small to medium size aluminum, steel and other types of melting furnaces. These burners need to be designed for retrofit application in a variety of size ranges. |
| | Burners that offer high turn-down for batch operations using a variety of fuels without affecting heat flux-heat transfer for furnaces designed with relatively small combustion volume. These burners should allow use of optimum air-fuel ratios. |
| Fabricated Metal Products | Burners for a variety of small to medium size batch or continuous heating systems using flexible fuels. These burners should maintain optimum air-fuel ratio to avoid excess air operation during 'soak' or for low heating requirements. |
| | Small to medium size (< 5 MM Btu/hr capacity) burners for fuel flexibility with integrated heat recovery systems such as self-recuperation or regenerative systems with simplified controls. Burners need to be designed for retrofit to existing systems. |
| Food Processing | Direct fired burners with acceptable minimum generation of NOx and contaminants that might affect product quality. Distribution of heat flux along the heating surfaces has to be maintained to ensure product quality during a variety of heating processes. |
| | Burners for boilers, liquid heaters and air heaters that allow flexibility of fuel while maintaining current levels of productivity. |
| Paper and Allied Secondary Industries | Direct fired burners that use a variety of fuels with acceptable temperature and heat flux distribution uniformity for pulp and paper drying applications without affecting NOx and other emission levels. This applies to all burners used for steam drying. |

**Government Role**

In spite of the implications for fuel costs during periods of constrained supply, fuel flexibility is not being pursued to any great extent by the private sector due to the lack of incentives. Thus, industry has few options to incorporate fuel flexibility, even if desired, as new fuels emerge. Government funds could help provide the needed fundamental data on fuels needed to enable burner development; provide support for burner design and testing; and create tools and training programs to raise awareness and understanding of the alternative fuels available as well as the economic and other benefits of fuel flexibility. Government support for consortia-like activities (e.g., burner consortia for fuel flexibility) might provide a collaborative mechanism to encourage development of burners and auxiliary equipment to promote fuel flexible options for industrial heating and steam generation. There is also the opportunity to leverage efforts in fuel flexibility currently ongoing at the Federal level (DOE).

### *2.3.2. Process Measurement, Diagnostics and Optimization*

Industrial processes are often complicated systems comprised of numerous unit operations, fabrication and forming processes, energy generation, and supply networks working together. They require reliable, consistent inputs of energy (natural gas, electricity, coal, and oil), other utilities (water, air, oxygen) and raw materials to operate efficiently and

productively. During the process, how these inputs are utilized or converted to products impacts energy efficiency as well as product yield and quality.

To ensure optimal performance and production, the inputs to industrial processes, as well as the quality of products must be accurately monitored and controlled throughout the system. Measuring systems can also provide important information on how much of an input is being used, enabling optimization of raw materials and energy.

How the process is configured also has an impact on energy efficiency. There may be ways to reduce processing steps and eliminate some portion of energy demand. Process cycles may be outdated, too long, or inefficient, and could be improved (potentially with a resulting decrease in energy required) through a reevaluation of product specifications.

Optimization of process efficiency through measurement, monitoring and process innovation can have a significant impact on energy consumption and natural gas use in particular. While the potential may not be as great as that achieved through heat recovery or other more revolutionary measures, energy reductions of from 2 to 10 percent have been reported. A marginal improvement in energy use, particularly under high natural gas price scenarios, can have a great impact on the bottom line for smaller and mid-sized manufacturing facilities.

Effectively managing energy performance can have an overall impact on a company through increased share holder value, corporate profits, and image. Firms that pursue strategic approaches to energy management can create savings not only for their employees and their shareholders but for society as a whole. Better energy management can translate directly into operating efficiency and customer satisfaction of manufactured goods.

**Technology Limitations**

Optimizing industrial processes is often difficult simply due to the amount and complexity of parameters. Large industrial furnaces, for example, require precise time-temperature cycles, each designed to meet productivity and quality requirements. These systems can have 50 or more burners combusting fuel at any one time that must be monitored to effectively meet process needs while optimizing overall thermal efficiency. A chemical process may require extremely accurate measurements of several parameters such as temperature, pressure, chemical components, and flow rate in addition to other inputs (e.g., energy, water) and outputs (byproducts, gases).

The key impediments to technology and process innovation are cost of development and the possible risk associated with changing process and product configurations. It may be difficult to justify the time and effort expended on pursuing innovation when processes are already operating at some level of productivity and profits are being made. During periods of sustained high gas prices these innovations become more economically attractive. In some cases, the technology to optimize processes may not exist, may not be cost-effective, or is difficult to implement and use.

The inability to accurately measure, monitor and optimize process parameters and diagnose potential problems has a detrimental effect on productivity and the use of natural gas and energy in general. Potential impacts include:

- Greater number of rejects and waste or byproducts – energy used to produce rejects and wastes is inherently lost
- Over-design or over-sizing of equipment and processes, and resulting inefficiencies – the energy used in the process is greater than that required, sometimes by a large margin
- Poor energy management practices – energy is wasted simply because operators do not understand energy flows in the plant
- Reduced ability to predict the need for maintenance and to mitigate catastrophic failures – energy is wasted through excessive plant shutdowns and startups for maintenance and failures
- Reduced productivity and product assurance – lower yields and greater input of raw materials leading to wasted energy inputs

In addition to energy impacts, all of the above can clearly affect profit margins by increasing production costs. In addition, health and human safety can be impacted by the inability to predict and mitigate catastrophic failures.

**Technology Solutions**

There are several ways to address the issue of process and energy optimization. Energy management tools, such as metering, energy assessments, pinch analysis and others can provide key information on energy use and enable identification of trouble spots or low-cost ways to quickly improve energy efficiency. Financial analysis tools can help plant energy managers to provide justification for implementing energy projects once they have been identified through analysis of return on investment and solid economic arguments. Operator training and awareness of the relationship between energy use and economics could impact overall process performance and cost. Energy management solutions are essentially external to the configuration of the process (out-of-the-process black box) but are relatively low-cost to implement and can still have a significant impact on process efficiency overall.

Innovations to processes or product cycles also have the potential to impact energy efficiency and natural gas use. Advanced or lower-cost control systems, for example, can provide more efficient, accurate, real time, or global controls that enable process parameters to be fine-tuned, with a resultant increase in efficiency. In some cases, re-configuring the process/product configuration or cycles can reduce or eliminate an energy-intensive process step or enable production with less cycle time. These solutions are *internal* to the process, but may be more risky and require more time and investment to develop and implement.

### ***Energy Metering and Monitoring***

Industries in California have indicated there is a need to develop affordable, advanced real-time metering systems to measure and monitor energy consumption or intensity (e.g., Btu/production dollars, Btu/unit product). While metering systems are available, they are often expensive or too difficult to implement and use. In some cases, suppliers develop and promote technology that provides a very high level of accuracy and /or resolution – a specification that is costly to obtain and not always necessary in some applications.

While larger companies may already have complex energy monitoring systems in place, the same may not be true for smaller and mid-sized companies due to cost. The availability of low-cost reliable systems for monitoring energy use could have a significant impact on energy efficiency in these facilities. With these systems, plant personnel can better understand how energy is being consumed in specific unit operations, where sources of inefficiency are located, how thermal efficiency might be changing over time, and the true costs of inefficiencies. For example, by monitoring the natural gas into a furnace or burner, along with the air or oxygen line, the combustion process can be optimized. Proper control of the air/fuel ratio can improve efficiency, lower fuel consumption, improve product quality and increase product yields.

**Technology Gaps and Opportunities**

The focus of this area is on low cost metering systems for natural gas use in major equipment systems and energy-intensive processes, including boilers, furnaces, and other process heaters. Metering can be implemented at the point of natural gas entry into the plant; this allows operators to periodically determine overall consumption (hourly, daily, etc), assess if operating efficiencies are being maximized, and whether there should be adjustments for peak usage. Sub-metering at various locations or on specific systems can be utilized to assess departmental inefficiencies, assign costs to variable operating areas, and identify opportunities for energy conservation or efficiency improvements. Technology applications areas may include:

- Low cost metering and monitoring systems capable of widespread use in multiple applications across industrial sectors; real-time systems to measure parameters such as natural gas consumption, air/fuel ratios, oxygen in flue gases, and other energy-related elements
- Metering in high temperature and harsh environments (e.g., optical, ultrasonic, acoustic, microwave system), resilient to dust, dirt and other contaminants
- Metering systems for multiple points working in series or parallel (multiple burner systems) to help identify point failures
- Simplified reporting system based on measurements to communicate energy use and trends in terms of production equipment or unit production

Reliable technologies for natural gas measuring and monitoring at point of use or sources could find application in all natural gas-using industries, regardless of size. However, there is a particular need for lower-cost systems suitable for use in smaller and mid-sized

facilities, where lower accuracy may be acceptable.

**Government Role**

There are a number of possible roles for the Energy Commission's PIER program in energy metering and monitoring. The first is in funding pre-competitive RD&D to lower the cost of existing metering systems and/or encourage development of systems for specialized environments, cost-shared with instrument suppliers and industrial users. The second is systems demonstration and validation on a small scale to obtain performance data and assess potential benefits. The results could potentially be replicated in numerous industries since these systems are relatively generic in nature. There may also be a role for the Energy Commission to develop programs that encourage the use of metering systems in general as a means of reducing energy intensity, either through information dissemination or economic or other incentives.

### ***Energy Efficiency Assessment and Analysis Tools***

Application of energy saving methods to the operation and maintenance of existing equipment can lead to substantial energy savings without major investments. Best energy management practices to improve energy efficiency for natural gas include optimization of plant utility and systems such as steam, process heating, and engine driven-air compressors and pumps. Critical elements of this optimization process include training and empowerment of management, process engineers, equipment operators and maintenance personnel to identify, analyze and apply commonly used energy saving methods. Process heat integration is a key element of this platform and may take the form of energy optimization models where energy flows are tracked, and/or heat pinch analyses where the optimum interface between thermal processes is identified. Desktop evaluation tools and energy use assessments are useful resources in identifying energy projects.

Industry representatives in California have identified the need for additional resources in the form of simple, low cost, easily usable energy management tools to aid in energy saving efforts for natural gas systems. Widespread use of these tools could lead to achievement of 5 to 15 percent energy savings with minimum investment, resulting in very attractive payback and quick actions by the plant. Development of user-friendly tools, together with appropriate instructions and guidelines will offer:

- Identification of areas of energy losses
- Simple steps to measure key process and operating parameters that affect energy losses
- Guidelines on types of instruments that can be used for measurement of key parameters (i.e. temperature, pressure, flue gas analysis) and data collection methodology
- Simple methods to estimate energy losses based on measured parameters

- Guidelines on possible methods or technologies that should be considered to reduce or eliminate energy losses while maintaining or enhancing production, product quality, and other parameters
- Simplified methods and software tools that can be used to analyze and estimate energy saving benefits by application of alternate energy saving methods or technologies
- Cost benefit analysis that provide dollar savings possible via application of one or more methods or technologies
- Estimation of CO2 reduction associated with each energy saving method or technology

Pioneering efforts and application of simplified tools during limited training and energy assessments promoted by some California utility companies (Southern California Edison and Sempra Energy) and U.S. DOE have shown that this approach offers the most cost effective method to achieve near-term energy savings, energy cost reductions and fewer CO2 and NOx emissions. Development of these tools, however, requires knowledge of industrial processes and identification of the common features of a wide variety of processes. It is difficult for one plant or even one industry group to develop tools that can have broad applications.

**Technology Gaps and Opportunities**

Energy efficiency assessment tools may be applied to the following:

- Process heating optimization (e.g. optimum combustion, reduction of flue gas losses, recovery of flue gas heat, preheat combustion air, cascading of waste heat, heat loss reduction through better insulation, elimination of heat losses, pressure control, humidity control, control of LEL)
- Steam system optimization (e.g., boiler performance control, blow-down water control and heat recovery, steam trap maintenance, steam leak maintenance, insulation of distribution and other components, reduction of steam use, cleaning of heat exchangers)
- Compressed air (engine driven) optimization (e.g., heat recovery from jacket cooling water, exhaust gas heat recovery, elimination of inappropriate end uses)
- Heat integration (e.g., heat cascading systems, process heat integration, pinch analysis)

A few specific areas of application are given in Table 2-12**.** All software tools described can be used for many applications in California industries using natural gas. Specific applications will depend on the type of plant and processes used. While key targets are the largest gas users, these facilities often have an energy manager working onsite to take advantage of energy management tools.

**Table 2-12: Opportunities for Energy Efficiency Assessment and Analysis**

| Opportunities for Energy Efficiency Assessment and Analysis | |
|---|---|
| **Industry** | **Description** |
| Oil & Gas Extraction | Tools that allow technical and economic analysis of integrated methods for low and medium temperature heat recovery, and reduction of energy use in compressed air and liquid heating systems. |
| Petroleum Refining | Analysis tools for improved operating practices, maintenance and low to medium temperature heat recovery, including use of waste heat for cooling applications. |
| Glass & Cement Residual | Analysis tools for oxy-fuel combustion, radiation losses, high temperature heat recovery and electric boost for glass melting applications. |
| Chemical & Allied Products | Tools for low to medium temperature heat recovery for air preheating, heat cascading, use of CHP and steam systems savings. |
| Primary Metal Industries | Analysis tools for improved operating practices, maintenance and low to high temperature heat recovery including use of waste heat for cooling applications. |
| | Tools to analyze improved maintenance for better heat containment (air leaks, radiation losses, water cooling). |
| Fabricated Metal Products | Tools for heat recovery, heat cascading, use of hybrid (gas-electric) systems, and other innovative techniques or systems. |
| Food Processing | Tools for analyzing use of CHP, absorption cooling, and heat recovery from vapors from large exhaust air in dryers, ovens, and similar equipment. |
| Paper Industry | Tools for analysis of make-up air control, humidity control in exhaust air, and low temperature heat recovery, including heat recovery from water vapor in exhaust air. |

**Government Role**

Smaller and mid-size manufacturers often do not have a dedicated energy manager, and would benefit more from government assistance in this area. Taken together, natural gas reductions achieved from these smaller facilities could be substantial. Tool development of this nature requires background and knowledge of energy systems in many industries, and the ability to present relevant energy-saving aspects in a common platform that can be used to benefit all industries. As a result, few such tools are available. The leadership and support of state organizations such as the Energy Commission, along with utility companies interested in pursuing demand-side management will be critical to developing and distributing tools that would meet the needs of California industries.

### ***Financial Analysis Tools***

Additional resources and tools are needed to assist plant personnel in estimating the energy savings and other benefits of energy management projects. While the energy use reduction or technical advantages of a project to improve efficiency may be readily apparent, it is often difficult to evaluate the economic benefits (e.g., payback). This justification is essential to sell the project to upper management, particularly when there are limited funds for investment, and/or the corporate spending philosophy is geared toward return on investment for shareholders. There is no good substitute for a cost/benefits justification based on solid data and financial analysis.

Financial analysis tools are readily available, but these may be too difficult for technical plant personnel without financial expertise to readily adapt for use. They may also not be specific enough to the individual industry, or may require too much time and effort.

**Technology Gaps and Opportunities**

Financial tools to enable analysis and justification for new energy projects that increase natural gas use efficiency may include the following:

- Calculation of equipment or system paybacks and return on investment, using standard economic tools such as discounted cash flow, with default variables built-in to ensure some measure of usability for the non-expert, to include both retrofit and new systems
- Estimation of economic penalties (cost of wasted energy)
- Scenario analysis to estimate economic benefits under different natural gas prices scenarios
- Economic benefits of switching between fuels
- Resources for investment cost data or estimates for proposed projects

All industries could benefit from effective financial analysis tools that enable evaluation of the economics associated with energy efficiency projects. While key targets are the largest natural gas users, these facilities often have energy managers on-site that are well-versed in how to sell energy projects to management and already take advantage of energy management tools. Smaller and mid-size manufacturers do not always have the funds to have a dedicated energy manager, and could benefit from user-friendly financial tools geared toward energy projects.

**Government Role**

There is potentially a government role for the Energy Commission and PIER to provide assistance for development of financial analysis tools tailored to industrial uses/energy efficiency, targeted financial training seminars for energy projects, or outreach and communication mechanisms. The objective would be financial tools that are more tailored to industrial users and require only limited financial expertise to use. There may be a greater government role for assisting small and mid-sized manufacturers with applying financial analysis to justify and reap the benefits of energy efficiency projects.

### ***Advanced Controls***

Sensor and control technologies are vital, yet often unseen, components of virtually every industrial process. Acting as part of a plant's "nervous system," these technologies work together with information processing, robotics, and wireless technology to improve process efficiency. Industry has identified the need for affordable, advanced real-time control systems to better manage and optimize energy performance or intensity (e.g., Btu/production dollars, Btu/unit product), with the overall objective of achieving greater efficiency.

Monitoring and control of processes can be a complicated and costly proposition, sometimes requiring extensive networks of sensors, computer processors, and other devices working in parallel. These systems measure process parameters and provide important information that allows plant operators (or feedback control systems) to diagnose problems and make corrections as needed to ensure efficiency and productivity. By developing reliable controls to maintain optimum air/fuel ratios, oxygen, and other parameters that impact energy use, plant personnel are empowered with the knowledge to optimize process heating and utility systems.

**Technology Gaps and Opportunities**

There are relatively few reported instances of control designed explicitly for energy savings. The objective is to increase the overall productivity of an operating process and indirectly achieve energy benefits. Studies have indicated that end-users estimate potential energy savings to range from about 2 to 25 percent; system vendors suggest savings on the order of 1 to 5 percent.[10] Technologies of interest include:

- Multivariable predictive control or nonlinear model predictive control for energy intensive unit operations: kilns, furnaces, dryers, boilers, distillation columns, and reactors
- Inferential control of product quality or soft-sensing, including the design of estimation schemes for key quality variables (as a surrogate for measurements obtained directly from hardware sensors); estimation could facilitate direct control of inferred variables, and thereby allow both direct and indirect energy savings
- Instrumentation and systems to monitor and control combustion and improve thermal efficiency, including process energy utilization controls and real-time energy use sensing
- Controls to monitor conditions in high temperature and/or pressure or harsh/corrosive environments (e.g., optical, ultrasonic, acoustic, microwave sensing and controls); other examples include wireless control and measurement technologies; non-invasive sensors for measurement of equipment integrity and condition; remote control systems; under-insulation systems; and fired system heat or product profiling (e.g., furnace heat flows, metal or glass melts)
- Integrated control of plant or mill, including cogeneration systems, including unit operations; includes coordinated control of power plant operations with the main plant-wide distributed control system (DCS)

Table 2-13 provides examples of technology applications where advanced sensors and controls could potentially be used to impact natural gas use and energy efficiency.

[10] EERE, 2004, http://www.eere.energy.gov/industry/sensors_automation/pdfs/doe_report.pdf.

**Table 2-13: Opportunities for Advanced Controls**

| Opportunities for Advanced Controls | |
|---|---|
| **Industry** | **Description** |
| Chemicals, Petroleum Refining, Cement, Food Processing, Pulp and Paper | Multivariable predictive control, nonlinear model predictive control for cement kilns, ethylene furnace, paper dryers, ovens, steam generation, chemical or petroleum distillation/fractionation, food pasteurization, chemical reactors |
| Chemicals, Plastics, Paper and Paperboard, Glass, Metals | Inferential control of product quality or soft sensing for plastics extrusion, chemical product separations, paper forming and drying, glass forming, metal casting |
| Chemicals, Petroleum Refining, Food Processing, Pulp and Paper | Integrated control of plant/mill and utility systems (e.g., biomass gasification or other pulping operations) |
| Chemicals, Petroleum Refining, Pulp and Paper, Primary Metals, Glass | Controls for condition assessment or processing in high temperature/harsh environments, such as those found in catalytic cracking, thermal coking, hydrotreating, ethylene furnace, glass melting |

**Government Role**

There is a potential government role to support precompetitive RD&D to develop advanced controls, through cost-shared projects with industrial partners (end-users and suppliers). These projects should emphasize the creation of low-cost, reliable, widely applicable systems for improving energy efficiency in natural gas-intensive industries. While accuracy is important, it should be balanced with the need for low cost and applicability. Preference should be given to systems that could be used in multiple industries (e.g., high temperature systems) to enhance the potential for greater replication of benefits. Government funding for demonstration and/or validation of the performance of these systems in practical operations could also encourage more widespread acceptance and use.

***Innovative Processes***

Innovations to industrial processing and product manufacture encompass 1) changes in instrumentation systems, product cycles or process configurations to improve operating efficiency that require little RD&D, 2) supply chain management improvement concepts, and 3) introduction of innovative or radical process and technology concepts that are more efficient but require some level of RD&D to implement. The ultimate objective for both approaches is to lower natural gas inputs.

Adjusting controls for part load operations and reconsidering outdated cycle times are examples of low cost changes that can significantly impact natural gas use but require little or no RD&D to implement. Many times operating cycles are mandated by outdated specifications (e.g., internal, or government mandated or regulated). Product and process specifications may include a built-in safety factor and are overly conservative, being derived based on an historical perspective of low natural gas prices. Plant engineers and operators may not understand the incentives and benefits of undertaking a relatively simple reevaluation of processing or product innovations from an energy viewpoint. However, these can lead to incremental improvements in energy efficiency that when taken in the

aggregate translate into significant cost savings for the plant. Supply chain management that includes process operations to meet just-in-time requirements while operating the systems at full load or near full-load could result in significant energy savings. This could provide increased thermal efficiency, and reduction of losses associated with the equipment operations at or near idling conditions to meet "rush" order requirements.

Areas that require RD&D might include innovative process designs or reconfiguration of processing to reduce processing steps and/or eliminate or reduce byproducts. These technology innovations would require some level of RD&D and are higher risk, both in terms of technology and economics. However, because they represent more radical changes, these improvements could result in more substantial impacts on natural gas use. Industry may be reluctant to undertake these innovations independently, primarily due to the technical and economic risks, long-term investment required, and difficulty in justifying the project to management.

**Technology Applications**

Near-term, low-cost optimization of process cycles and product specifications may include:

- Utilization of external energy management experts to evaluate process cycles and product specifications with the goal of reducing or eliminating inefficiencies, emphasizing potential impacts on natural gas use. These are highly process/product-specific solutions, and would require knowledge of energy aspects as well as unique industry requirements.
- Review and refining product specifications set by the government (e.g., military specifications in the metals industry) that may inadvertently be impacting energy efficiency, working cooperatively with regulating/specifying agency.
- Potential for reduction in natural gas use through closer integration of product and process specifications with process heating and cooling; this would be especially applicable to industries where products are produced via direct contact with the heating or cooling source, or where uniformity of heating or cooling impacts product quality.

Technologies requiring RD&D and representing more significant shifts in conventional processing methods may include:

- Process redesign for efficiency, with reduced processing steps, increased yields, or reduction/mitigation of byproducts and waste; this could include "green processing" where process redesign emphasizes both energy and environmental benefits. An example might be a process for chemicals manufacture, where a new synthesis path is utilized to eliminate an energy-intensive separation step. Emphasis would be on industries with more complex processing configurations utilizing numerous heat sources and sinks, such as petroleum refining, chemicals, and pulp and paper manufacture.

Table 2-14 provides selected examples for the application of innovative processes in California industries.

**Table 2-14: Opportunities for Innovative Processes**

| Opportunities for Innovative Processes | |
|---|---|
| **Industry** | **Description** |
| Chemicals, Petroleum Refining, Cement, Food Processing, Pulp and Paper, Fabricated Metals | Process and product cycle and specification reevaluation, with potential application in fabricated products governed by military or other government specification; drying times (food, paper, cement, other solids, fabricated metals) to achieve desired specifications; plastics extrusion |
| Chemicals, Plastics and Rubber, Food Processing | Product and process redesign for efficiency and/or recycle, particularly for chemicals manufacture (synthesis and separation); plastics forming and extrusion |

**Government Role**

A potential government role is to offset the risks of innovation through support for both near-term and longer-term cost-shared RD&D to improve processing and energy efficiency. Development of tools and/or targeted programs to incorporate innovation as a means of reducing natural gas use, conducted in cooperation with utilities, and utilizing the expertise of energy consultants, may be appropriate for government support. These might include the use of incentives (economic or other) to encourage innovative, brand new concepts or inventions that reduce natural gas use and increase efficiency. A grant program designed to foster near-term process innovations could be conducted to produce concepts that could be replicated across multiple industries and increase energy benefits.

### ***Non-Thermal Energy Alternatives to Process Heating***

Rethinking how energy is supplied to the process or product can lead to innovations that reduce natural gas use. For example, using microwaves as a substitute for direct heating could provide an alternative that requires no natural gas and a lower amount of electricity. In some cases, technology innovations may require RD&D and are higher risk, both in terms of technology and economics. However, because they represent more radical changes, they could result in more substantial impacts on natural gas use. Industry may be reluctant to undertake these projects independently, primarily due to the technical and economic risks, possible disruptions to process flow or product quality, long-term investment required, and difficulty in justifying the project to management.

**Technology Gaps and Opportunities**

Non-thermal alternatives such as microwaves could provide an alternative to more energy-intensive drying processes. In the past, attempts to employ microwaves in commercial processes requiring uniform heating have been unsuccessful and costly. Technologies are now emerging that achieve uniform microwave heating for continuous planar and cylindrical (e.g., through a pipe) processes on a production scale. This means microwaves could be applied to webs of fabric, sheets of paper, strands of foam, conveyed beds of material, streams of chemicals, lines of food, and similar processes for cost-effective heating, drying, bonding, curing, reacting, pasteurizing, or sterilizing. While microwaves rely on electricity, the overall energy requirements are thought to be much less.

Another example is membranes, which operate at ambient temperatures, and could be used to replace inefficient and high energy-using distillation processes. Membranes have also been successfully used in conjunction with distillation to replace more energy-intensive separation in the column, creating a hybrid separation system that substantially reduces direct fuel use (e.g., natural gas). Innovative process designs may be needed to accommodate alternate forms of energy. Table 2-15 provides some examples where non-thermal alternatives may be applied to reduce natural gas used in industrial processes.

**Table 2-15: Opportunities for Non-thermal Alternatives**

| Opportunities for Non-thermal Alternatives | |
|---|---|
| **Industry** | **Description** |
| Chemicals, Petroleum Refining | Hybrid distillation and other hybrid separations used for chemicals manufacture (synthesis and separation); crude fractionation; steam injected stripping towers |
| Food Processing Pulp and Paper | Microwaves, heat-activated power for drying of paint, foods, paper, chemicals, plastics, other solids |
| Iron and Steel, Pulp and Paper, Cement, Lime, Plastics and Rubber, Food Processing | Energy re-direction (substitution of steam for direct heat, others); steam-driven mechanical drives, curing processes, calcining, steelmaking, forming processes |

**Government Role**

In many cases non-thermal alternatives are radical innovations and may require substantial pre-competitive, longer term, higher risk RD&D. Demonstration of these technologies in practical operating conditions will be critical to ultimate acceptance and deployment at commercial scale, as they are relatively unproven for industrial applications. The potential government roles are to offset the risks of innovation through support for RD&D cost-shared with industry partners; support fundamental RD&D as needed to provide empirical and other operating data; and some measure of support for demonstration and validation at both pilot and larger scales if needed to encourage potential commercialization and use by industry partners.

### *2.3.3. Renewable Energy for Greenhouse Gas Reduction*

Renewable energy resources, such as wind, solar or bioenergy, are attractive because they are continually replenished and provide an alternative to finite fossil energy resources. Renewable resources are abundant in California and could provide an alternative to natural gas in some applications. Initial targets for industrial use would include solar and wind energy for process heating, cooling and on-site power generation, and liquid fuels derived from biomass (crops, agricultural and forestry residues, switchgrass and other energy crops, manure, and oil seeds) for industrial transport and power or heat production. Other bio-derived energy sources include methane from landfills (biogas) as a direct substitute for natural gas, and combustion of wood or wood byproducts for process heating.

Renewables may be more cost-effective than fossil fuels and less subject to supply and price volatilities. Many renewable resources also have better environmental footprints and produce fewer or no emissions of greenhouse gases. The generation of electricity from

solar, wind, geothermal, or hydropower sources, for example, contributes no carbon dioxide or other GHGs directly to the atmosphere. Fuels derived from cellulosic biomass (corn stalks, switchgrass, forest residues) have been shown to potentially decrease emissions of GHGs by as much as 86 percent when compared with conventional transportation fuels in combustion engines.[11] Increasing the contribution of renewables to the California energy portfolio will directly lower GHG intensity in proportion to the amount of carbon-emitting energy sources displaced. As an alternative to natural gas, renewables could provide reductions in emissions of criteria pollutants, particularly nitrogen oxides that result from combustion of natural gas in process heaters, boilers and other systems.

**Technology Limitations**

Despite advances in technologies, renewable energy makes a relatively small contribution to the California energy supply for industrial plants. A number of barriers continue to limit the market penetration and more widespread use of renewable energy technologies. High costs in some cases still hinder the implementation of solar technology for many uses. Renewables are still considered market risks by many industrial and other investors. Some renewable power generation technologies such as wind and solar also have increased perceived risk related to the variability of the resource. Biomass power and fuels are subject to a perceived high risk related to availability of a long-term supply.

Regulatory policy can favorably impact the use of renewables, particularly via state mandates to increase use of these resources. However, policies that seek to limit criteria pollutants (e.g., such as those requiring new power installations to use natural gas-fired systems) could potentially make it difficult to use renewables for generation of power at industrial facilities. Permitting and siting requirements in general can create delays in the construction and operation of renewable as well as other energy systems.

**Technology Solutions**

Significant technology advances continue to be made and are facilitating the more widespread use of solar and wind energy and biomass-derived fuels. The development of these technologies has helped increase their potential for commercialization by lowering costs, increasing efficiencies, and improving performance.

Solar, wind and other technologies could potentially be harnessed to provide process heating or electricity at industrial facilities in lieu of natural gas. Some industrial facilities are already taking advantage of solar technology in particular to provide heat for building envelopes and other uses.

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[11] Wang, "Updated Energy and Greenhouse Gas Emissions from Fuel Ethanol", 2005, http://www.transportation.anl.gov/pdfs/TA/354.pdf.

### 2.3.3.1. *Renewable/Alternative Energy Sources*

***Renewable Fuels***

Industry has identified a need for further development of renewable/alternative energy sources that may be used in place of natural gas in industrial applications. Renewable fuels that could be targeted initially for industrial users would come from dedicated biomass (crops, agricultural and forestry residues, switchgrass and other energy crops, manure, and oil seeds), in-plant byproducts (scrap organics, process fumes, residual carbonaceous materials) or waste sources such as methane from manure, landfills (MSW), sewage plants, and others. These alternatives may have better environmental footprints and produce less impact on climate change (fewer emissions of greenhouse gases), or may represent a valuable use for wastes that must currently be disposed of in landfills or treated.

While some of these fuels are now more widely available (ethanol, biodiesel) from commodity crop sources, technology RD&D is still needed to overcome cost and other hurdles of producing biofuels from cellulosic biomass such as residues and energy crops. Opportunities exist to use these fuels in industrial transport systems (on-site) or in fuel-flexible combustion equipment capable of firing both liquid and gaseous fuels. Gases that are primarily methane, produced from sources such as landfills and manure, could provide a gaseous fuel that is directly substitutable for natural gas in power or heating systems. There are barriers associated with the consistency of composition, supply in the required quantities for large- to medium-sized plants, distribution infrastructure, siting and permitting of these sources, however, and the need to co-locate sources close to the industrial site to reduce the cost of transport and storage.

**Technology Gaps and Opportunities**

Gasification of biomass to produce low or medium-Btu synthesis gas (syngas) is perhaps the most viable technology option for creating an alternative fuel in the near term for industrial uses. While gasification is a mature technology, there is only one biomass gasification demonstration facility currently operating in the United States (although others are planned). Pyrolysis to produce fuel oil is another viable option, but is less developed. Landfill gas from municipal landfills or farm digesters is another potential option for using a biogas substitute for conventional methane.

- **Gasification of biomass to produce synthesis gas for heat and power** – Nearly any biomass can be gasified to produce a syngas that can be combusted as fuel in natural gas-fired equipment. Biomass gasification is a high-temperature process (~1000 to 1800˚F) to decompose the complex hydrocarbons of biomass into simpler gaseous molecules, primarily hydrogen, carbon monoxide, and carbon dioxide. In most cases, char and tars are also formed, along with methane, water and other constituents. Hydrogen and carbon monoxide are the desired product gases, because they can be directly fired into a gas turbine or used in chemical synthesis. The product gas must be cleaned of solids, tars, and other contaminants sufficient for the intended use. Biomass gasification produces a combustible mixture of raw gases that vary according to the feedstock and gasification approach. Steam reformed, indirect, and

oxygen fired direct gasification systems produce biobased syngas, a medium energy combustible and reactive mixture rich in hydrogen and carbon monoxide with a heating value in the range of 10 to 20 MJ/Nm$^3$. Air fired direct gasification systems produce a low-energy, bio-based fuel gas, with a heating value of 2.5 to 8.0 MJ/Nm$^3$. Biomass gasification units vary from small scale systems that generate 5 to 25 kW of electricity to industrial and electric utility scale systems in the 5 MW to 12 MW range. The pulp and paper industry is already pursuing gasification as a technology platform for producing both heat and power using black liquor as well as wood residues. While there are technologies available, they have not been adequately demonstrated for industrial applications.

- **Pyrolysis of biomass to produce liquid and gaseous fuels** – Fast pyrolysis technologies encompass the bubbling fluidized bed, circulating fluidized beds/transport reactor, rotating cone pyrolysis, ablative pyrolysis, vacuum pyrolysis and Auger reactor. Typical yields for pyrolysis are oils 60 to 70 percent, char 12 to 15 percent, and gas 13 to 25 percent. Using wood, the major product is 75 percent bio-oil (by weight), which can substitute as fuel oil or diesel in static operations in boilers or other unit operations. The gases can be fired in a boiler or in a gas engine; the char may be combusted in the pyrolysis unit to drive the process auto-thermally. Technical barriers include combustion deposits, maintaining high yields, bio-oil stability, and preparing the feedstock for pyrolysis. Technologies have been tested at pilot and commercial scale here and abroad, with variable success. Limited demonstrations have been conducted for industrial uses in the U.S., although food processors in Europe have used bio-oils to power process heaters and boilers.
- **Landfill gas as natural gas supplement** – Landfill gas is the natural by-product of the decomposition of solid waste in landfills and is comprised primarily of carbon dioxide and methane. Recovering landfill gas prevents emissions of methane (a powerful greenhouse gas) and provides energy from waste. Landfill gas is extracted from landfills using a series of wells and a blower/flare (or vacuum) system. This system directs the collected gas to a central point where it can be processed and treated depending upon the ultimate use for the gas. From this point, the gas can be used to generate electricity, replace fossil fuels in industrial and manufacturing operations, fuel greenhouse operations, or be upgraded to pipeline quality gas.

Table 2-16 summarizes some of the industrial applications for renewable fuels produced via gasification or pyrolysis, or existing fuels such as ethanol and biodiesel. Some of these could be more readily implemented (gasification in the pulp and paper industry) or are already being explored. Others may require co-siting of facilities (biogas) or be limited by the supply of readily available fuels.

**Table 2-16: Opportunities for Renewable Fuels**

| Opportunities for Renewable Fuels | |
|---|---|
| **Industry** | **Description** |
| Food Processing, Pulp and Paper, Chemicals | Gasification of biomass to produce syngas for combustion; used for gasification of wood wastes in pulp mills; gasification of solid food processing wastes; feedstock for chemical products (ammonia) |
| All industries with capability to switch from natural gas to other fuels | Substitution of biodiesel, ethanol, other biofuels in combustion equipment, such as process heaters or boilers direct-fired with natural gas |
| Chemicals, Food Processing, Pulp and Paper | Substitution of landfill or manure methane for natural gas used in direct-fired process heaters or boilers, gas, co-location with rural sources |

**Government Role**

The State of California has committed to increasing the use of renewables through various policies and legislative actions. The potential role for the Energy Commission is in development of industry-specific applications with industrial cost-sharing, and in demonstration of these technologies in actual operating situations at the pilot or commercial scale. This would provide valuable operating data to reduce the risk of investment and foster the potential for more widespread acceptance and use. While there is tremendous interest in using alternatives, particularly renewable, these projects may be difficult to justify to management. Thus, there may also be an outreach role to increase awareness of the potential options for using alternatives and the costs and benefits.

***Solar, Wind and Other Renewables for Electricity and Heat***

Solar, wind and other renewable sources could be harnessed to provide on-site generation of heat and/or power in industrial facilities. An older survey conducted to determine potential applicability of solar thermal energy to industrial processes in California found that if the heat for all industrial processes at temperatures below 212°F were supplied by solar energy, total state energy consumption could be reduced by 100 trillion Btus (2 percent), while the use of solar energy in processes between 212°F and 350°F could displace 500 trillion Btus.[12] Solar energy was found to be technically feasible for processes with thermal energy requirements below 212°F with the design and degree of technical, economic and management feasibility being highly site-specific.

A key barrier to the widespread deployment of solar photovoltaic (PV) systems is the lack of purchasing channels and trained installers. PV products are difficult to find and are often not available as complete, certified, and guaranteed systems. PV technology needs to become simple enough to be purchased, installed, and serviced by nationwide retailers. Systems may also need to be tailored to specifically fit industrial applications, requiring additional engineering and design work.

[12] Pivirotto, "Solar Energy in California Industry-Applications, characteristics and potential", 1978.

**Technology Gaps and Opportunities**

In addition to PV systems currently in the market, advanced solar technologies in thin-film semiconductors can provide increases in efficiency in the near future. For example, cadmium telluride thin-film technology is actively commercialized with cell efficiencies of more than 16 percent in the laboratory and commercial module efficiencies projected to be in the nine percent range in the manufacturing plants. Industrial applications could include:

- Water preheating in a multitude of industries
- Powering of oil and gas field operations (production and exploration); Chevron Energy, for example, has completed installation of one of the larger PV systems in the U.S. in Bakersfield, CA to power oil field operations
- Modular renewable electric heating to replace natural gas dryers and other heaters
- Remote or wireless technologies

**Government Role**

Various incentives already exist in California to support the use of solar industrial energy. The California Public Utility Commission (CPUC) rebates, together with state and federal tax incentives, provide considerable subsidies for the cost of commercial solar systems. The California Solar Initiative (CSI) allocates $2.95 billion for solar energy rebates in the state for the next 7 years, expected to provide for the installation of approximately 2,640 MW of solar energy. This is roughly the power equivalent of six large natural-gas fired power plants. The CPUC will provide customer incentives for solar projects on existing residential buildings, as well as all public buildings, industrial facilities, businesses, and agricultural facilities.

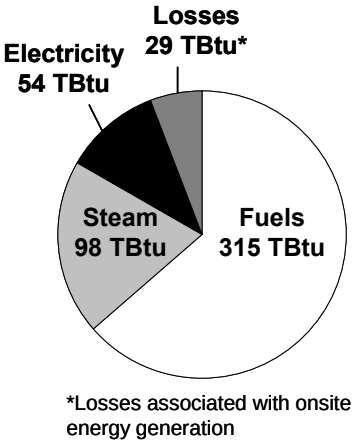
California rebates for solar systems start at $2.50 per watt and $0.39 per kWh and will decrease with increases in installed capacity. There is a state property tax exemption for 100 percent of the value of solar energy system equipment and 75 percent of the value of pipes and ducts used to carry both solar energy and energy derived from other sources.

# 3.0 Petroleum Refineries

## 3.1. Introduction

As in the United States, petroleum refineries are the largest industrial users of natural gas and electricity in California. In 2001, petroleum refineries in California consumed nearly 500 trillion Btus of energy, over 67 percent in the form of natural gas or other fuels Figure 3-1.[13] The industry is also a major contributor to the California economy, employing almost 13,000 people and accounting for 15 percent of the total value of manufacturing shipments from the state. In addition, California's refineries account for 12.5 percent of the workforce and value of shipments of the U.S. petroleum refining industry.[14]

**Figure 3-1: Distribution of Energy Use in California Refineries**




The Energy Commission conducted a workshop in Los Angeles, California in January 2004 to provide input for a technology roadmap of RD&D needed to address energy challenges faced by California petroleum refineries. Representatives from California refineries were asked to provide input and help build consensus for the technology roadmap effort. The goal was to develop information that would reflect the views of at least 80 percent of California refineries (by volume production). California's refineries with associated production capacity and participation level are shown in Table 3-1.

California refiners were asked to provide their views concerning current and future energy challenges by responding to a series of topical questions, including:

- What are the current goals and corresponding strategies that should be undertaken to ensure the availability of cost-effective, reliable energy resources for California refineries, and to minimize industrial demand for both electricity and natural gas?

[13] Worrell, 2003.

[14] EIA, 2006.

- What are the drivers, barriers and challenges (technical or otherwise) to reducing energy demand in California refineries?
- What technological RD&D activities should be undertaken to improve energy utilization in California refineries and ensure the availability of energy supplies? What demonstrations are needed to promote the use of more efficient energy technologies?

The resulting roadmap document, *Energy Efficiency Roadmap for Petroleum Refineries in California*, is summarized in this chapter. The following sections summarize top priority RD&D needs and current regulatory and policy issues as identified by California refiners. The report was updated in 2009 to reflect additional regulatory and policy issues that have emerged since its publication. The roadmap provides a good overall perspective of the current energy situation facing California refiners and some of the components that could serve to improve conditions in the future.

**Table 3-1: California Refineries**[15]

| California Refineries | | | |
|---|---|---|---|
| **Refinery** | **Location** | **2009 Production Capacity (barrels/ day)** | **Roadmap Participant?** |
| ChevronTexaco | El Segundo | 279,000 | Yes |
| BP West Coast Products | Los Angeles | 265,000 | Yes |
| ChevronTexaco | Richmond | 245,000 | Yes |
| Tesoro Refining | Martinez | 166,000 | Yes |
| Shell Oil Products, U.S. | Martinez | 156,000 | Yes |
| ExxonMobil | Torrance | 149,000 | Yes |
| Valero | Benicia | 144,000 | Yes |
| ConocoPhillips | Wilmington | 139,000 | Yes |
| ConocoPhillips | Rodeo | 120,000 | Yes |
| Tesoro Refining | Wilmington | 97,000 | Yes |
| Ultramar | Wilmington | 81,000 | No |
| Big West of California | Bakersfield | 66,000 | No |
| Kern Oil and Refining Company | Bakersfield | 26,000 | Yes |
| Edgington Oil Co Inc | Long Beach | 18,000 | No |
| San Joaquin Refining Company, Inc. | Bakersfield | 15,000 | Yes |
| Greka Energy | Santa Maria | 9,500 | No |
| Lunday Thagard Co | South Gate | 8,500 | No |
| Valero | Wilmington | 6,300 | Yes |
| Tenby Inc | Oxnard | 2,800 | No |
| Paramount Petroleum Corporation | Paramount | 0 | Yes |
| Total Operating Capacity Represented | | 1,103,000 | |
| Total California Operating Capacity | | 1,994,000 | |
| Percent of California Represented | | 90.6% | |

[15] EIA, "Capacity of Operable Petroleum Refineries by State", 2009.

## 3.2. Energy Goals & Strategies

The overarching energy goals identified by California refineries and potential strategies for reaching those goals are shown in Table 3-2. On the energy supply side, ensuring the availability of a reliable, stable energy supply is a goal that could potentially be met by increasing flexibility in the selection of energy resources and establishing more productive partnerships with energy suppliers. Taking advantage of innovative energy resources such as coke-based synthesis gas, fuel cells, hydrogen, and fuels produced from biomass or landfills would increase the energy options available to refiners and enhance energy stability.

From an energy efficiency standpoint, implementation of more efficient technologies is a key goal. Strategies for meeting this goal include the use of government dollars to accelerate technology development and use (RD&D and other cost-sharing), and making sure government understands industry needs and where technology will have the most impact.

Improving the flow of information about new, more efficient technology, and developing data that will make the case for adoption of technology is an important goal and critical to reducing future energy demand in refineries. For example, case studies of successfully implemented efficiency projects could advance investment in efficient equipment.

**Table 3-2: Energy Goals and Strategies**

| Energy Goals and Strategies | |
|---|---|
| Stable, Available Energy Supplies | • Eliminate the barriers to selecting the most efficient energy resource (dynamic energy supply – energy environment is changing daily, sometimes hourly).<br>• Reduce the cost of power in California.<br>• Develop more innovative partnerships between utilities and refineries to maximize overall electrical and fuel supply system; create more efficient business arrangements while serving the needs of both refineries and the public.<br>• Take better advantage of the large heat sink that refineries represent (co-location). |
| Innovative Energy Resources | • Build coke gasification plants in northern and southern California.<br>• Clarify the role of refineries in fuel cells and the hydrogen economy.<br>• Make stationary fuel cells and alternate energy sources available at refinery sites.<br>• Take advantage of gas expansion in refineries (e.g., to generate power).<br>• Create innovative energy partnerships with non-utilities (e.g., landfill gas usage). |
| Development, Demonstration and Adoption of Energy Efficient Technologies | • Identify the most capital-efficient energy reduction opportunities; use government dollars to offset capital limits (without strings attached).<br>• Undertake the energy efficiency projects that have been identified.<br>• Provide feedback to the Energy Commission regarding which technologies need demonstration and validation for California refineries.<br>• Let government serve as the connection between venture capitalists and technology innovators for energy efficiency.<br>• Move standards from lowest common denominator to encourage adoption of newer, more efficient technologies. |
| Improved Energy Information and | • Create a central information source for low-capital technology vendor options, including past use information. |

| | |
|---|---|
| Communication | • Establish a database of refineries and energy specialists to form communication lines; work together to avoid vendor bias; create 5-page case studies of successful implementation of efficient technology (i.e., "what it took").<br>• Enhance access to available information on improving efficiency; feedback is needed on what information is most valuable. |

## 3.3. Drivers, Barriers & Challenges

The drivers, barriers and challenges facing California refiners now and in the future include innovative energy sources, technology development and deployment, permitting and regulation, cogeneration, power supply, and plant investment (Table 3-3).

In 2006, the California state legislature passed the Global Warming Solutions Act (Assembly Bill 32, Nunez, Chapter 488, Statutes of 2006 (AB32)), a comprehensive long-term policy aimed at reducing the state's greenhouse gas emissions. Along with many other industries, the petroleum industry was identified as a key target area for emissions reductions. In the scoping plan it released in December 2008, ARB identified six early actions to meet AB 32's reduction goals for petroleum refineries. This list includes four early action targets related to energy efficiency:

1. Increase CHP generation by 30,000 GWh (Scoping plan identifies utility incentives, feed in tariff and creation of CHP portfolio standard as mechanism for increasing CHP generation)
2. Limit GHG emissions from flaring
3. Refinery energy efficiency audits to target GHG sources (combustion and otherwise)
4. Improved methane leak detection, process modification, equipment retrofits and replacements and best management practices

ARB's priorities reinforce the importance and relevancy of PIER's IAW RD&D roadmap for petroleum refineries. The first two early actions listed above correspond with specific priorities identified in this report. The next two early actions listed reaffirm the importance of energy efficiency technology for petroleum refineries in California.

### *3.3.1. Innovative Energy Sources*

Fuel flexibility would improve the energy options available to refiners. Advances in technology are needed to ensure that fuel flexibility and processing goals are not at odds. There are also many technical challenges to using refinery gas and coke instead of other fuels. For example, current technology is inadequate for cost-effectively cleaning some refinery off-gases so they can be used to displace natural gas during periods of high prices. Significant energy is required to remove the last few parts per million (ppms) of contaminants, and more efficient technology is needed to accomplish clean-up.

Improvements are also needed for coke and asphalt gasification to utilize these byproducts as fuels (e.g., produce liquid fuels that are sulfur-free), with cleanup of gasification streams

constituting a major issue. Technology is also lacking for the economic and efficient use of some excess energy resources, especially low grade waste heat generated in the plant.

### 3.3.2. Technology Development and Deployment

Deployment of energy efficient technology can be inhibited by lack of proven reliability. For example, plant owners may not be convinced that high-efficiency motors are sufficiently reliable. Variable speed drives are in use at some refineries, particularly those that have upgraded their infrastructure. However, some new motors and variable speed drives have not proven to be reliable, leading to lost opportunities for improving efficiency. Another issue is the limited availability of updated codes and standards for new technologies, which increases the risk of deployment.

More efficient technology can have a significant impact on energy use and plant profitability, especially when fuel prices are high. There are many technologies on the shelf (commercially available) that were not considered before, but should be re-evaluated in light of higher gas prices. In some cases, innovation may be required. Better catalysts for hydrogen plants, for example, could make refineries more responsive to natural gas price peaks.

### 3.3.3. Permitting and Regulation

California refineries are being squeezed by rising demand, increasing regulations, and difficulties in obtaining permitting. Permitting is fragmented and non-uniform across the State, which creates uncertainty in the permitting process and adds complexity to new energy projects. The length of time required for permitting affects the economics and ability of companies to take on some energy efficiency projects. The lack of a broader view behind permitting in California makes it difficult for refiners to take advantage of opportunities to export excess energy (e.g., electricity) back to the local grid. This impacts their propensity to add new, more efficient onsite generation facilities.

Regulations are costly to comply with and often provide disincentives to energy efficiency. New Source Performance Standards, for example, are a disincentive to putting in new, efficient equipment versus rebuilding or retrofitting of old equipment. If a refiner builds and installs new equipment, regulations dictate the use of natural gas, which eliminates the possibility of using inexpensive, readily available waste gases. $NO_x$ reduction efforts may reduce heater efficiencies because equipment is already working at technology limits, with the end result of increasing energy use.

Regulations put pressure on refineries to make cleaner fuels such as low sulfur diesel (which requires higher processing energy and results in greater plant emissions) and simultaneously reduce plant emissions. As a result, refiners are faced with a difficult balance between environmental and energy regulations. Refineries are too often faced with trying to survive economically while regulations surpass technical capabilities.

**Table 3-3: Drivers, Barriers, and Challenges**

| Drivers, Barriers, and Challenges |
|---|
| Innovative Energy Sources |
| • Technical challenges to using refinery gas and coke versus other fuels<br>• Inadequate technology for efficient use of excess energy, especially low grade waste heat<br>• Conflicts between fuel flexibility and processing goals |
| Technology Development & Deployment |
| • Lack of updated codes and standards for new technologies<br>• Variable reliability of high-efficiency motors<br>• Catalytic limitations in hydrogen plants and impacts on natural gas demand<br>• Commercial technologies not fully evaluated for energy savings potential due to low fuel costs |
| Permitting & Regulation |
| • Fragmented, non-uniform permitting<br>• Time required for permitting<br>• Disincentives of New Source Performance Standards<br>• Trade-off between NOX reduction and heater efficiencies<br>• Regulations based on technical targets vs. specific additives<br>• Balancing regulations for cleaner fuels and plant energy emissions<br>• Constantly changing regulations<br>• Regulations dictating use of natural gas vs. plant waste gases<br>• Inadequate understanding of refineries by regulators |
| Cogeneration |
| • Significant permitting issues for new cogeneration facilities<br>• Long payback and increased risk due to fuel price uncertainty<br>• Constantly changing (and hostile) regulations in California toward generation of electricity onsite<br>• Regulations preventing plants from being "good neighbors" and providing excess power to communities<br>• Higher energy costs creating a push toward cogeneration<br>• Refineries approaching maximum cogeneration capacity |
| Power Supply |
| • Power interruptions/bumps<br>• Inadequate, outdated power protection systems in refineries<br>• Standardized reaction at utility to voltage dips<br>• More demanding electricity quality and reliability requirements of new technology<br>• Variability of energy use and availability<br>• Response of refineries to peaks |
| Plant Investment |
| • Lack of capital for installation of new equipment<br>• High upfront cost for efficiency projects (capital, permitting) and long paybacks<br>• No means of communicating the economic and resource value associated with energy efficiency<br>• Justifying energy conservation projects with uncertain fuel situation |

### *3.3.4. Cogeneration*

Refineries continue to explore cogeneration as an option due to high energy costs in California. Cogeneration, the production of electricity and steam, has a high thermal

efficiency and could provide benefits to refineries and the public. However, cogeneration technology has many barriers preventing widespread adoption.

From an economic perspective, the long payback period and fuel price uncertainty increases the associated investment risk. Additionally, permitting and regulation do not encourage the use of cogeneration. Cogeneration facilities are difficult to build in California due to constantly changing (and perceived hostile) regulations toward onsite electricity generation. Volatile natural gas prices are also driving a desire to use alternative fuels in cogeneration, but significant permitting issues remain a barrier. In some cases, refineries are reaching their maximum capacity for use of cogeneration, particularly when it is difficult to transport excess energy offsite. While plants in suburban settings would like to take "good neighbor" actions and provide excess power to the community, regulations prevent this transaction.

### 3.3.5. Power Supply

Power interruptions and bumps are extremely detrimental for refineries. Coordination among utilities and refineries to minimize bumps could be an effective approach to mitigate these potential issues (e.g., have preliminary discussions before bringing a 10,000 hp motor on-line). Power protection systems in refineries are often old and inadequate for the power requirements of new technologies. In addition, the standardized reaction of the utility to voltage dips does not always benefit the industry. Utilities and refineries can work together to identify and address these issues.

New and advanced technologies tend to have electricity quality and reliability requirements. The variability of electricity use eventually impacts utility rates and the capability to ensure energy is available during peak periods.

### 3.3.6. Plant Investment

Refineries typically lack capital for installation of new equipment. Exacerbating the problem is that the upfront costs for efficiency projects can be prohibitively high (capital, permitting, delays). These projects often have longer paybacks and can be stalled or prevented by the difficult regulatory and permitting process. In justifying the investment, it is difficult to gain the full value for energy saved due to fuel imbalances, the cost of meeting regulations, and utility constraints.

Energy conservation projects overall are often hard to justify because of the uncertainty in fuel price and supply. It is also difficult to demonstrate and quantify the real economic and resource value of improving energy efficiency in refineries, in order to justify such projects to corporate, State government, or other decision-makers. Under the current investment climate, funds for such projects must also compete with investments for environmental compliance or product-related research with a more transparent return on investment. Utilities have some funds available for energy efficiency projects, but indicate that these would need to be leveraged by refinery cost-sharing, and that refineries would need to make the technology available.

## 3.4. Technology Research, Development and Demonstration

### *3.4.1. Technology RD&D*

RD&D needs were identified in five major areas: treatment and sulfur removal, process improvements, electricity conservation and generation, energy systems and energy management, and new process technology. A prioritized summary of RD&D needs is shown in Table 3-4. From the prioritization of ideas emerged a group of 'top ten' research topics that were of interest to California refineries. The technical elements of these 'top ten' research topics are illustrated in Figures 3-2 to 3-11.

**Table 3-4: Technology Research and Development Needs**

| Technology Research and Development Needs | | | | |
|---|---|---|---|---|
| Refinery Priority = ● Other Participant Priority = ◘ | | | | |
| **Treatment and Sulfur Removal** | **Process Improvements** | **Electricity Conservation/ Generation** | **Energy Systems/ Energy Management** | **New Process Technology** |
| Gas treatment technology to enable use of plant gas instead of natural gas ●●●●●●◘◘◘<br><br>Desulfurization of fuels via biotreatment to eliminate hydrotreatment ●●●●●●<br><br>Alternative fuel processing technology to meet future low sulfur fuel requirements ●<br><br>More efficient low capital and operating cost process to remove sulfur and ammonia ●<br><br>Technology to mitigate fuel gas corrosion and trap oxygen during fuel gas processing ● | Advanced technologies for online inspection of pressure vessels and piping ●●●●◘<br><br>Reduce corrosion and fouling in cooling water systems, particularly in higher load areas; better understand heat exchanger fouling ● ●●◘◘<br><br>More activity from existing reactors (e.g., better catalysts) for diesel treating and hydrocracking ●<br><br>Air preheat technology demonstration in California without increasing $NO_X$ ●<br><br>Improved desalting technology (e.g., examine upstream factors that impact desalter performance) | Use gasification gas for electrification or gas-to-liquids projects ●●●●●◘◘◘<br><br>Efficient recovery of low-level heat for useful electrical or thermal energy ●●●<br><br>Combine coke gasification with municipal waste disposal ●●<br><br>Lower-cost, smaller scale cogeneration systems ●<br><br>Capture low grade waste heat with industrial heat pumps or adsorption chillers ◘◘ | Software to help end-users understand where energy is used ●◘◘◘<br><br>Energy management systems specific to refineries ●◘◘<br><br>Hydrocarbon properties available in an easy-to-use format ●<br><br>Monitors for $NO_X$, O2 to control fuel streams to heaters and optimize efficiency ◘◘<br><br>Smart systems to optimize electrical applications and reliability<br><br>Reliable steam traps (not | Innovative ways to supply heat/power to unit operations to reduce losses (e.g., microturbines) ●●●◘◘◘<br><br>Alternatives to steam-methane reforming for hydrogen production (e.g., recovering hydrogen from hydrogen sulfide and ammonia) ●●●●●●●◘<br><br>Membrane separations for propane/butane as alternative to distillation ●●●<br><br>Better technology to cut coke, remove coke from coke drum ◘<br><br>Microwaves for heating feed streams to towers ◘<br><br>Advanced distillation |

| | | | | |
|---|---|---|---|---|
| Characterization of crude oils with respect to sulfur compounds | Less energy-intensive, more reliable flare/purge gas recovery systems | | incremental improvements) | processes |

Some of the highest priorities identified were in the area of treatment and sulfur removal (Figures 3-2, 3-3). With increasingly stringent fuel formulation requirements on the horizon, and the decreasing quality of crude, cost-effective treatment and upgrading of refinery streams is becoming even more critical. Research is needed to explore new technologies such as biodesulfurization of fuels and treatment of refinery waste gases to upgrade fuels and remove fouling components. Waste gas clean-up, for example, will be critical to greater utilization of byproduct fuels as an inexpensive energy source.

Research to develop new process technology (Figures 3-4 to 3-6) is another high priority. Innovative or alternative ways of integrating energy-intensive operations in the refinery with energy sources could optimize energy use and improve control of processes. Another priority is the development of advanced technologies that represent alternatives to current processes that are energy-intensive. This might include technologies to replace distillation, which is used throughout the refinery, and steam reforming of methane for hydrogen production. Both are large energy consumers and relatively inefficient. New technologies for recovering hydrogen from refinery gases such as hydrogen sulfide and ammonia could provide alternative sources of hydrogen.

The development of energy management (Figure 3-7) tools was identified as a priority for enabling energy optimization and control in refineries. Effective tools could provide real-time analysis of refinery data and relay information on energy sources and sinks within the plant. Beta testing of software and models for improving energy efficiency was also identified as a potential area for future demonstrations.

A priority issue for improved process operations (Figure 3-8) is the ability to monitor the condition of pipes, vessels, and other equipment. On-line inspection technology is needed to reduce failures, improve productivity and run times, and reduce energy use associated with maintenance, shut downs and startups. Another priority is the mitigation and control of corrosion and fouling in plant equipment. Better understanding of fouling mechanisms is a key component.

Priority topics identified in electricity conservation and generation (Figures 3-9 to 3-11) would broaden the energy options available to refineries and increase fuel flexibility. Gasification of refinery byproducts such as coke or residuals could provide fuels to run turbines and process equipment, and also be a source of hydrogen. Low level waste heat is a large source of energy that could be recovered with the right technology and used productively in the plant for thermal or electrical energy. While some technology exists, innovative working fluids and new heat exchanger designs may be needed.

### *3.4.2. Technology Demonstration*

Demonstration and validation are important in fostering industry adoption of new technology. For energy efficiency projects, input should be obtained from industry on a project-by-project basis to assess the level of interest in specific technology demonstrations. Soliciting refinery interest at the front end will provide a clear understanding of the value of the demonstration to other refineries in the state.

The Energy Commission and refiners should devise innovative ways to work together on demonstrations. The Energy Commission, for example, could provide equipment instead of cash or loans. Another approach would support collaborations for technology sharing (e.g., vendors working with end-users to validate technology). Beta testing of new energy management software is a potential demonstration activity that could yield benefits for refineries with little investment required.

## 3.5. Priority Research Areas

### Figures 3-2 and 3-3: Priority Research Areas – Sulfur Treatment and Removal

**Treatment and Use of Refinery Plant Gas**

Technology is needed to treat plant fuel gas to remove fouling components ($SO_2$, moisture) so it can be used to replace natural gas in turbines and other equipment without causing performance problems or additional emissions.

**Key Technical Elements**

- Capable of meeting equipment feed requirements (e.g., turbines, gas engines, hydrogen plant feed, tank blanketing)
- Disposal requirements must be adequately addressed
- Constituents of concern: $H_2$, $O_2$, S (not $H_2S$), water, combustion characteristics (olefins, $H_2$, Btu variability)

**Risk**

LOW — HIGH

Technical Risk

Requires considerable RD&D, multi-disciplinary

Commercial Risk

New technology, not demonstrated

**Potential Partnerships**

Suppliers of equipment utilizing the gas (turbine manufacturers)
Suppliers of process equipment
Refining industry
AQMD

**Benefits to Industry**

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:** Mid-term (3 years)

**Desulfurization of Fuels Via Biotreatment**

The goal is replacing conventional hydrotreatment with a less energy-intensive biotreament process for desulfurization of fuels. Biotreatment requires less severe operating conditions (lower pressure and temperature), which results in a reduction in energy use and associated emissions.

Key Technical Elements

- Resilient to process upsets and varied conditions (reliability)
- Capable of handling necessary fuel flow rates
- Successful resolution of scale-up issues
- $H_2S$ handling capability

**Risk**

LOW — HIGH

Requires considerable RD&D, basic science and

Commercial Risk

New technology, not demonstrated, trade-off between energy and O&M costs not known.

**Potential Partnerships**

Universities
Biotechnology companies specializing in biotreatment
Refining industry
Federal – funding for university and national laboratory RD&D

**Benefits to Industry**

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:** Long-term (more than 10 years)

**Figures 3-4 and 3-5: Priority Research Areas – New Process Technology**

### Innovative Heat and Power Sources

Innovative ways of supplying heat and power to refining unit operations are possible through more effective integration of units operations with utility systems. In addition to energy savings, heat integration analysis will provide an energy footprint and improve process control.

**Key Technical Elements**

- Heat integration analysis
- Heat recovery and heat pumping
- Total system design /development: up-front connection of unit operations to utilities
- Entropic analysis versus enthalpic analysis

**Risk**

LOW — HIGH

Technical Risk

Moderate RD&D required

Commercial Risk

Low to moderate capital investment

**Potential Partnerships**

Equipment vendors
Gas turbine/engine manufacturers
Electric and gas utilities
Process technology developers/ designers
U.S. DOE
National laboratories
Energy Commission

**Benefits to Industry**

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:** Mid-term (3 to 7 years)

### Alternatives to Steam Methane Reforming for Hydrogen Production

Natural gas supplies are variable, and the U.S. will likely continue to be net importers of natural gas. Technologies are needed to provide alternatives for producing hydrogen that are not based on natural gas. RD&D advances will help to prove technical viability of new options.

**Key Technical Elements**

- Reduced cost of electrolysis
- Production options using ethanol, methanol, renewables (solar and wind), and nuclear energy
- High volume capacity
- Recovery of hydrogen from hydrogen sulfide or ammonia

**Risk**

LOW — HIGH

Technical Risk

Considerable RD&D required

Commercial Risk

Unproven technology, large capital investment

**Potential Partnerships**

Industrial gas suppliers
Power companies
U.S. DOE
National laboratories
Energy Commission

**Benefits to Industry**

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory ($CO_2$)

**Time Frame for Results:** Long-term (> 7 years)

**Figures 3-6 and 3-7: Priority Research Areas – New Process Technology & Energy Systems and Energy Management**

### Membrane Separation Technologies for Liquid Hydrocarbons

Physical separation technologies for liquid hydrocarbons are needed to replace or supplement distillation.

#### Key Technical Elements

- Identification of high potential streams for separation
- Screening of existing membranes (e.g., molecular sieve)
- Evaluation of new options, i.e., electrophoreses
- Cost effective scale-up to meet capacity requirements
- Adequate service life

#### Risk

LOW — HIGH

Technical Risk

Considerable RD&D

Commercial Risk

Unproven technology, large capital investment

#### Potential Partnerships

Universities
National research laboratories
Membrane manufacturers
Catalyst/separation/sieve manufacturers
U.S. DOE
Energy Commission
Refinery Industry

#### Benefits to Industry

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:** Mid-Term (3 to 7 years)

### Energy Management Software Tools

User-friendly, simple, low-cost energy management software tools are needed to analyze and control energy usage in refineries. Energy software will enable refinery operators to better understand where energy is being used and identify opportunities for optimizing energy.

#### Key Technical Elements

- Design to accommodate data dumping
- Requires long-term maintenance support
- Must be maintainable by user
- Supported by effective training curriculum

#### Risk

LOW — HIGH

Technical Risk

Does not require extensive new RD&D or fundamental science

Commercial Risk

Relatively easy to implement, low upfront investment

#### Potential Partnerships

Software developers
Refining industry
U.S. DOE
Energy Commission
Electric Power Research Institute
Utilities

#### Benefits to Industry

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:** Near Term (within 3 years)

**Figures 3-8 and 3-9: Priority Research Areas – Improved Process Operations & Energy Conservation and Generation**

### Online Inspection of Pressure Vessels and Pipes

On-line inspection technology is needed to more effectively monitor and assess condition of pipes and equipment with regard to corrosion, fouling, and boundary integrity. On-line inspection would increase run time of process equipment and reduce energy use associated with start-up and shut-down.

**Key Technical Elements**

- Fiber optic/wireless systems
- Non-intrusive
- Monitoring of corrosion in pressure vessels, piping and tanks

#### Risk

LOW — HIGH

Technical Risk

Requires moderate RD&D and demonstration

Commercial Risk

Retrofit technology, moderate up-front investment, requires demonstration.

#### Potential Partnerships

Refining industry
National laboratories
Sensor Companies
Energy Commission

#### Benefits to Industry

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

Fast Response to Safety Issues

**Time Frame for Results:**
Mid-term (3 to 10 years)

### Reduction of Fouling and Corrosion in Cooling Water Systems

New technologies and predictive or preventive measures needed to reduce fouling and corrosion in cooling water systems.

**Key Technical Elements**

- Capabilities for high load areas
- Better fundamental understanding of heat exchanger fouling mechanisms

#### Risk

LOW — HIGH

Technical Risk

Some technologies exist.

Commercial Risk

Moderate to low investment, good payback.

#### Potential Partnerships

Universities
National research laboratories
U.S. DOE
Energy Commission
Refinery Industry

#### Benefits to Industry

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:**
Mid- to Long-Term (3 to 7 yrs)

**Figures 3-10 and 3-11: Priority Research Areas – Energy Conservation and Generation**

### Gasification for Electricity and Fuels

Technology is needed to utilize gasification syngas for electrification or gas-to-liquids. Feedstock options might include coke-to-gas, resid-to-gas, or tower bottoms-to-gas. Gasification could also provide a source of hydrogen and methane.

**Key Technical Elements**

- Reliability of refractories
- Optimized flexibility between liquid to gas
- Utilization of byproducts
- Capital cost

**Risk**

LOW — HIGH

Technical Risk

Proven technology

Commercial Risk

Reliability is an issue

**Potential Partnerships**

Universities
U.S. DOE
Energy Commission
Refinery industry

**Benefits to Industry**

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:**
Near Term (up to 3 years)

### Recovery of Low Level Heat Streams

Technology is needed to cost-effectively recover and utilize low value energy streams, such as low pressure or temperature steam, for thermal or electrical energy.

**Key Technical Elements**

- Low pressure condensing turbine
- Absorption chillers
- Alternative fluid power generation
- Heat pumps

**Risk**

LOW — HIGH

Technical Risk

Proven technology

Commercial Risk

Medium to high

**Potential Partnerships**

Equipment suppliers
Utilities
Refinery industry

**Benefits to Industry**

LOW — HIGH

Energy

Potential to Reduce Electric Demand

Potential to Reduce Natural Gas Demand

Production Cost Benefits

Productivity/Yield Improvements

Environment/Regulatory

**Time Frame for Results:**
Near Term (up to 3 years)

# 4.0 Data Centers

## 4.1. Introduction

### *4.1.1. California context*

When California's electric utilities began receiving requests for huge electrical demands for data center facilities in the mid-1990s, it became evident that little information existed to validate actual data center electrical performance, or to see how the energy performance could be improved. As a result, California utilities and the California Energy Commission became interested in learning more about the data center market. Utility case studies and preliminary investigations confirmed the merits of research designed to reduce the large, continuous electrical demand of data centers, however, the role of public interest research for these types of facilities was clearly defined.

To tackle this problem, PIER IAW set out to define and prioritize energy efficiency research areas by engaging professionals in the data center industry. In 2003, researchers from Lawrence Berkeley National Lab (LBNL) facilitated workshops, participated in industry forums, and researched energy issues related to data centers, an effort that resulted in the in the creation of *High-Performance Data Centers: A Research Roadmap*. This RD&D roadmap focused primarily on market characterization, development of an industry energy baseline and suggestions for future research topic areas. Since 2003, several projects have received funding through PIER.

There are many types of data centers in California ranging from corporate data centers in a wide range of industries, banks, telecommunication facilities, and Internet hosting facilities. Data centers are also found in other institutions such as research organizations, universities, national laboratories, and government facilities. The crosscutting nature of the market involves many California industries that directly or indirectly rely on data centers as well as the suppliers of goods and services for data centers. The data center market represents an important facet of the California economy and one in which PIER is uniquely positioned to enable significant improvements in energy efficiency.

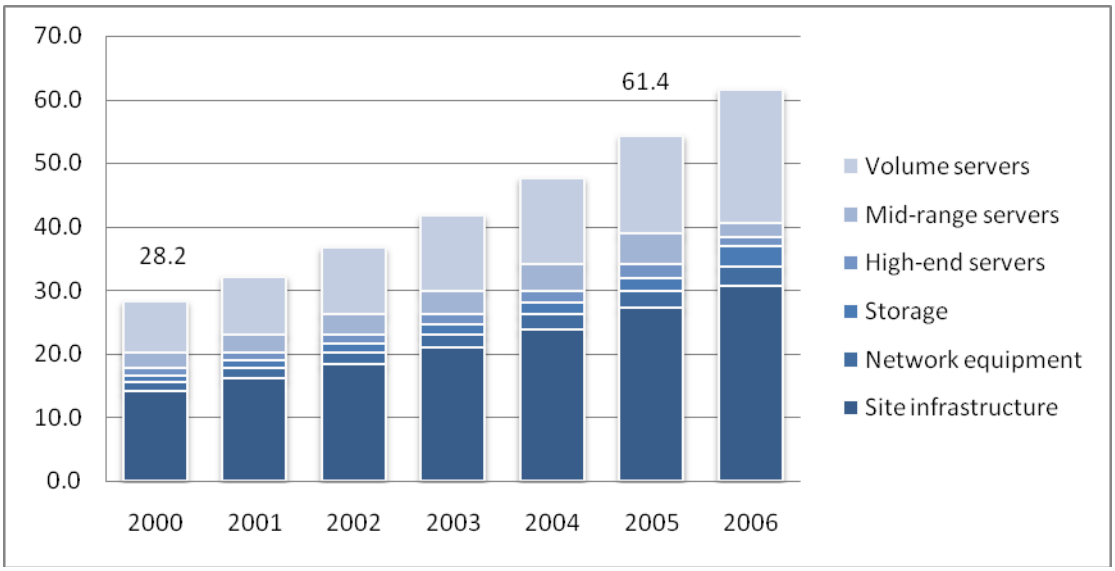
### *4.1.2. Industry Overview*

The stock of data centers and their load intensity in California is difficult to estimate. The market is characterized by constant change and there is no reliable, up to date source of market data covering all of the various types of data centers. Additionally, although they are 40 times more energy intensive than conventional office buildings, data centers are often intermixed with other commercial properties, which means isolating and characterizing energy usage for the sector is particularly challenging.

The most comprehensive set of energy data for data centers was published through the U.S. Environmental Protection Agency (EPA), which estimated that data centers consumed 61,000 GWh of energy in 2006, double their energy consumption in 2000. At the time, the sector's growth was expected to continue on this trajectory, eventually reaching 100,000 GWh per year

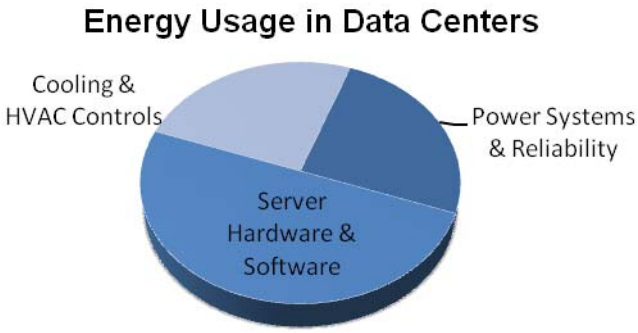
in 2011.[16] The associated energy costs for U.S. companies topped more than $4.5 billion. Within Northern California, data centers are responsible for 500 MW of peak load within the Pacific Gas & Electric (PG&E) service territory (2.5 percent of the total peak load). Figure 4-1, shows the growth in energy usage of key data center hardware and infrastructure components over the period from 2000 to 2006.

**Figure 4-1: Electricity Use by End-Use Components, 2000 to 2006[17]**




In California's data centers, energy use is split between three main areas: server hardware and software, power systems and reliability, and cooling and HVAC controls. These three areas are highly interdependent; gains in equipment and software, such as improving server power management, will also result in a decrease in power supply energy through a reduction in peak load. Figure 4-2 shows the breakdown in energy usage between these three areas.

**Figure 4-2: Energy Usage in Data Centers[18]**




[16] EPA, "Report to Congress on Server and Data Center Energy Efficiency", 2007.

[17] Ibid.

[18] DOE, "Routing Telecom and Data Centers Toward Efficient Energy Use", 2009.

## 4.2. 2003 Roadmap and RD&D progress

In 2003, PIER, LBNL and the Rocky Mountain Institute (RMI) brought together over 75 leading stakeholders in the data center market for a "charrette" to identify issues and potential solutions. Following on this workshop, LBNL developed the *High-Performance Data Centers: a Research Roadmap* to better understand the energy usage of the data centers sector and support measures to improve energy efficiency within California's data centers. The 2003 roadmap measures focused on:

- Understanding the data center market
- Understanding data center energy end use
    - Baseline information
    - Performance over time
    - Trends
- Identifying and accelerating adoption of best practices
    - Best practices from case studies and benchmarking
    - Guidelines and recommendations
    - Incentives for use of best practices
- Aligning energy efficiency, reliability, and availability
- Reduction of total and peak electrical power consumption
- Development of strategies to overcome barriers inhibiting energy efficiency
- Market transformation through education, training, and financial Incentives

Since creation of the 2003 Roadmap, PIER and LBNL have worked extensively to implement the recommended actions and develop critical research topics that go beyond even those envisioned in the first roadmap. LBNL's work includes projects on benchmarking, energy performance testing for data center components, demonstration of new technologies and development of LEED standards for data centers.

### *4.2.1. Benchmarking*

One of the critical gaps in understanding data center energy use and efficiency opportunities is the establishment of accurate, up to date baselines of energy usage from both individual components and facilities as a whole. Baselines enable identification of components that consume significant amounts of energy, measure improvements, and development of business cases aimed at industry professionals.

**Energy Efficient Data Centers Benchmarking**

In addition to developing the 2003 roadmap document, PIER engaged LBNL to conduct benchmarking assessments of six data centers in Northern California. The project completed eight additional assessments in Northern California and New York. These benchmarking reports include energy usage of all major components and recommendations for implementation of best practices.[19]

[19] For more information on LBNL's benchmarking assessments see: http://hightech.lbl.gov/benchmarking-dc.html.

**Business Case for Energy Efficiency**

A joint PIER, LBNL and DOE study on costs of inefficient equipment in data centers titled "High-Tech Means High-Efficiency: The Business Case for Energy Management in High-Tech Industries". This study included a comparison of data center energy use relative to other facilities and a generalized framework for institutionalizing energy management best practices in a corporate setting.[20]

### 4.2.2. Energy Performance Testing

In 2005, PIER-sponsored analysis of uninterruptable power supplies (UPS) systems and server power supplies. Activities included the development of standardized test protocols, laboratory and field testing of power supplies and dissemination of results industry-wide. Tests were conducted on these two components largely for the magnitude of their energy usage and potential for improvements. These tests found that UPS systems account for 5-12 percent of all energy consumption in data centers, and server power supplies which currently operate at efficiencies of 65 to 75 percent could be upgraded to 80 to 90 percent efficiency.[21]

### 4.2.3. Demonstration Projects

In addition to testing existing technologies, PIER and LBNL have also sponsored the implementation of demonstration projects in several areas. These projects have addressed the cooling, power supply, and controls priority areas including:

- DC Power
- Improved Air Management Designs
- Free Cooling with Outside Air
- Wireless Temperature Sensors for HVAC Control
- Server Temperature Sensors for HVAC Control
- Modular Cooling Systems (Chill Off!)

PIER and LBNL demonstration projects have been undertaken in cooperation with the Silicon Valley Leadership Group (SVLG), and have included installation and monitoring of advanced data center components at high-tech facilities throughout California. For more information on demonstration projects see: http://hightech.lbl.gov/demonstrations.html.

### 4.2.4. LEED for Data Centers

The benchmarking, performance testing, and demonstration projects undertaken by PIER and LBNL were largely developed from the research priorities identified in the 2003 RD&D roadmap. The development of Leadership in Energy and Environmental Design (LEED) criteria for new data center construction currently being undertaken by LBNL is one of the few projects that did not emerge directly from the original roadmap document. This project is a partnership between SVLG, LBNL, PIER, Green Grid, ASHRAE, 7x24 Exchange, Uptime Institute and Critical Facilities Roundtable.

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[20] Shamshoian, "High-Tech Means High-Efficiency", 2005, http://eetd.lbl.gov/emills/PUBS/HighTechBusinessCase.html

[21] For more information on LBNL's energy performance testing see: http://hightech.lbl.gov/tech.html.

A draft of the LEED guidelines developed through this project was submitted to the U.S. Green Building Council (USGBC) in February 2009 and is presently under consideration for adoption. There are 3 data centers in California (and 17 nationwide) currently undergoing LEED Certification, and acceptance of the proposed LEED for Data Centers guidelines by USGBC may encourage many more companies to address site infrastructure issues, which comprise up to 50 percent of data center energy usage.[22]

## 4.3. Priority Research Areas

In August 2007, EPA published a report entitled, "Report to Congress on Server and Data Center Energy Efficiency", which focused on data center energy usage across the nation with a particular emphasis on federal data centers. Though not formally considered as an RD&D document, this report included several recommendations for future RD&D efforts on data centers including:

- Improve testing protocols to measure energy efficiency of IT equipment
- Improve virtualization software to ease configuration and management
- Develop lower server power states for use at lower utilization levels
- Improve power management for storage systems
- Develop efficient modular and scalable power systems
- Develop components for DC-only data centers
- Quantify benefits of CHP and DG through demonstrations
- Cost benefit analysis of hardening IT equipment
- Water economizer cooling research
- Develop market survey of data centers sector and energy usage

In May 2009, DOE published a roadmap for RD&D for data centers title "Routing Telecom and Data Centers Toward Efficient Energy Use." The report was developed through a "Vision and Roadmap Workshop" conducted in Sunnyvale, CA in October 2008 that brought together industry experts nationwide to develop industry priorities for RD&D research to improve data center energy efficiency. Although this roadmap highlights priority research areas on a national scale, many of the research initiatives detailed in this report are applicable to current or potential PIER IAW work. Figure 4-3 provides a summary of the DOE RD&D roadmap workshop on information and computer technologies (ICT).

[22] For more information in the LEED criteria see: http://hightech.lbl.gov/dc-epc.html.

**Table 4-1: 2009 Roadmap Summary**

| Information and Computer Technologies Vision and Roadmap Summary | | |
|---|---|---|
| **Equipment and Software** | **Power Supply Chain** | **Cooling** |
| **Vision** | | |
| ICT hardware and software will increase the computing power of a watt by at least an order of magnitude, meeting future demand without increasing energy consumption or total cost of ownership and substantially decreasing the environmental footprint to ICT facilities. | Reduce power losses in data centers and telecommunications central offices by 50 percent from service entrance to end use while maintaining or improving reliability and decreasing the total cost of ownership. | Reduce cooling energy as a percentage of ICT power to a global average of ≤20% for retrofit and <5% for new construction. Cooling systems will be adaptable, scalable, and able to maximize utilization and longevity of all assets over their lifetimes while maintaining system resiliency and lowering total cost of ownership. |
| **Potential Technology Solutions** | | |
| Advanced power management in ICT hardware<br>Dynamic network power management<br>New data storage technologies<br>Free cooling and equipment standards<br>Hardened ICT equipment<br>Novel computing architecture<br>Nano-electric circuitry<br>All-optical networks<br>Superconducting components | Eliminate voltage conversion steps<br>High-efficiency power system components<br>Efficiency-optimized control systems<br>Transition to DC operation<br>On-Site DC generation and micro-grid | Advanced air cooling<br>Liquid cooling of hardware<br>Advanced cooling of individual hardware components<br>Efficiency-optimized control systems |
| **Key Benefits** | | |
| Efficiency gains in ICT equipment and software drive savings in all areas of ICT facilities by reducing loads for the power supply chain and cooling systems.<br>Hardening equipment to perform reliably in extreme environments may obviate or greatly reduce ICT cooling. | Improved efficiency will reduce power system losses and associated cooling loads.<br>Most strategies to reduce power losses focus on reducing the number of voltage steps, which likely will reduce the number and cost of power system components.<br>Green energy can avoid carbon output. | New approaches for cooling can lower energy costs and facilitate greater ICT hardware densities. |

Based on the recommend actions identified in these two roadmaps, California industry priorities and PIER priorities, the priority research areas in Table 4-2 are suggested for future PIER IAW attention.

**Table 4-2: Priority Research Areas**

| Priority Research Areas | | |
|---|---|---|
| **Research Area** | **Need** | **Potential RD&D Project** |
| **Server Hardware & Software** | Optimization of server usage and design | Encourage development of IT equipment with minimized idle performance |
| | | Determine strategies to optimize infrastructure systems, operating systems, and IT Equipment to respond efficiently to computing demands |
| | Improved control algorithms for server efficiency | Develop software to redirect computing to eliminate thermal spikes on chips |
| | Demonstrate energy saving devices, systems or strategies | Demonstration of direct spray cooling of refrigerant onto computer chips or processors, including alternate cooling media |
| | | Demonstration of monitoring and control to match cooling to varying heat load in localized areas |
| | | Demonstration of best practice for idle mode performance |
| | | Baseline energy efficiency research on containerized data centers |
| **Power Systems & Reliability** | Reduce AC/DC conversions and losses | Demonstrate more efficient power distribution |
| | Demonstration of DC | Demonstrations of DC-only data center components and facilities |
| | Demonstration of onsite generation | Demonstrate a thermal-based cooling system that uses an on-site generator's waste heat to drive absorption, desiccant or other cooling cycle technology |
| | | Accelerate the development of reliable, clean, and economically feasible distributed generation technologies (such as fuel cells) for critical power applications |
| | | Develop protocols that include and integrate energy efficiency into data center performance metrics (e.g., availability, reliability) Develop case studies to evaluate the related construction and operational cost implications of these key areas |
| **Cooling & HVAC Controls** | Free cooling demonstration | Conduct a study to estimate the costs and benefits associated with using economizers in the data center sector in a variety of climate areas |
| | | Survey manufacturers of data center HVAC equipment to determine the market penetration of air economizers in data centers and barriers to adoption |
| | | Provide research to develop better economizer technologies and operating techniques which have the potential to increase market penetration |
| | | Provide training and raise awareness of free cooling benefits |
| | Equipment hardening | Participate in the development of data center standards through participation in the ASHRAE TC |
| | | Once guidelines or standards are established, provide training for data center designers and operators in California |

| | | |
|---|---|---|
| | | Use models of data center HVAC systems to estimate the energy savings that could be achieved under a variety of temperature and humidity control scenarios |
| | | Survey data center designers and equipment manufacturers to research their basis for current data center environmental specifications |
| | Liquid cooling | Collaborate with CEETHERM and other industry associations to assess the limits of current and emerging technology |
| | | Survey the state of development of direct cooling technologies for electronic equipment and the relative energy efficiency of each |
| | | Investigate the costs and benefits of these technologies |
| | | Identify and address barriers to the widespread deployment of these technologies |

# 5.0 Electronics

## 5.1. Introduction

### *5.1.1. Introduction to Electronics Roadmap*

For the purpose of describing and assessing the California electronics industry, the industry has been defined using the NAICS code 334 for Computer and Electronic Product Manufacturing. Using NAICS, the electronics industry is defined as including the manufacturing of computers, communications equipment, audio & video equipment, semiconductors, navigational, medical, measurement and control instruments, and magnetic and optical media. California based Fortune 100 companies in this sector include Intel, Cisco, Apple and Hewlett-Packard

Employing approximately 225,000 workers and producing $81 billion in goods on an annual basis, California's electronics industry is the largest manufacturing sector in the state. California represents 20 percent of the industry nationwide.

PIER work on the electronics manufacturing sector began in the fall of 2001, when Electricity Innovation Institute was tasked to develop an RD&D roadmap to address short and mid-term energy efficiency challenges within the industry. Developed through a series of stakeholder workshops and surveys, the *RD&D Plan and Roadmap for Enhancing Energy Efficiency and Supply Reliability for California's Electronics Industry* was published in June 2003.

### *5.1.2. 2003 RD&D Roadmap*

In its annual report on the economic health and quality of life in Silicon Valley, the SVLG reported in 2001, "Silicon Valley is still vulnerable to power disturbances…. The Valley is acknowledged to be a global leader in the implementation of the digital society of the 21st Century. Now we need to develop a world-class infrastructure to maintain this leadership position."[23] With this perspective as a backdrop, a network of industry stakeholders served as the primary counsel for the development of the RD&D plan. Forums for feedback included workshops, web conferences, a needs survey, one-on-one interviews, meetings, and telephone calls. An Energy Advisory Committee comprised of representatives from the industry as well as representatives from the RD&D community was established to serve as a channel for synthesizing and consolidating feedback. Interim results were also shared with the SVLG Energy Committee to obtain their perspective. Since the SVLG Energy Committee was comprised of members that extended beyond actual end-user companies (such as consultants, service providers and government representatives), an effort was made to specifically engage the industrial end-users in the development of the Roadmap and Plan.

Specific activities included:

- Workshops held with Electronics Industry representatives in the Silicon Valley (November 2001) and San Diego (June 2002)

[23] Silicon Valley Leadership Group, 2001.

- Four web conferences held between September 2002 and February 2003 with members of the Energy Advisory Committee for this project
- One-on-one interviews with Electronics Industry representatives over the course of the development of this RD&D plan
- A needs survey administered to a sampling of Electronics companies from Silicon Valley
- One-on-one interviews with a variety of RD&D industry experts throughout the country

In the first workshop held for this program in November 2001 in Silicon Valley, the SVLG Energy Director noted that decision-making related to energy had become overly politicized and stressed the need for the technology sector to drive more business friendly decisions. In a survey of member companies, SVLG found that 62 percent of its members considered the power supply and transmission situation in Silicon Valley to be factor in their decision to expand operations or relocate.

A second workshop was held with electronics industry representatives in June 2002 in San Diego. At that time, the industry conveyed additional feedback indicating an urgent need to manage the cost of energy while at the same time addressing reliability concerns.

From the workshops and outreach activities, the Industry Advisory Committee settled on the following statement to represent a vision of the future energy infrastructure in the state that will help meet their needs:

> By 2006, all electronics-dependent enterprises in California will be able to obtain reliable electricity supply at a reasonable, competitive, and predictable cost. Companies in California will have the tools and technology they need to control and manage energy consumption and use. Energy customers will have alternative sources of energy supply and services from which they will be able to choose.

That vision is represented in Table 5-1, which lays out a set of destinations that were identified in order to realize the vision. These destinations were the basis for the development of the *2003 RD&D Plan and Roadmap for Enhancing Energy Efficiency and Supply Reliability for California's Electronics Industry*.

**Table 5-1: Technology Development Destinations for the Electronics Industry**

| Technology Development Destinations for the Electronics Industry |
|---|
| Minimal Power Quality Disruptions |
| Reliable Energy Supply at the Meter |
| Reduced Energy Costs |
| Stable/Predictable Energy Cost |
| Customer – Controlled Load Management |
| Customer Choice of Energy Supply |
| Energy Impacts on the Environmental Minimized |
| Use Energy for Improved Productivity |

## 5.2. Electronics Industry in California

### *5.2.1. Industry Overview*

The electronics industry has been a substantial contributor to California's economic growth. The most current data indicates that the industry accounted for 28 percent of the state's exports and employed over one quarter of a million highly skilled technology workers (22 percent of the industry nationwide).[24] Table 5-2 summarizes the basic economic statistics for the electronics industry based on U.S. Census' Annual Survey of Manufactures data for 2006. Table 5-2 provides an overview of the economic statistics associated with the electronics industry.

**Table 5-2: California's Electronics and e-Commerce Industry Statistics for 2006**

| California's Electronics and e-Commerce Industry Statistics for 2006 | | | | | |
|---|---|---|---|---|---|
| **Key Industry** | **NAICS** | **Employees** | **% of Total** | **Value of Shipments ($ millions)** | **% of Total** |
| Computer and Peripheral Equipment Mfg. | 3341 | 18,400 | 8.1% | $5,300 | 6.5% |
| Communications Equipment Mfg. | 3342 | 44,200 | 19.5% | $24,700 | 30.5% |
| Audio & Video Equipment Mfg. | 3343 | 4,500 | 2.0% | $2,900 | 3.6% |
| Semiconductor & Other Electronic Component Mfg. | 3344 | 74,500 | 32.8% | $20,600 | 25.4% |
| Navigational, Measuring, Medical & Control Instruments Mfg. | 3345 | 77,000 | 33.9% | $25,100 | 31.0% |
| Mfg. & Reporting Magnetic & Optical Media | 3346 | 8,400 | 3.7% | $2,400 | 3.0% |
| TOTAL | | 227,000 | | $81,000 | |

### *5.2.2. Energy Use*

According to the Energy Commission's Energy Analysis Office, in 2008 the electronics industry used 6,197 GWh of electricity. This represents roughly 13 percent of the state's total industrial consumption, and 2 percent of the state's entire electricity consumption in 2008.

Figure 5-1 provides a breakdown of the industry's electricity usage by end-use equipment. The majority of the consumption is tied up in machinery, followed by process heating or cooling, and then HVAC for space conditioning in the facilities where the electronics manufacturing process is occurring. Figure 5-2 provides a breakdown of the industry's natural gas usage by end-use equipment. A vast majority of the natural gas consumption is from boilers and process heating applications such as curing and drying.

While data were not available to reflect end-use consumption characteristics for the e-commerce industry, it can be inferred that energy consumption patterns closely follow the characteristics of commercial office buildings with most of the electrical usage assigned to cooling and lighting applications and most of the natural gas usage going toward space heating applications. Many

[24] US Census Bureau, Office of Trade and Industry Information, 2009.

e-commerce facilities have extensive computer server systems, thus a large share of the electricity consumption is devoted to powering as well as cooling those systems.

**Figure 5-1: Electric Usage by End-Use – Electronics Industry**

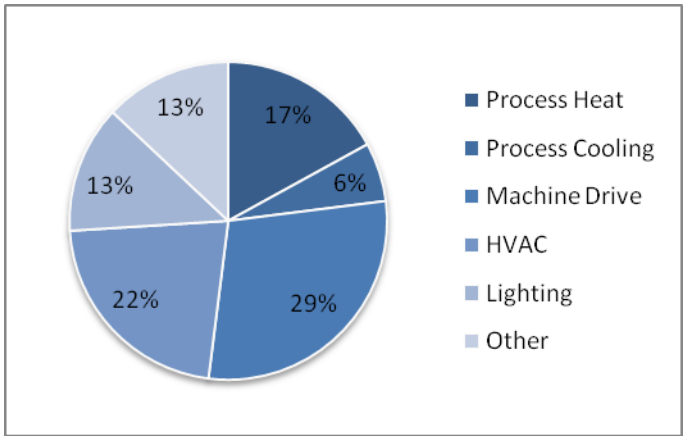
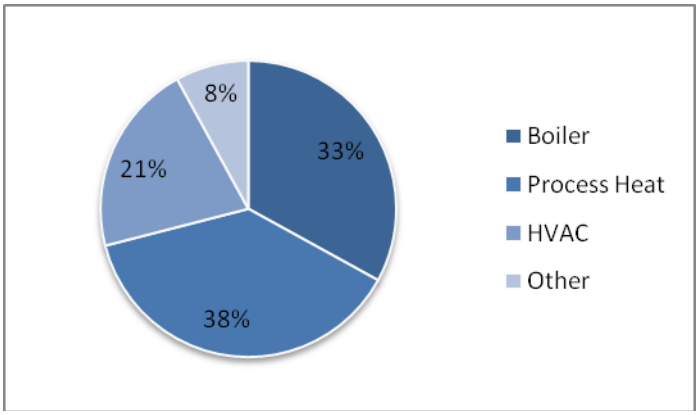



**Figure 5-2: Natural Gas Usage by End-Use – Electronics Industry**




## 5.3. 2003 Roadmap Methodology

This vital industrial engine provides jobs, products for export, and tax revenue to the state. As a result of the energy crisis in 2000 and 2001, the electronics industry has expressed concerns about future power supply shortages and rising energy costs.

To more fully understand industry concerns and find solutions, a comprehensive program was established with the Electricity Innovation Institute (E2I) in the fall of 2001 that addressed short-term needs and defined a longer-term implementation strategy. The program was designed to engage participants from inside and outside the industry in a collaborative effort to identify needs, explore solutions, and take action to reinforce confidence in California's energy infrastructure. The effort also sought to reveal end-user solutions that can be applied on the customer side of the meter.

This RD&D plan presented a portfolio of research initiatives for consideration by PIER IAW. The Plan provided intermediate range (5 years maximum) solutions to help the industry meet the energy challenge unique to California.

The plan built on the Roadmap by presenting a coordinated portfolio of research initiatives that PIER IAW could undertake to facilitate efforts within the electronics industry. The eight destinations (represented in Table 5-1) were agreed upon by the Industry Advisory Committee and provided a framework for relating the full breadth of issues. Destinations were ranked by level of importance to Industry.

Close examination of the Roadmap revealed that most of the issues and needs feedback by Industry could be addressed by focusing attention on the top three destinations. As such, the Project Team consolidated issues among destinations, synthesizing the feedback into the following three Strategic Industry Issues that best represents the major concerns of Industry:

- The Cost of Energy
- Impacts from Power Outages
- Impacts from Power Quality Disruptions

A screening analysis using the PIER filtering criteria for defining public interest energy RD&D activities was then performed to identify the initiatives that are most appropriate to be undertaken by the PIER IAW Program. In addition, a set of recommended actions for the Plan's implementation was prepared.

During the stages of industry issue identification, input was received primarily from representatives within the industry. As the issues synthesized and evolved into strategic research initiatives, experts from the RD&D community were consulted and polled for their ideas on feasible initiatives that could be implemented by PIER over the next three to five years.

## 5.4. Priority Research Areas

Research areas identified in this table were developed in the 2003 roadmap.

**Table 5-3: Electronics Industry Research Areas**

| Electronics Industry Research Areas | | | |
|---|---|---|---|
| | **Research Areas** | **Need** | **Priority** |
| **Cost of Energy** | Reduce energy consumption of equipment or processes | Emerging technologies that reduce energy consumption of industrial process equipment and raise the market penetration levels for high-efficiency products in the long-term (ASDs), power supplies, industrial lighting) | High |
| | Controls for load management | Innovative software, methods, and monitoring/control devices for peak shaving and load management | |
| | Dynamic energy pricing | Advanced/enhanced market-based, dynamic pricing alternatives | Medium High |
| | Real-time energy price tools | Advanced/enhanced integration tools/networks for real-time energy and pricing information | |
| | Combined heat and power (CHP) | Advanced combined heat and power systems (design concepts, technologies, and operating procedures) for industrial facilities | Medium |
| | Local renewables | Advanced renewable technologies for industrial facilities | |
| | Distributed Generation Interconnections | Enhanced regulatory, permitting, and interconnection rules, procedures, and pricing for generation systems at industrial facilities | |
| | Retail market reform | Enhanced design concepts and implementation approaches that guarantee a functioning and competitive retail market open to all customers | |
| **Power Outage Impacts** | Energy storage | Novel/enhanced energy storage technologies for long-term ride-through at the component, subsystem, and facility level | Medium High |
| | Distributed generation | Wider range of environmentally acceptable, high efficiency, reliable on-site generation options for industrial customers incorporating fuel diversity (back-up, base load, peak shaving applications) | Medium |
| | Micro-grids for distributed generation | Wider range of distributed energy resources (generation, storage, power delivery) technologies and configurations for large industrial customers operating with independent micro-grids | |
| | Interconnection for distributed generation | Advanced/enhanced interconnection technologies for generation systems at industrial facilities | |
| **Power Quality Disruption Impacts** | Protection from voltage sag | High Efficiency technologies to protect facilities and individual electronic equipment from voltage sags | Medium High |
| | Harmonics protection | High Efficiency technologies to protect electronic equipment and local distribution networks from harmonics | |
| | Short term storage | Novel energy storage alternatives to lead-acid batteries for short-term ride-through | |

# 6.0 Food Processing

## 6.1. Introduction

This document synthesizes the core components of two PIER roadmapping efforts for the food industry: (1) Technology Roadmap: Energy Efficiency in California's Food Industry, published in 2006; and (2) Energy Efficiency Roadmap for the California Food Processing and Beverage Industry, published in 2009.

### *6.1.1. Technology Roadmap: Energy Efficiency in California's Food Industry (2006)*

The roadmapping process that culminated in *Technology Roadmap: Energy Efficiency in California's Food Industry* emerged from concerns over increasing population and urbanization, and sharper competition for water and energy resources. The costs and liabilities associated with the co-production of waste in many food processing operations had become significant factors that limited the growth of operations.

Increasing labor costs, high natural gas and electricity prices, the 2001–2002 energy reliability crises, environmental regulations, higher costs for operating older, inefficient factories, and global market competition were also cited for creating a challenging economic environment for food manufacturing firms in California. In combination, these factors resulted in factory closures (e.g., Del Monte Foods, San Jose; Hunt Wesson, Fullerton and Davis; and Tri Valley Growers, Modesto, and Gridley) and consolidation of food processing facilities across the state.

Despite the difficulties, the food industry continued investing in California to supply the most important market with quality food products. Some large, newly constructed factories (Cheese and Protein International, Tulare; Brawley Beef, Brawley) and pilot plants (ConAgra, Irvine; Creative Research Management, Stockton) incorporated automated and energy efficient technologies to achieve economic advantages. Among the technologies adopted were those with the ability to track and trace food at all points in the process.

On behalf of Energy Commission, the California Institute of Food and Agricultural Research (CIFAR) at the University of California at Davis, established a Food Industry Advisory Council (FIAC) comprised of industry and technology experts that lead discussions aimed to determine the state of the industry, prioritize research needs, and develop a vision and plan for the future. CIFAR facilitated this process and followed with several public forums and meetings to develop the California food processing roadmap. These outcomes supported the Energy Commission's Public Interest Energy Research Program.

The FIAC set an agenda for a research program and proposed an industry vision with missions and targets:

- Vision: To continuously improve the global competitiveness of the diverse California food industry with respect to improving energy and productivity efficiencies and reducing water use.

- Mission: To manage energy and other resources to meet or exceed all standards and benchmarks.
- Target: To identify cost-effective savings with payback within 2 years.

The committee identified nine priority research and development areas, along with targets and possible approaches, aimed directly at improving energy and productivity efficiencies and reducing water use in California's food processing industry. The nine research and development areas included:

- Optimize equipment and utilities
- Validate existing technologies
- Improve thermal efficiencies
- Optimize cold chain management
- Improve power quality and reliability
- Improve water use efficiency
- Reduce supply chain waste
- Ensure food safety and security
- Develop seasonal infrastructure

The central objective of the research program was reducing the power required to produce a unit of production in the food processing process, with a target of 20 to 30 percent energy use productivity improvements. Additionally, FIAC set its mission to manage energy and other resources to meet or exceed all standards and benchmarks, followed by a target to provide cost-effective savings, with payback within two years. Table 6-1 provides a summary of the most significant goals and benchmarks.

**Table 6-1: Food Industry Goals and Benchmarks**

| Food Industry Goals and Benchmarks | |
|---|---|
| **Goals** | **Benchmarks** |
| Efficient use of energy<br>Distributed power and flexible fuel plants<br>Enterprise Energy and Asset Management Systems<br>Microprocessor-based control systems<br>Integrated unit operations<br>Capture and re-use low grade power<br>Best energy efficiency practices | Reduce energy use (KWh) per "stock keeping unit" by 35% |
| Efficient use of water resources<br>Capture and re-use water in plant | Reduce water use per "stock keeping unit" by 40% |
| Total material handling and utilization | 95+% of materials utilized<br>Reduced costs and liability |
| Safe and secure food supply<br>Track and trace (on-line)<br>Smart cards, radiofrequency identification | "Seal of safety" enhances consumer confidence |
| Environmental stewardship<br>Adopt new air emission standards | "Sustainable" label enhances consumer loyalty |

The report emphasized that progress in isolated technical areas, such as pumping systems, new materials, or refrigeration improvements, would not prove as effective as inter-related research projects conducted in a parallel and coordinated manner. Additionally, FIAC found many instances where improvements in one technology area could have implications that overlapped with other areas. The roadmap called for coordination with the DOE and industry organizations to ensure that PIER research would be conducted in concert with other projects and utilize crosscutting technologies.

### *6.1.2. Energy Efficiency Roadmap for the California Food Processing and Beverage Industry (2009)*

Building on the 2006 Technical Report, the 2009 report *Energy Efficiency Roadmap for the California Food Processing and Beverage Industry* provided up to date guidance on the Energy Commission's funding decisions. The Commission engaged industry partnerships in an energy efficiency roadmap meeting in November 2008, in Modesto, California to ensure that the report was informed by the needs of owners and operators. The results of the meeting provided the raw material for the development of the roadmap published in 2009.

## 6.2. Industry Overview

California's food processing and beverage industry is an important, diverse, and dynamic industrial sector in the state's overall economy. Building upon California's premier agricultural industry, the food processing industry represents a $50 billion dollar industry that provides thousands of jobs.

The industry is also a significant consumer of California's energy and water resources. Air pollution and waste management are key considerations for long-term protection of the environment and public health. A sustainable and prosperous food processing industry that operates in alignment with California's economic and environmental needs is a vision that is in the best interest of the industry and the public.

### *6.2.1. Industry Overview*

The food processing industry in California is highly diversified. It comprises more than 3,000 plants processing commodities that can be sourced from over 75,000 farms. About 240 commodity and trade associations represent food and agricultural interests in California.

Although agricultural and food processing activities occur throughout the state, these industries are concentrated in the Central Valley. The Central Valley is home to over 3,000 factory sites including the world's largest factory sites for processing fluid milk (California Dairies, Inc.), cheese (Hilmar Cheese Company), milk powder/butter (California Dairies, Inc.), wine (E & J Gallo), and poultry (Foster Farms).

California ranks 5th in the world in agricultural production ($36.6 billion in 2007 and 12.8 percent of the total U.S. production), and first in the U.S. for total food processing output, when defined as total value of shipments was $73.1 billion in 2006, or 11.2 percent of the US total.[25] Table 6-2 shows products which California produces greater than 90 percent of the US's total production.[26]

**Table 6-2: California's Unique Agricultural Products**

| Agricultural Product | % of US Production in California |
|---|---|
| Peaches, Clingstone | 100% |
| Olives | 100% |
| Almonds | 99% |
| Walnuts | 99% |
| Plums, Processed | 99% |
| Artichokes | 99% |
| Figs | 99% |
| Kiwifruit | 97% |
| Pistachios | 96% |
| Tomatoes, Processed | 95% |
| Celery | 95% |
| Plums, Fresh | 95% |
| Nectarines | 95% |
| Broccoli | 93% |

[25] US Census Bureau, 2006.

[26] California Department of Food and Agriculture (CDFA), "California Agricultural Resource Directory 2008-2009", 2007, http://www.cdfa.ca.gov/statistics/files/CDFAResourceDir08_final.pdf.

| | |
|---|---|
| Strawberries, Processed | 93% |
| Apricots | 92% |
| Lettuce | 90% |
| Avocados | 90% |

The diversity of California's agriculture across all sectors of food operations is reflected in the range in size of the processing facilities. They include all types and sizes, from the "Mom and Pop" shops to the largest single site operations in the world. California is home to the world's largest single-site manufacturing plant for cheese (Hilmar Cheese, Hilmar); tomato products (Morningstar Packing, Williams); poultry (Foster Farms, Livingston); and wine (E & J Gallo, Livingston). This report includes only those broad sectors of food processing that require the most water and energy namely, fruits and vegetables; dairy (cheese, milk powder/butter); meat (beef, poultry); and wine.

## 6.3. Value of Industry

One way of expressing the value of processing sectors is to describe them in terms of the unprocessed commodities. In this report, we want to emphasize the impact of value-added processing and show both the total value of the top unprocessed food commodities (Table 6-3) and the added value of processing these commodities (Table 6-4).

**Table 6-3: Value of California's Top 20 Food Commodities**[27]

| Value of California's Top 20 Food Commodities | | | | | |
|---|---|---|---|---|---|
| | Food Products | Value (in millions) | | Food Products | Value (in millions) |
| 1 | Milk and Cream | $ 7,328 | 11 | Rice | $ 583 |
| 2 | Grapes | $ 3,077 | 12 | Pistachios | $ 562 |
| 3 | Lettuce | $ 2,178 | 13 | Oranges | $ 518 |
| 4 | Almonds | $ 2,127 | 14 | Carrots | $ 495 |
| 5 | Cattle and Calves | $ 1,784 | 15 | Celery | $ 401 |
| 6 | Strawberries | $ 1,338 | 16 | Lemons | $ 394 |
| 7 | Tomatoes | $ 1,241 | 17 | Peaches | $ 332 |
| 8 | Walnuts | $ 754 | 18 | Poultry | $ 324 |
| 9 | Chickens | $ 713 | 19 | Raspberries | $ 285 |
| 10 | Broccoli | $ 669 | 20 | Avocados | $ 251 |

*The values represent commodity values

[27] Ibid.

**Table 6-4: Value-Added for Food and Beverage Processing in California[28]**

| Value-Added for Food and Beverage Processing in California (in Millions) | | | |
|---|---|---|---|
| **Processing Sector** | **Cost of Materials** | **Value Added** | **Total Value** |
| Food Manufacturing | $30,700 | $24,900 | $55,600 |
| Beverage Manufacturing | $8,100 | $9,400 | $17,500 |
| Total | $38,800 | $34,300 | $73,100 |

### *6.3.1. Resource Demands*

The food processing industry consumes an enormous amount of the water and energy resources available to the State of California. The amount of water and energy (electricity and natural gas) used by major food processing sectors were estimated on an annual basis, employing a variety of sources with verification by representatives of the dominant processing facilities within each sector as estimated in Table 6-5.

[28] US Census Bureau, 2006.

**Table 6-5: Food Processing Resources Requirements**[29]

| Food Processing Resource Requirements | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Fruit & Vegetables | | Dairy | | Meat | | Wine | Refrigerated Warehouses |
| | Processed | Fresh | Cheese | Milk Powder | Beef | Poultry | | |
| **Water** | | | | | | | | |
| Water Used (MM gallons) | 30,000 | ----- | 600 | 360 | 1,200 | 2,000 | 2,900 | Negligible |
| Water Discharged (MM gallons) | 29,000 | ----- | 2,100 | 1,000 | 1,000 | 1,200 | 2,500 | Negligible |
| Potential Target Opportunities | • Crops<br>• Washing<br>• Processing | • Crops<br>• Washing<br>• Processing | • Pollution<br>• Water for cattle | • Pollution<br>• Water for cattle | • Pollution<br>• Water for cattle | Water for poultry | • Crops<br>• Processing | |
| **Energy** | | | | | | | | |
| Gas (MM Therms) | 300-400 | ----- | 43 | 33 | 5 | 40 | 23 | Negligible |
| Electricity (GWh) | 600-800 | ----- | 583 | 130 | 88 | 360 | 406 | 1,000 |
| **Pollution & Waste Management** | | | | | | | | |
| Air | Emissions from farms & plants | Emissions from farms & plants | Cattle & manuf. Emissions | Cattle & manuf. emissions | Cattle & manuf. emissions | | | |
| Waste | By-products | By-products | Cattle manure | Cattle manure | Cattle manure | Chicken manure | By-products | |
| Safety | Contamination | Contamination | Contamination | Contamination | Contamination | Contamination | | |

[29] Alcohol, Tobacco, Tax and Trade Business, Dec. 2001 (574 M gal wine produced), and Wine Institute report (5 gal water per gal wine), does not include water inputs to production of grapes.; CLFP data, 2003. Post-harvest only and does not include irrigation water; Personal communications with International Association of Refrigerated Warehouses, and World Food Logistics Organization, 2004, T. Struckmeyer, Hilmar Cheese, 2004, J. Gomes, California Dairies, Inc., 2004, Jim Oltjen, UC Davis, 2004, J. Maxey, Beef Packers, Fresno, 2004, Bill Mattis, California Poultry Federation, 2004.

Table 6-5 demonstrates the significant quantity of water consumed and discharged by the food processing industry. Fruit and vegetable processing, in particular, is a major consumer of water; during processing season, many fruit and vegetable plants use 0.5 to 3 million gallons per day.

Moreover, an average of 88 percent of the water used in fruit, vegetable, and wine operations becomes effluent water. Fruit and vegetable processing generates the most effluent water by far when compared to the other major energy intensive sectors (Table 6-6). Increasing demand for water treatment can force cities to allocate maximum allowable effluent levels per plant, which can constrain the expansion of processing operations. For example, Petaluma Poultry Processors could no longer expand plant capacity because it had reached the maximum level of effluent that could be processed by the City of Petaluma municipal treatment facility.

As a result, many fruit and vegetable operations have examined technologies that might reduce their effluent volume and allow in-plant reuse of this water stream. Separation of suspended and dissolved solids from the effluent water has been found to reduce the effluent load (BOD, COD) discharged from the plant to water treatment plants and has offered alternative uses for the separated solids. Technologies such as membrane filtration, in combination with pre- and post-treatment have proven useful (e.g., to Sunkist in Bakersfield).

Table 6-6 provides a breakdown of electricity and natural gas use by food processing sectors. The values and percentages are estimates, as there is a wide range in types of plants within each category. Within the fruit and vegetable sector, tomato processing dominates operations in thermal processing. In contrast pumping and refrigeration are the dominant uses of energy in dairy and wine processing.

Despite the significant energy demands of food processing operations, energy efficiency has become a priority within the past few years. Increased demand for limited energy resources raised operational costs significantly. Quality and reliability of available power has been a more consistent concern since any interruption in utility service can result in significant production losses and may impact product safety.

**Table 6-6: Estimated Distribution of Energy (%) Within Major Food Processing Sectors in California**

| Estimated Distribution of Energy (%) Within Major Food Processing Sectors in California | | | | |
|---|---|---|---|---|
| **Food Processing Sector** | **Pumps<br>Motors<br>Fans<br>Conveyors<br>Lighting** | **Pasteurization<br>Heating Systems<br>Evaporators<br>Dryers<br>Sterilization** | **Cooling<br>Freezing<br>Refrigeration** | **Sanitation<br>Clean in Place** |
| Fruits & Vegetables | 10 | 70 | 15 | 5 |
| Dairy | | | | |
| Cheese | 35 | 40 | 20 | 5 |
| Milk Powder | 25 | 55 | 15 | 5 |
| Meat | | | | |
| Beef | 30 | 20 | 40 | 10 |
| Poultry | 30 | 20 | 40 | 10 |

| | | | | |
|---|---|---|---|---|
| Wine | 50 | | 40 | 10 |
| Rice (drying) | 20 | 80 | | |
| Refrigerated Warehouses | 15 | -- | 80 | 5 |

### *6.3.2. Characteristics of Industry Sectors*

**Fruits and Vegetables**

California is the leading producer of fruits and vegetables in the United States. Processing fruits and vegetables is the largest food sector in California, creating about $5.4 billion of added value a year. This sector includes 184 companies operating 336 factories that produce $10.4 billion of processed fruits and vegetables a year (19.5 percent of the nation's total). This is $1 billion more in production than that of the next two states combined. This sector produces more than 500 million cases of canned products and 1.8 billion pounds of frozen products every year.[30]

The fruit and vegetable industry's energy use is highly seasonal, with 80 percent of natural gas and 60 percent of electricity consumed during the peak summer processing season of mid-July to mid-October. Demand-side energy management is increasing, driven by incentives, rebates, and rate increases. Further, as steps to affect the supply side become more limited, companies are mainly focusing on the demand side of managing energy costs. In addition, this food processing sector uses by far the highest quantity of water compared to other food processing sectors in the state.

The fresh-cut produce category has not been included with traditionally processed fruits and vegetables, although it involves significant water washing, cutting, conveying, mixing, controlled atmosphere packaging, and refrigeration. Three plants in the Salinas area dominate this sector, Fresh Express, Dole Packaged Products, and River Ranch. The sector has grown at a rate of about 11 percent in the last few years, constrained by regulatory issues related to water and air quality.[31] The numbers for energy and water use plus effluent water disposal given in Tables 6-4 and 6-5 would be higher if fresh-cut were included.

**Dairy**

California's significant dairy industry is based on 1.5 million milking cows that delivered 35 billion pounds of milk in 2002, with 75 percent of the available milk solids being processed into cheese, milk powder, and butter products. The state's milk production has grown by almost 12 billion pounds since 1993, and in 2002, growth in production of milk (5 percent), cheese (5 percent), milk powder (9 percent), and butter (11 percent) set new records compared to the previous year.[32] Milk production (80 percent) is largely controlled by four major dairy cooperatives: California Dairies, Inc. (Artesia); Land O' Lakes (Tulare); Dairy Farms of America (Modesto); and Humboldt Creamery Association (Fortuna).

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[30] California League of Food Processors (CLFP), 2002.

[31] IFPA data, 2002.

[32] Cheese Reporter, 2003.

A significant amount of electricity is required to operate water and vacuum pumps for milking, and refrigeration for cooling. Incorporating variable frequency drives in pumps for milking and refrigeration and using premium high efficiency motors have been shown to improve energy efficiency.[33]

Across the board, large cheese processors have modern facilities that incorporate new technologies to keep costs down and ensure safety and quality.

Food safety and security, together with environmental and energy issues, are the primary concern facing the dairy industry. The U.S. dairy industry is recognized as a national security concern to be protected from incidents, intended or accidental. In addition, large dairies (so-called mega-dairies) are having difficulty in getting operating permits because of environmental issues. There are further constraints on growth because of regulatory issues associated with air and water quality. Energy has become an important factor in their business because of uncertain rate structures and high costs. Processors feel there are few options for favorable future contracts for electricity and natural gas.

**Meat**

Meat processing plants inspected by the US Department of Agriculture (USDA) in California in 1999 were estimated at 726. The plants inspected include egg, poultry, beef, lamb, and pork and tallow processing facilities, including rendering as well as non-commercial entities such as prisons and university meat labs. Meat products from California include meat snacks, fresh cut meat and poultry, and prepared foods, such as soups, frozen dinners, and canned meats. Some meat processors, such as Campbell Soup (Sacramento) and Kraft (Buena Park) use meat as a food ingredient. Beef and poultry represent the bulk of meat processing in California.

**Beef**

The California beef industry has a capacity to process more than 2 million beef cattle per year. Beef Packers, Inc. (Fresno) is the largest beef packing plant west of the Rocky Mountains, and it continues to expand with new construction, including its own wastewater treatment plant. The second largest plant in California is newly constructed Brawley Beef of Imperial Valley, which is utilizing irradiation to ensure safety of its products. Three other beef processors complete the big five that dominate the state's beef industry: Harris Ranch Beef Company (Selma), Central Valley Meat Company (Hanford), and Hallmark Meat Packing (Chino). Energy use is primarily associated with refrigeration and sanitation.

**Poultry**

The poultry industry processes an average of 250 million birds a year.[34] The largest single poultry plant in the world is Foster Farms (Livingston) where about 0.5 million birds per day are processed. Foster Farms and Zacky Farms (Fresno) represent the largest plants in California. Petaluma Poultry Processors (PPP, Petaluma) represents a medium-sized processor that has incorporated technology to minimize chemical inputs and maximize energy and water use

[33] PG&E, 2002.

[34] California Poultry Federation, 2004.

efficiencies in plant operations. PPP has replaced chlorine with chlorine dioxide as a sanitizer. Temperature regulation and refrigeration are the primary uses for energy in the plant, and between 7-10 gallons of water are used per bird.

**Wine**

California ranks fourth in the world in wine production after Italy, France, and Spain. The state is responsible for 88 percent of all U.S. wine, producing more than 444 million gallons of wine valued at $8 billion a year in over 669 commercial wineries.[35] E & J Gallo is the largest wine producer and wine supplier in the United States, has fully integrated energy and water efficient systems plus waste utilization on their plant sites.[36]

**Refrigerated Warehouses**

There are 220 refrigerated storage facilities in California with approximately 12 million cubic meters of storage capacity that require at least 360 MW of electricity per year. This sector is an important service category of California's food industry and it is growing. The warehouses are networked through two organizations: The International Association of Refrigerated Warehouses (ARW) and the World Food Logistics Organization (WFLO). The members of ARW are operators of public refrigerated warehouses (distinct from warehouses maintained by the food processor before shipment of finished product).

## 6.4. Trends

**Food Product Reformulation**

Food product reformulation, also called co-packing, is a growth segment of California's food industry, as indicated by the number of food reformulation facilities that have been established or expanded recently. About two-thirds of the food processing plants belong in this sector, because their raw materials are been processed once, (e.g., tomato paste) and then reprocessed into prepared food products and packaged for sale. Mexican foods, salsas, pasta, soups, organic soy, and rice milks are some of the products manufactured, with most of the plants being located close to population centers.

**Commodity Processing**

Commodity processing is being consolidated into centrally located and newly automated plants, resulting in closure of smaller, less-efficient plant or plants overcome by urban sprawl. This trend is apparent in facilities for fruit and vegetable canning (e.g., tomato, asparagus, and artichoke canning). Most new construction and expansion of plants is located in areas where environmental compliance is achievable. A number of pilot facilities have emerged recently (e.g., Creative Research Management, National Food Laboratory) to demonstrate the value of applying new processing and packaging technologies (e.g., electron beam, x-ray, aseptic line, pulsed electric field, high pressure) to food operations.

[35] US Census Bureau, 2002.

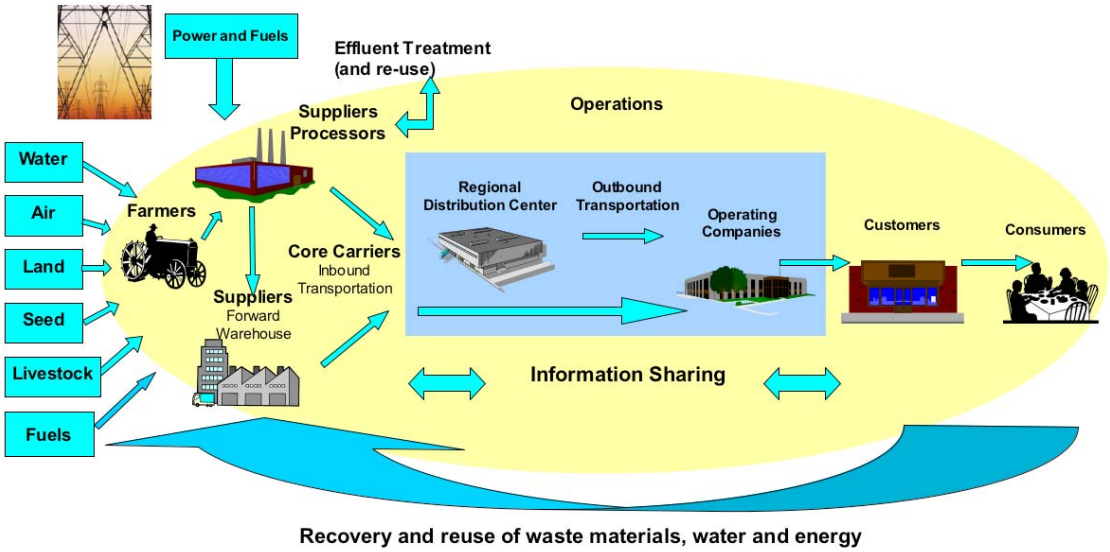
[36] Foodnavigator.com, 2004.

**New Processing Methods**
New processing methods are being employed with the increase in multicultural food production, based upon ingredients provided by a wide range of sources. The trend to use automated processing equipment and sensors is reducing overall energy use by making the process more efficient with less human error, resulting in less re-work and waste.

**Complete Byproduct Utilization**
Complete and better byproduct utilization in processing operations has become increasingly important to profitability. California agriculture-based processing industries will further benefit from better utilization of materials that go to waste and/or animal feed. These materials often contain useful nutraceutical components that are not being recovered because appropriate technologies needed for their cost-effective recovery have not yet been developed.

**Food Distribution System**
A food distribution system using supply chain infrastructure and management is essential to cost-effective delivery of food from farms to consumers. It is of increasing importance to ensure the safety and security of the food system for delivery at any time and to any location for a wide range of product categories. Essential components to such a system are illustrated in Figure 6-1.

**Figure 6-1: Supply Chain Management**




Closely networked systems embrace all components of the supply chain on a real-time basis. The components of the supply chain must include high speed communications, "track and trace," appropriate temperature and moisture controls, transportation systems to originate from a multitude of suppliers and deliver through many intermediate points to a multitude of retailers and consumers. Water and waste management systems are integrated into the supply chain to support sustainable and cost-effective operations. There is also increasing pressure on producers and processors to implement socially responsible strategies (e.g., animals, environment). The consumers want to know where their food is coming from and that the process of making it is consistent with their values.

**Water Supply, Energy Supply and Sewage Removal**

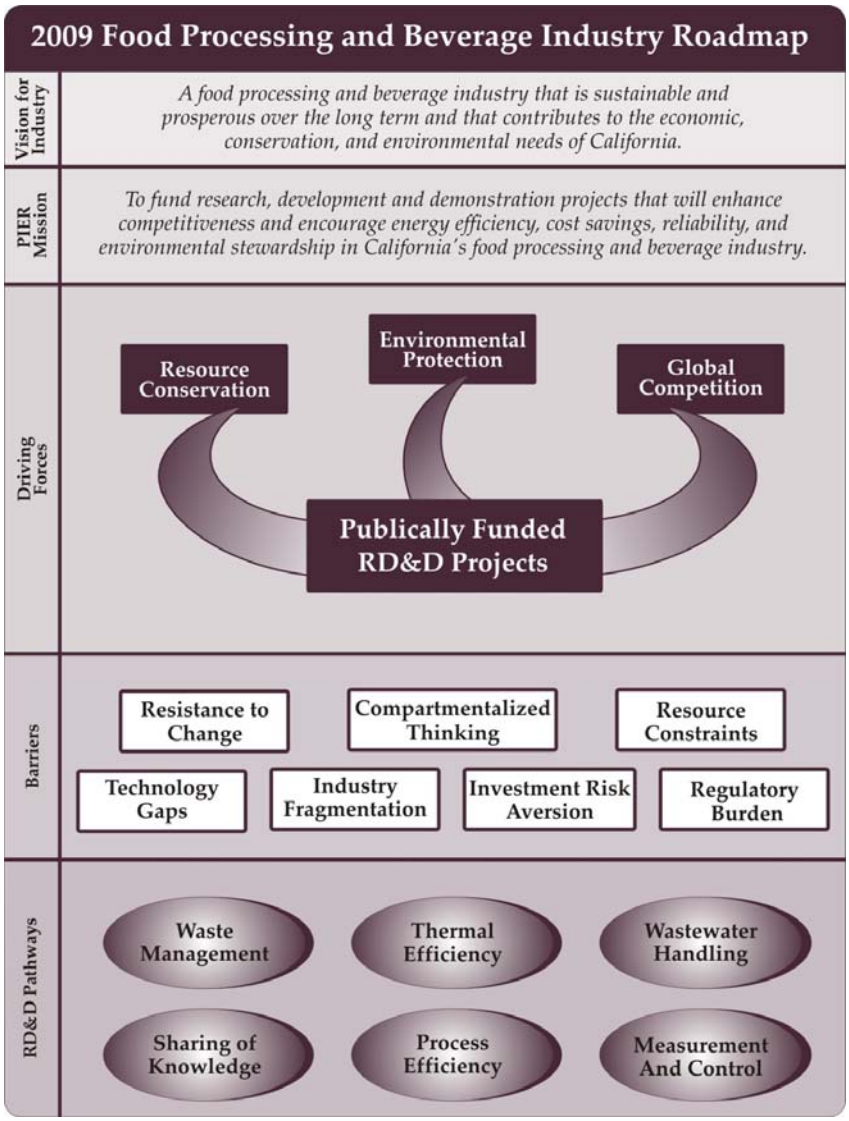
Water supply, energy supply, and sewage removal are essential to most food and beverage facilities. These services, once inexpensive and taken for granted, have become expensive and sometimes unreliable, placing California food processors at a serious disadvantage in the face of intense competition from both domestic and foreign producers. For example, the impact of the availability of foreign fresh and processed food imports, including peaches, garlic, apples and rice, has devastated some of California's fresh and processed food markets. The industry has responded to these challenges with improved conservation, relocation, self-reliance, and other innovative approaches to water supply, energy supply and sewage removal. (Examples: protein recovery from cheese whey, zero discharge in olive processing, sugar recovery for fermentation in raisin processing, cogeneration, standby generators, demand management systems.)

**Food Safety**

With animal disease, pest outbreaks, and food-borne illness escalating worldwide, food safety is still a top issue for consumers. Much of the discussion continues to focus on the pathogen jump from animals to humans, which has particularly impacted the meat industry. Future concerns will likely revolve around toxins in the food supply (e.g., in grain storage). The increase in microbial counts in the air has led many processors to think about different practices, such as conveying products in open areas, and bulk packaging products for shipment. Biomonitoring will increasingly be used to track the consequences of environmental pollutants on health.

Food safety and security are areas of intense recent attention and discussion, with increased levels of concern over bio-terrorism and the need to secure facilities, as well as ensure safety of food and food ingredients from foreign sources. Our vulnerabilities to terrorism are adding a new wrinkle of insecurity and are re-defining food production and processing practices. The need for secure facilities is expected to require technologies, such as time clocks with biometrics to sense personal identity that will increase energy use and sensitivity to power quality.

**Figure 6-2: 2009 Food Processing and Beverage Industry Roadmap**




## 6.5. Drivers & Barriers

The challenges of functioning more efficiently and competitively in an environmentally conscious climate drive the RD&D efforts of the food processing and beverage industry. As the industry attempts to reconcile these driving forces through the implementation of a robust RD&D program, it must also address barriers such as resource constraints and compartmentalized thinking that can inhibit progress. To maximize the public and its own interest, the food processing and beverage industry must implement RD&D initiatives that overcome tradeoff challenges and strike a balance between competing demands.

### *6.5.1. Industry Driving Forces: The Challenge for RD&D*

While many factors shape the food processing and beverage industry's path toward a sustainable and prosperous future, this roadmap highlights three driving forces of particular importance: resource conservation, environmental protection, and global competitiveness.

These driving forces require the food processing and beverage industry to face competing demands and increasingly difficult tradeoffs. To achieve its vision of a sustainable and prosperous future and to maximize benefits to the public, the industry must establish RD&D initiatives that meet the competing demands of each driving force. New developments that help the industry meet demands in one area at the expense another serve neither the industry nor public interest.

### *6.5.2. Owner/Operator Barriers*

While the industry's driving forces provide a general picture of the challenges RD&D must address, it is also important for funding decisions and research initiatives to account for the barriers facing owners and operators. This roadmap describes the seven categories of barriers that inhibit companies from coping with the challenges created by the driving forces: resistance to change, resource constraints, technology gaps, regulatory burden, industry fragmentation and isolation, investment risk aversion, and compartmentalized thinking.

As a whole, the seven categories of barriers paint a useful picture of the range of issues that owners and operators must address. The implication for researchers is that pursuing a narrow technical focus to the exclusions of these broader challenges may limit the potential impact of a program, especially relative to those with a wider scope and farther reaching objectives.

### *6.5.3. Driving Forces*

The future sustainability and prosperity of California's food processing and beverage industry is dependent on the ability of owners and operators to effectively respond to three overarching driving forces:

**Figure 6-3: RD&D Driving Forces**

These drivers stem from changing external conditions, both locally and globally, and give rise to competing demands that force the industry to deal with increasingly difficult tradeoffs. In effect, the challenges created by the interaction and influence of these driving forces will provide the targets for research initiatives and the criteria for research outcomes over the coming years.

**Resource Conservation**

The food processing and beverage industry is one of the state's largest consumers of energy and water. These two resources are becoming increasingly scarce and costly. To ensure the sustainability and prosperity of its future in California, the industry must find ways to both reduce future demand for these resources and improve the efficiency of existing uses.

**Environmental Protection**
The state of California has always been a national pioneer in establishing environmental programs that aim to reduce environmental risks posed by air and water pollution, solid and hazardous waste management, and pesticide application. Over time, the food processing and beverage industry has made changes to reduce emissions and improve the disposal and/or reuse of waste products. Increasing environmental regulations and controls are inevitable and industry must be prepared to meet the demands of these increasing standards.

**Global Competition**
While the food processing and beverage industry is an important contributor to California's economy, it also operates in an increasingly global market. Global competition is putting pressure on the industry to reduce costs, increase quality, and bring new products to market. In the long-term, "do more with less" is a challenge that can only be met through innovation that increases capability, efficiency, and product quality. It is not enough to simply push the facility to run longer and harder; it is time to upgrade technology or reinvent the manufacturing process itself.

### *6.5.4. Barriers*

The California food processing and beverage industry faces a number of barriers to pursuing a sustainable and prosperous future. The most significant barriers fall into seven general categories that were identified at the roadmap meeting:

**Figure 6-4: RD&D Barrier Categories**

Participants identified these seven barrier categories as the top issues working against the identified driving forces. As a whole, the seven categories provide a useful picture of the range of issues currently facing owners and operators and identify specific technical challenges that must be addressed, particularly with regard to thermal management and the disposal or reuse of waste byproducts. The technical challenges are also intertwined with broader business, economic, and regulatory issues, which emphasizes the need for a broader scope of projects with far-reaching and strategic RD&D objectives.

**Resistance to Change**
The competing demands of resource conservation, environmental protection, and global competition place increasing pressure on food processing and beverage industry owners and operators to change their processes and procedures and upgrade their equipment. When external pressures place a premium on innovation, it is often easier for industry to fall back on 'tried and true' techniques instead of pursuing opportunities for advancement. The resource

investment required to implement new technologies and processes is often a deterrent and contributes to the mindset of resistance to change. While for the most part this resistance is due to a lack of awareness and education about the issues at hand, it can become a serious barrier to a sustainable and prosperous future for the industry.

**Resource Constraints**
The success of the food processing and beverage industry is dependent on the availability of reasonably priced resources, especially energy and water. In the face of California's continued population growth and industrial development, these two resources are becoming increasingly scarce and expensive. Shortages and unpredictable price fluctuations are a barrier to operational efficiency and the competitiveness of the industry.

**Technology Gaps**
The food processing and beverage industry faces specific technical barriers in meeting the demands of the competing driving forces. The technical barriers revolve around thermal management, waste and byproduct disposal and reuse, and food processing operations. In effect, these technical barriers identify specific needs for innovative technology solutions.

**Regulatory Burden**
Regulations and standards established and enforced by the government are necessary to protect the public interest and ensure the sustainability of the state's industries. However, changes in regulations and standards often outpace industry's ability to respond. Anticipating and keeping up with these changes now and in the future compounds the difficulty industry faces in balancing the competing demands of resource conservation, environmental protection, and global competition, and at times places additional burden on the adoption of new technologies and practices. Some plants have even indicated that regulatory compliance often takes precedence over taking the time to strategically improve process efficiency.

**Industry Fragmentation & Isolation**
In the food processing and beverage industry, there is a lack of crosscutting partnerships both within industry boundaries and across industry boundaries. The industry also lacks a mechanism to compile and disseminate information on cutting-edge technologies. As a result, many owners and operators face the barrier of being isolated and out of touch with industry-specific technical developments, best practices, and product knowledge. Without effective outreach and crosscutting partnerships, the food processing and beverage industry will continue to question the validity of new technologies and may overlook advancement opportunities, including partnering with vendors to develop products that are tailored to the needs of smaller, individualized markets.

**Investment Risk Aversion**
The adoption of new technologies is costly and generally requires significant upfront investment with a delayed and uncertain return. The food processing and beverage industry has reached a point where the potential benefits of new technologies are no longer enough to overcome the risk and uncertainty. Owners and operators are in the difficult position of needing new technology to stay competitive, but face the barrier of exposing their companies to

unacceptable levels of business risk. Thus, many owners and operators are forced to delay the adoption of these technologies as long as possible.

**Compartmentalized Thinking**

Within both industry and government, there is a tendency to adopt solutions or approaches that sub-optimize or work against each other. This issue results directly from a lack of a holistic or systems planning and understanding of the issues and tradeoffs involved. Conflicting regulatory requirements have prevented industry from investing in cogeneration and other approaches to self-generating electricity. Without a unified plan, government requirements may sometimes overlap or inconsistencies that create an unnecessary barrier to operational effectiveness may arise. At the plant level, owners and operators find it more difficult to diagnose inefficiencies without a big-picture view of the tradeoffs or a systems analysis of operations, and will continue to have difficulty recognizing opportunities for whole-system improvement if this barrier persists.

**Lack of Education & Training**

The industry continues to have a difficult time hiring well-trained, competent staff that can properly operate automated systems and controls. Although this roadmap does not address the education issue, the Energy in Agriculture Program of the Energy Commission sponsors the delivery of DOE Best Practice training and education workshops on pumps, motors, compressed air, and steam systems. The program is also involved in a U.S. DOE State Technologies Advancement Collaborative (STAC) partnership with other western states to develop a clearinghouse of information service. This service targets cost-effective emerging technologies to reduce energy costs, increase productivity, and improve quality. The partnership includes the states of Oregon, Washington, and Idaho, as well as the CLFP, the Northwest Food Processors Association, Del Monte Foods, and LBNL.

## 6.6. RD&D Pathways & Priorities

### *6.6.1. Background*

During the 2006 roadmapping process, the FIAC aimed the detailed research agenda directly at improving energy and productivity efficiencies and reducing water use in California's food processing industry by identifying nine research areas (Table 6-7 shows the priority ranking from left to right)along with corresponding targets and approaches.

**Table 6-7: Needs and Priorities for California's Food Processing Industry**

| Research Area | Targets & Approaches | |
|---|---|---|
| Optimize Equipment and Utilities | • Sensors<br>• Pumps<br>• Waste heat | • Sterilization<br>• Computerization<br>• Benchmarks |
| Validate Existing Technology | • Heat pumps<br>• Electric motors<br>• Power metering | • Process simulation<br>• Separations<br>• Maintenance |
| Improve Thermal Efficiencies | • Controls<br>• Chillers<br>• Freezers | • Peak loads<br>• Solar energy<br>• Facility design |
| Cold Chain Management | • Controls<br>• Chillers<br>• Freezers | • Refrigerants<br>• Peak loads<br>• Facility design |
| Improve Power Quality | • Voltage sags<br>• Harmonics<br>• Microelectrics | • Reliability<br>• Interruptions<br>• Affordability |
| Improve Water Use Efficiency | • Use reduction<br>• Recycle<br>• Separations | • Recovery<br>• Microbial control<br>• Benchmarks |
| Develop Total Raw Material Utilization | • Residue reduction<br>• Process integration<br>• Capture by-products | • Capture co-products<br>• New processing<br>• New products |
| Ensure Food Safety and Security | • Sensors<br>• Detection<br>• Traceability | • Risk management<br>• Integration<br>• Standards |
| Develop Seasonal Infrastructure | • Extend season<br>• Co-processing | • Time shifting<br>• Modeling |

The 2009 roadmap identified six RD&D pathways and their associated RD&D priorities. Within each pathway, the roadmap specified one or more priority solutions. These priority solutions represent the current needs and priorities for the food processing and beverage industry. Key technical elements, benefits and risks, barriers to implementation, and key results of these priority solutions are described in detail.

There are several areas of overlap between the priorities identified in the 2009 roadmapping process and those captured during the 2006 roadmapping process (illustrated in Figure 6-7 above). Content from the 2006 report has been integrated with the 2009 content and the RD&D pathways and priorities have been updated to reflect these additions and changes (see Table 6-8 below).

**Table 6-8. Combined Food Processing Pathways & Priorities**

| Pathway | Priority Solution |
|---|---|
| Waste & Wastewater Management | • Separation technologies for waste & wastewater solids<br>• Wastewater solids disposal<br>• By-product reuse & recycling<br>• Volume reduction of residues<br>• Environmentally-friendly peeling of fruit |
| Thermal Energy Enhancements | • Low temperature heat recovery<br>• Waste heat cooling through heat pumps<br>• Improved multi-state cooling<br>• Efficient burners<br>• Efficient drying & dehydration technologies |
| Non-Thermal Energy Enhancements | • Efficient blowers<br>• Efficient chillers, refrigerants, compressors<br>• Solar energy<br>• Solar drying technologies |
| Process & Controls Optimization | • Process & resource mapping<br>• Improved peak load management<br>• Optimize dryers and use of zone drying<br>• Improved temperature control across distribution chain |
| Sharing of Knowledge | • Outreach & education |

### *6.6.2. Research Pathways*

These five solution pathways and associated priorities indicate the need for a diverse range of RD&D that results in the development of new products and technologies. The pathways and priorities demonstrate the need for RD&D efforts that provide food processors with a better understanding of existing technology and inform their management, investment, and operational decisions.

#### 6.6.2.1. *Waste & Wastewater Management*

The industry would benefit from new technologies and practices that help food processors separate, remove, dispose of, and/or recycle waste and wastewater solids safely and efficiently. Priority technologies, processes, and end uses may include separating solids from liquids, especially salinity removal, energy generation from solid waste and wastewater solids, composting of green waste, innovative by-product reuse, production of co-products, and the production of potable water.

#### 6.6.2.2. *Thermal Energy Enhancements*

Thermal energy enhancements would improve the efficiency of natural gas use within several stages of food processing that apply across many subsectors. Priority opportunities include low-temperature waste heat recovery, waste heat cooling through heat pumps, improved multi-state cooling, and more efficient burners and drying and dehydration technologies.

#### 6.6.2.3. *Non-Thermal Energy Enhancements*

Non-thermal energy enhancements would improve the efficiency of electrical energy use and develop applications for renewable energy at various stages of food processing. Priority technologies and processes include efficient blowers, chillers, refrigerants and compressors, use of solar energy and solar drying technologies.

#### 6.6.2.4. *Process and Controls Optimization*

Facilitated by measurement and control technologies, opportunities exist to improve or institute process efficiency technologies and techniques for specific operations or steps in food and beverage production. Characterizing plant processes and mapping inputs and outputs throughout the specific processing operation(s) will in turn improve the effectiveness of technologies and techniques that optimize dryers, process temperatures, and peak load management. Process and control optimization may also improve the effectiveness of waste and wastewater management strategies and various energy-related technologies. Technologies that improve the process of automated fruit peeling would also provide valuable environmental, energy and cost benefits.

#### 6.6.2.5. *Sharing of Knowledge*

The food processing and beverage industry will benefit from testing and research initiatives that identify best practices and enable more effective use of current technologies. This includes guideline information to help companies determine the best products or technologies to meet specific operational needs. It also includes the development of centralized mechanisms for testing technologies as well as for compiling and disseminating knowledge.

### *6.6.3.* Priority Solutions

Priority solutions for the food processing industry stem from the priority pathways described in Section 6.6.2 and Table 6-7. These solutions also address the Energy Commission's mission of reducing energy costs, increasing efficiency, enhancing the ability to cope with demand and reliability issues, and meeting environmental challenges along with energy efficiency.

The priority solutions address the food processing and beverage industry's identified needs and priorities. Some of the priority solutions involve cutting-edge technology RD&D while others leverage more readily available approaches, such as improved resource measurement, partnering, and communications. Three of the solutions address the topic of wastewater treatment and handling, a subject of growing importance to the industry. The industry has also identified some non-traditional priorities, including renewable solar energy and byproduct reuse. A detailed analysis of the solutions, including key technical elements, benefits and risks, barriers to implementation, and key results, are presented in Figure 6-5 to 6-13. However, priorities that were introduced from the integration of the 2006 roadmap will not appear below.

**Figure 6-5: In-process technology to separate solids from wastewater**

## RD&D Priority

### In-process technology to separate solids from wastewater

#### Description

Development of robust, energy-efficient separation technologies that separate soluble and insoluble solids from wastewater streams. The technology should be applied in the plant and integrated with other processes as applicable.

#### Key Technical Elements

- Insoluble vs. soluble solids separation
- Extent of separation purity of effluent or solids
- Integrating with wash strategy
- R&D needed to evaluate biological vs. mechanical separation

#### Benefits to Industry

- More opportunity for water reuse
- More opportunity for resource recovery with biological processes
- Less discharge/disposal costs
- Lower water consumption
- Potential for energy recovery

#### Risks of Not Doing It

- Uncertain future discharge costs and options
- Uncertain future water supply
- Loosing potential resource/revenue stream as plant discharge

#### Key Barriers

- Technology costs
- Current cost of potable water and energy

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Commercialized industrial-scale integrated recovery system as a demonstration | • Lower-cost system | • Broad industry acceptance and incremental improvement in technology |

**Figure 6-6: Clean and efficient wastewater solids disposal**

## RD&D Priority

### Clean and efficient wastewater solids disposal

#### Description

There is a need for improved wastewater solids disposal options. One suggested solution is a centralized co-operative wastewater treatment facility providing clean and efficient wastewater processing and solids handling with waste recovery and generation of an energy product.

#### Key Technical Elements

- Determine specific technology needs
- Identify emissions produced
- Identify host/recipient of produced energy product

#### Benefits to Industry

- Allows companies to focus on core business again
- It is a green solution that avoids sending solids to landfill
- Neutral cost payout or possible money making proposition

#### Risks of Not Doing It

- Adding solid waste to landfill
- Distraction from core business focus
- The high costs will continue to get higher
- Regulations will force actions that are not necessarily deemed to be the best solutions

#### Key Barriers

- Permitting across Air Quality Management Districts and county lines, etc.
- Regulatory buy-in/approval

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Obtain industry buy-in to participate across wide spectrum<br>• Allocate CEC funds to support building pilot facility/ facilities | • Roll-out to multiple facilities being built | • Zero landfill |

**Figure 6-7: Process to recycle wastewater to potable quality**

## RD&D Priority

### Process to recycle wastewater to potable quality

#### Description

Various treatment technologies will be necessary to produce potable water from recycled food and beverage processing wastewater. Regulatory requirements including content of salts, organics, biological oxygen demand and other standards will need to be addressed. A combined treatment process is needed to produce potable quality water.

#### Key Technical Elements

- Removal of inorganics
- Trail of treatments, including pretreatment
- Energy efficiency
- Regulatory requirements

#### Benefits to Industry

- Sustainable long-term water management approach
- Potential cost saving through reuse of water
- Addresses critical water shortage issue

#### Risks of Not Doing It

- Increased water shortage may result in reduced product supply
- Businesses at risk due to shortages

#### Key Barriers

- Limitations in technology
- Disposal of salts
- High costs

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Assessment of treatment methods | • Demonstration of treatment process | |

**Figure 6-8: Low-temperature waste heat recovery**

## RD&D Priority

### Low-temperature waste heat recovery

#### Description

Development of cost-effective methods for capturing heat from liquid and gaseous waste streams.

#### Key Technical Elements

- An energy audit of waste heat streams
- Identification of available solutions
- Development of new ideas

#### Benefits to Industry

- Improved energy efficiency
- Fuel savings
- $CO_2$ reduction

#### Risks of Not Doing It

- Increased regulation
- Increased cost

#### Key Barriers

- Cost-effective process not available commercially
- Appropriate equipment not available commercially

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Develop a viable concept and prove it in a laboratory or bench-scale environment | • Pilot-scale demonstration project | • Commercialization project |

**Figure 6-9: More environmentally friendly peeling of fruit**

## RD&D Priority

### More environmentally friendly peeling of fruit

#### Description

Development of a robust, environmentally friendly, 'green' process to peel fruit that is cost effective and energy efficient. Blanching technologies that do not use steam, or alternatives that co-exist with steam should be considered (i.e., non-caustic chemicals or infrared).

#### Key Technical Elements

- Achieving a high level of energy efficiency
- Maintaining product quality throughout the peeling process
- Caustic separation
- Minimizing capital cost

#### Benefits to Industry

- Improved sustainability
- Potential for decreasing salinity
- Potential cost saving
- Possible fertilizer byproduct

#### Risks of Not Doing It

- Environment and/or ground water pollution
- Cost of traditional peeling, including energy cost

#### Key Barriers

- Technology is unknown
- High R&D costs
- Capital investment risk
- Securing regulatory approval and testing

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Circulate results of testing and economic analysis to solicit buy-in from industry | • Demonstrate technology | • Full-scale technology application |

**Figure 6-10: Detailed process and resource mapping**

## RD&D Priority

### Detailed process and resource mapping

#### Description

Detailed mapping and characterization of plant inflows and outflows that will enable holistic management of water, energy, and air emissions.

#### Key Technical Elements

- Evaluate the volume of water use and wastewater generation for individual processing steps
- Identify process steps that use the most resources and generate the most waste
- Target priority steps for improvement

#### Benefits to Industry

- Justification for regulatory agency collaboration
- Holistic management approach based on measuring and understanding flows leads to better decision making

#### Risks of Not Doing It

- Hard to identify improvements

#### Key Barriers

- Costly to characterize wastewater and sub-meter variables

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Develop understanding of flows and identify and implement improvements | • Demonstrate progress and work toward integrating with the regulatory process | |

**Figure 6-11: Byproduct reuse to create value added products and/or energy**

## RD&D Priority

### Byproduct reuse to create value added products and/or energy

#### Description

Identify waste streams and potential highest value use of waste stream, including energy production or innovative energy saving process technologies to produce value-added food and feed products or ingredients.

#### Key Technical Elements

- Develop and evaluate models for determining highest use value of waste streams
- Develop/identify technology and methods for recovery of energy value from waste stream (byproducts)
- Develop/identify technology that will lower energy required to process waste

#### Benefits to Industry

- Reduced disposal cost
- Reduced energy cost
- Reduced regulation
- Meet or beat foreign competition
- New value-added products to expand California food industry

#### Risks of Not Doing It

- Increasing cost for byproduct disposal
- Increased regulation
- Increased cost of energy
- Markets lost to foreign competition
- Missed opportunity to add new value added products or add new markets

#### Key Barriers

- Regulatory oversight
- High cost of technology/process may inhibit adoption
- High cost of R&D to develop new technology or process

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Industrial-scale demonstration of technology | • Commercialization of technology for food industry | |

**Figure 6-12: Solar energy applications**

## RD&D Priority

### Solar energy applications

#### Description

Develop technology and applications for use of solar energy in food and beverage processing. Solar technologies may include thermal energy (for heating) or photovoltaics (for electricity).

#### Key Technical Elements

- Effective heat control including efficiency and quality parameters
- Possible solar-assist hybrid technologies

#### Benefits to Industry

- Free or low-cost energy
- Renewable energy source

#### Risks of Not Doing It

- Depletion of non-renewable energy sources

#### Key Barriers

- Capital cost for technology
- Space requirements for solar collectors

#### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Effective demonstration of concept | • Commercialization | |

**Figure 6-13: Outreach communication clearinghouse of best practices and technology**

## RD&D Priority

### Outreach communication clearinghouse of best practices and technology

### Description

Create a centralized information network to support energy efficiency efforts in the food processing and beverage industry. The clearinghouse may provide access to educational materials, information on best available equipment, partnering opportunities, and a process for cross-industry communication on lessons learned.

### Key Technical Elements

- Sharing ideas across multiple companies and industries
- Developing process to reliably obtain best practices from industry and scientific community
- Uniformity of information

### Benefits to Industry

- Increased energy efficiency
- Reduced continuing build-out of power generation

### Risks of Not Doing It

- Waste of human capital due to development of identical ideas along parallel lines

### Key Barriers

- Confidentiality of information

### Key Results and Time Frames

| Near-Term | Mid-Term | Long-Term |
|---|---|---|
| • Build website to access all topic areas | • Develop rewards program for best suggestions | |

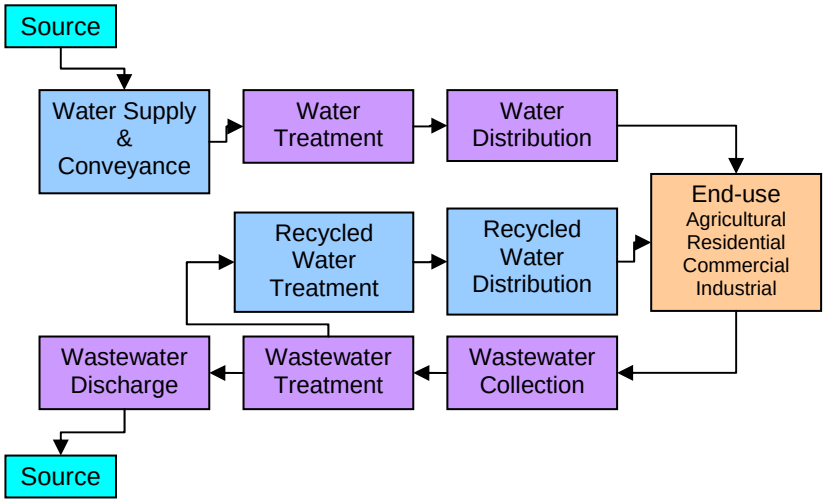
# 7.0 Water-Energy

## 7.1. Introduction

The significant interdependencies between water and energy came to the State's attention recently. In 2005, the Energy Commission published its white paper, "California's Water-Energy Relationship," which identified substantial opportunities for energy savings from water-related uses. This report informed the Energy Commission's 2005 Integrated Energy Policy Report that recommended policies to help the State harness water-related energy and climate benefits.

The Energy Commission found that water and energy resources are inextricably connected, and that water-related energy uses are significant. Transport and treatment of water resources, treatment and disposal of wastewater, and energy used to consume water account for nearly 20 percent of total electricity and 30 percent of non-power plant related natural gas consumed in the State. Demand for water resources is expected to increase at roughly the same rate, or more rapidly, than demand for energy - primarily due to population growth but also as a result of external factors such as climate change and increasingly stringent regulatory rules governing water quality.[37] Energy used to produce and transport water is considered "embedded" in the water, accumulating as water moves through the water use cycle (See Figure 7-1).

**Figure 7-1: California's Water-Energy Cycle**




PIER is uniquely positioned to focus RD&D innovation to achieve the incremental benefits that can only be realized by exceeding current practices. The challenge for PIER will be to invest in RD&D that maximizes water-related energy and climate opportunities given limited resources

[37] CEC, "California's Water-Energy Relationship", CEC-700-2005-011, 2005.

and data.[38] To accomplish this, PIER will need to develop a rational methodology for allocating RD&D funding at this early stage in the emerging field of water-energy.

## 7.2. PIER's Water Roadmaps

### *7.2.1. Water & Wastewater Industry Energy Efficiency: A Research Roadmap (2004)*

In 2003, the California Energy Commission (Commission) and the Awwa Research Foundation (Awwa RF) jointly sponsored the development of this report *Water and Wastewater Industry Energy Efficiency: a Research Roadmap*. The purpose of the Roadmap was to:

- Provide direction for the RD&D activities of the California Energy Commission's Public Interest Energy Research (PIER) program to meet the energy needs and priorities of the water and wastewater utilities based on the industry input.
- Provide specific project descriptions which Awwa RF can incorporate in request-for-proposals.

The Roadmap was developed through the collective contribution of public and private sector experts in energy use in water and wastewater utilities. The participants represented water and wastewater utilities, energy utilities, consultants, academia, government and other research organizations. Workshop participants identified eight primary research areas that represent potentially high yield in terms of energy savings and economic value, including:

**Table 7-1: Research Areas Identified in 2004 Water & Wastewater Industry Energy Efficiency Roadmap**

| Research Areas Identified in 2004 Water & Wastewater Industry Energy Efficiency Roadmap | |
|---|---|
| **RD&D Area** | **Objectives** |
| Advanced Treatment Processes | Enable lower quality sources to meet stringent quality requirements of drinking water supplies. |
| Desalination | Develop technologies that reduce the energy consumption of desalination processes. |
| Energy Generation & Recovery | Improve recovery of wasted energy in water & wastewater processes. |
| Societal & Institutional Issues | Optimize existing policies, practices and perceptions to lower energy consumption associated with conveyance, treatment, distribution, use and reclamation of water & wastewater. |
| Energy Optimization | Optimize existing systems for delivering and treating water and wastewater. |
| Sustainability | Investigate and quantify energy applications to offset increased demand, reduce non-point pollution, reduce cross-media pollution, and avoid impacts. |
| Decentralization | Examine the potential for decentralization to generate energy savings or reduce costs. |
| Total Energy Management | Examine the true energy cost of the anthropogenic water cycle to understand opportunities for optimizing the provision of water and wastewater service. |

[38] Because little is known about water-energy interdependencies, there are many gaps in the data and tools needed to effectively evaluate tradeoffs between water and energy.

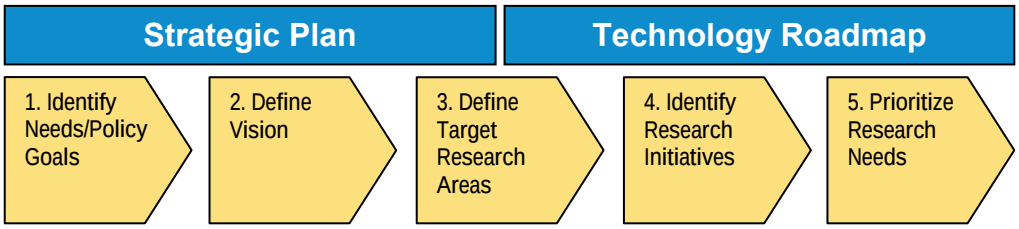
Additionally, the Roadmap identified 44 potential RD&D projects across these research areas. Many of these RD&D opportunities have received funding. The remaining priorities and projects have been reassessed in the context of the policy and technology framework established by the Water-Energy Strategic Plan and Technology Roadmap.

### *7.2.2. Water-Energy Strategic Plan and Technology Roadmap (2008)*

In response to the recommendations in the 2005 IEPR, PIER embarked on a two-phase planning process to identify water-energy RD&D opportunities. Phase 1, development of a near-term RD&D portfolio, was completed in 2006. Phase 2 is a long-term RD&D portfolio planning effort that commenced in 2007 and concluded with the publication of the "Water-Energy Strategic Plan and Technology Roadmap" in 2008.

The Water-Energy Strategic Plan establishes the policy context for PIER's IAW RD&D efforts in this area and defines the Target Research Areas (TRAs) that will guide PIER's long-term RD&D investments in water-energy. The Technology Roadmap relies upon the Strategic Plan's phase 1 and 2 framework, goals and objectives to identify and prioritize research initiatives.

**Figure 7-2: Strategic Plan and Technology Roadmap Planning Process**




The PIER Water-Energy program planning process, approach and components are consistent with those performed by other PIER program areas.

**Table 7-2: PIER Water-Energy Target Research Areas (TRAs)**

| PIER Water-Energy Target Research Areas (TRAs) | |
|---|---|
| **Target Research Area** | **Primary Objectives** |
| Supply & Conveyance | Optimize energy use and reduce peak demand of wholesale water supply and conveyance systems |
| Treatment | Reduce energy intensity of water and wastewater treatment systems and processes |
| Distribution | Reduce energy intensity and peak demand of distribution systems |
| End Use | Develop technologies, tools and techniques that maximize savings of energy embedded in water |
| Renewable Energy | Advance technologies that increase renewable energy production by water and wastewater systems |

**Key Elements of the Strategic Plan**

The Strategic Plan is comprised of a policy context, program vision and target research areas (TRAs). Relevant policies were compiled from the 2005 Integrated Energy Policy Report (IEPR), Joint Agencies' Energy Action Plan (EAP), California Water Plan (CWP), and the 2005 Federal

Energy Policy Act (2005 EPAct). Next, water-specific policies, requirements and issues were reviewed to understand their implications for energy use in California. Finally, energy and climate policy goals were assessed to determine whether or not actions in the water sector could help meet these goals.

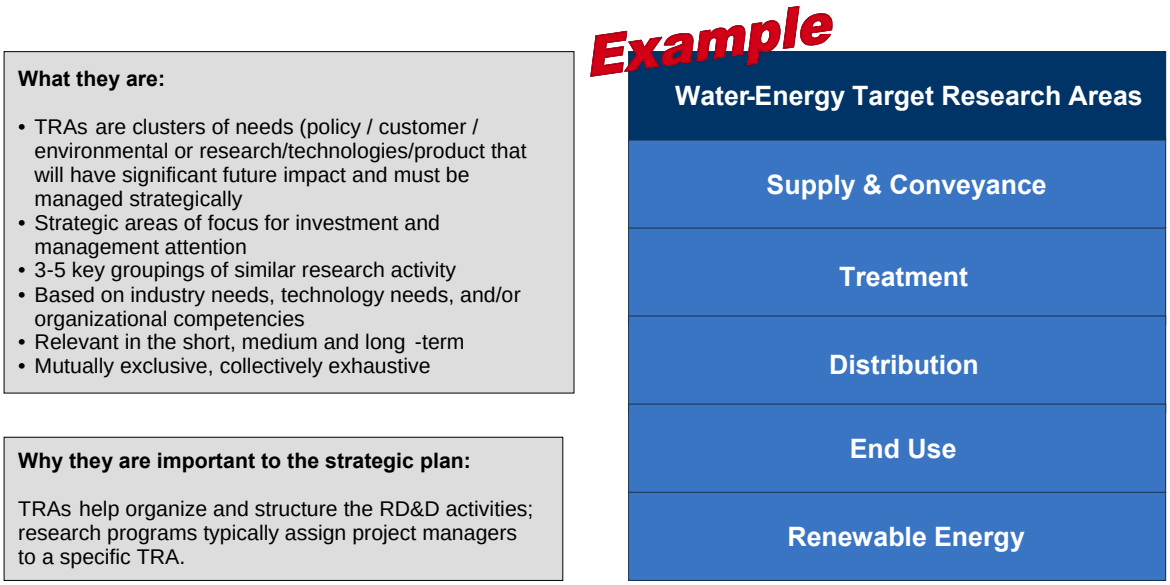
All of the relevant water policies, requirements and issues identified were mapped into a framework that follows the different stages of the water-cycle. The implication of each policy, requirement or issue on energy use was captured. In addition, possible actions were identified that could help reduce water-related impacts on energy use.

The policy context provided a framework from which the program vision and TRAs were developed. The vision consists of a statement that briefly describes the end-point that the program is trying to achieve and is directly tied to the policy goals and objectives.

Target Research Areas (TRAs) are the final piece of the Strategic Plan. TRAs help group RD&D activities necessary to achieve a policy goal (or set of closely related policy goals). TRAs are mutually exclusive, collectively exhaustive groupings of 3-5 similar research activities that have been derived from industry and technology needs, policy goals and/or organizational competencies. The water use cycle is a natural choice for PIER's TRA framework.

TRAs are relevant in the short, medium, and long-term.

**Figure 7-3: Target Research Area Framework**




**Role of Stakeholders**

Stakeholders were involved throughout the planning processes used for all roadmaps to ensure reasonableness and support. Early in the process, interviews were conducted with key water sector professionals who offered valuable insights as to the most important water and water-energy issues facing California today. In addition, stakeholders from public agencies, utilities, and private water technology firms participated in a Webex to contribute their ideas on potential research needs. In all, more than 30 external stakeholders from nearly 20

organizations contributed to development of PIER's Water-Energy Strategic Plan and Technology Roadmap. For a complete list of participating stakeholders see the Appendix 7-B.

## 7.3. The Water-Energy Policy Context

The water-energy policy context is comprehensive and very complex. It includes specific water-energy recommendations as well as separate energy and water policies. The water-energy policy context also includes the AB 32 carbon reduction policy goal that overlays other policies and is the overarching context for all state agencies. Those policies that lie at the intersection of both water and energy and at the intersection of water, energy, and climate inform the Strategic Plan.

Water-related energy uses comprise a significant portion of State consumption and can therefore play an important role in helping California meet its energy and climate goals. Water related uses (by water agencies and end-users) comprise the largest electricity user group in the State, consuming nearly 20 percent of California's electricity. Peak electricity demand by water agencies and end-users is estimated to be approximately 9,000 MW[39]. Roughly 30 percent of all non-power plant related natural gas consumption in the State is attributed to the water sector. In addition, there is significant opportunity for the water sector to generate renewable energy using existing infrastructure (e.g., in-conduit hydropower) and byproducts (e.g., biogas).

### *7.3.1. 2005 Integrated Energy Policy Report (IEPR)*

The 2005 IEPR remains the main policy document that specifically articulates water-energy policy goals for the state. The 2005 IEPR and other policy documents (e.g., Energy Action Plan II and 2005 Water Plan Update) also include recommended actions that support these five priority areas. Specifically:

**Priority Area 1:** Increase water-related energy production
Recommended actions include increasing cost-effective, environmentally preferred self-generation by water and wastewater agencies; developing/enhancing tools for better environmental protection while optimizing hydropower operations; and increasing energy generation by water systems and decreasing their energy use.

**Priority Area 2**: Energy savings by end-users
Recommended actions include decreasing energy use associated with water end use in both the agricultural and urban sectors; maximizing energy and water savings through efficiency improvements in (a) water-using devices in homes and businesses, (b) devices that use or move water and (c) other options; reducing the energy intensity of conveyance and treatment systems; and reducing peak electric demand of the water supply system.

**Priority Area 3**: Increase energy benefits from water storage
Recommended actions include maximizing the use of water storage to shift loads off-peak (e.g., time of use (TOU)) and grid integration of intermittent renewable generation.

[39] Pro-rata based on a 19% energy factor. This assumes the water-related load factor is the same as the statewide average. Actual peak demand cannot be readily identified.

**Priority Area 4:** Study once-through cooling
Recommended actions include developing a consistent regulatory approach, including protocols and guidelines for assessing ecological and other effects of once-through cooling, and identifying alternatives such as cooling with non-potable water.

**Priority Area 5:** Energy savings through water efficiency
Recommended actions include increasing the understanding of water-energy interdependencies; identifying new and innovative technologies and measures for achieving energy and water efficiency savings; identifying potential savings throughout the water cycle; identifying and implementing cost-effective water system retrofits that reduce energy and peak demand; increasing savings through the development of TOU water tariffs and meters; and increasing flexibility in water deliveries.

The specific actions supporting the 2005 IEPR and other key policy recommendations can be mapped to the five segments of the water-use cycle: supply & conveyance, water treatment, distribution, end-use and wastewater treatment.[40]

### *7.3.2. Global Warming Solutions Act of 2006 (AB 32)*

In 2006, the California state legislature passed the AB 32, a comprehensive long-term policy aimed at reducing the state's greenhouse gas emissions. In the scoping plan it released in December 2008, the ARB identified six water related measures to meet AB 32's GHG reduction goals. The six areas of water use reduction are:

- Water use efficiency
- Water recycling
- Water system energy efficiency
- Reuse urban runoff
- Increase renewable energy production
- Public goods charge

ARB estimates that by 2020, "business as usual" would produce 596.4 million metric tons carbon dioxide equivalent ($MMTCO_2$) in annual emissions.[41] Of this amount, about 40.7 $MMTCO_2$ (6.8 percent) of emissions in 2020 is expected to be attributable to water-related uses.[42] In its "Climate Change Scoping Plan," issued December 2008, ARB identified these six strategies for reducing greenhouse gas emissions to 1990 levels as required by AB32. These six measures are estimated to reduce GHG emissions by 4.8 $MMTCO_2$ by 2020 and are in addition to reductions in water usage achieved by the electricity industry. In addition, reductions in water-

[40] See Figure 7-1: California's Water Use Cycle.

[41] ARB, "California's Greenhouse Gas Emissions Inventory", 2008.

[42] Based on prior findings by the Energy Commission that water-related activities account for 19.2% of all electricity consumed in California and about 30% of non-power plant natural gas.

related energy consumption will have a significant role in achieving the 26.3 $MMTCO_2$ reductions targeted through energy efficiency, combined heat and power, and solar water heating.[43]

### *7.3.3. Federal & State Water Laws*

Water sector policy, requirements and issues have implications on energy demand and consumption in California. Because water policy governs the way water is used in California, it affects the amount of energy used in managing water resources.[44] This section will describe the major issues affecting water policy and analyze the impact of water policy on the energy sector.

Four underlying issues are driving key water sector policy in California. Different policy responses have emerged to address each of these underlying issues. Specifically, policies encourage water conservation and new supplies, local supply control and supply diversity, water supply segregation by use, increased treatment, water source protection, and an integrated approach to flood and water management, including optimized use of groundwater storage capacity.

**Table 7-3: Underlying Issues Driving Key Water Sector Policy in California**

| Underlying Issues Driving Key Water Sector Policy in California | | |
|---|---|---|
| **Underlying Issue** | **Rationale for Importance** | **Policy Response to Issue** |
| Need for Adequate Supply | Important due to population growth, climate change, and environmental requirements | Address with water conservation and new supplies |
| Need for Reliable Supply | Important due to variability of water imports because of environmental requirements and climate change, as well as dry year augmentation needs | Address with local supply control and supply diversity |
| Need for Higher Quality Supply and Discharge | Important due to improved water quality requirements and emerging contaminants, increases in effluent treatment requirements, as well as the importance of public perceptions | Address with water supply segregation by use, increased treatment, and water source protection |
| Need for Flood Control | Important due to impact on reservoir management | Address with integrated approach to flood and water management, including optimized use of groundwater storage capacity |

Numerous policies, requirements and issues impact the water sector in California. In addition to five major federal water policies and eight State water policies, a number of issues including climate change, population growth, sustainable land use/smart growth, ethanol production, and agriculture-to-urban water transfers are significantly impacting water supplies, and in turn, energy use and greenhouse gas emissions.

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43 ARB, 2008.

44 Note that in some circumstances, policies may conflict (e.g., water conservation via drip irrigation may in some cases be more energy intensive than other types of irrigation practices).

**Table 7-4: Key Policies and Requirements Impacting California's Water Sector**

| Key Policies, Requirements and Issues Impacting the Water Sector in California |
|---|
| Federal government<br>• Safe Drinking Water Act (U.S. Code, Title 42, Secs. 330f et seq)<br>• Clean Water Act (U.S. Code, Title 33, Secs. 1251 et seq)<br>• Endangered Species Act (U.S. Code, Title 7, Sec. 136 et seq)<br>• Presidential Exec. Order 1/24/07, Sec. 2(d) (i.e. federal agencies to acquire water efficient goods and services)<br>• Central Valley Project Improvement Act (P.L. 102-575)<br>State government<br>• California Water Plan Update 2005 (various provisions in Volume 1 (Strategic Plan) addressing conservation, recycling, storage and facilities)<br>• Water Reuse Law of 1974 (Water Code Sec. 460 et seq); Water Recycling Law (Water Code Sec. 13500 et seq); Water Recycling Act of 1991 (Water Code Sec. 13575 et seq); Water Recycling Act of 2006 (Water Code Sec. 13555.5 et seq)<br>• Cobey-Porter Saline Water Conversion Law (Water Code Sec. 12945 et seq)<br>• Porter-Dolwig Ground Water Basin Protection Law (Water Code Sec. 12920 et seq)<br>• Agricultural Water Management Planning Act (Water Code Sec. 10800 et seq); Agricultural Water Suppliers Efficient Water Management Practices Act (Water Code Sec. 10900 et seq)<br>• Urban Water Management Planning Act (Water Code Sec. 10610 et seq)<br>• Water Conservation in Landscaping Act (Gov't Code Sec. 65591 et seq)<br>• Title 20, Cal. Code of Regulations, Appliance Efficiency Standards (Sec. 1601 et seq., re: water and energy, note possible federal pre-emption)<br>Other notable issues<br>• Climate change<br>• Population growth<br>• Sustainable land-use/smart growth<br>• Agriculture-to-urban water transfers<br>• CUWCC MOU on Best Management Practices |

Each key water policy, requirement and issue identified has implications on energy demand and consumption in California. The impact of water policy on the energy sector varied. In some cases, water policy supported reduced energy use; in other cases, water policy exacerbated energy use. Possible actions were then identified that could help reduce water-related impacts on energy use.

## 7.4. Target Research Areas

Target Research Areas (i.e., research platforms) are tools used to help organize, structure and manage RD&D activities. By focusing RD&D efforts on target research areas (TRAs), PIER can better manage its activities and ensure a comprehensive portfolio of activities that address a range of critical issues.

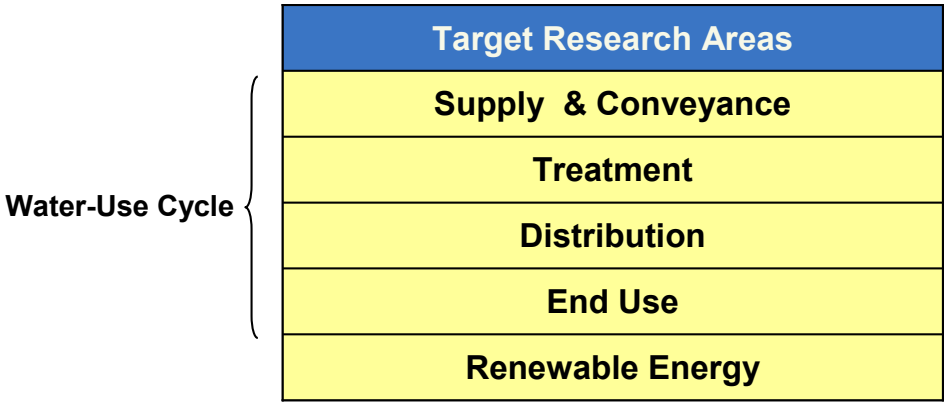
Each TRA is characterized by eight primary attributes:

- Definition: What is the scope of the TRA?

- Key Opportunities and Challenges: Why is the TRA important?
- Industry Receptiveness: Why does industry care?
- Policy Goals Addressed: How will the TRA help meet the policy goals?
- Key Stakeholders: Who should PIER work with to develop this TRA?
- Preliminary Set of RD&D Needs: What types of research are included?
- Size of Opportunity: What is the impact of success? (e.g., kWhs, MMths, kWs, $, tons of CO2)
- Strategic RD&D Objective: What is PIER Industrial's objective that will support the vision and the policy goals?

PIER has selected California's water-use cycle (Figure 7-4) as the basis for PIER's Water-Energy TRAs.

**Figure 7-4: Water-Energy Target Research Areas**




Renewable energy is also included as a TRA because there are multiple points in the water-use cycle where renewable energy can be generated, and renewable energy is an important state energy policy goal.

The table below lists the five water-energy TRAs and their primary objectives.

**Table 7-5: Water-Energy Target Research Areas and Objectives**

| Water-Energy Target Research Areas and Objectives | |
|---|---|
| **Target Research Area** | **Objective** |
| Supply & Conveyance | Identify opportunities that optimize energy use and reduce peak demand of water supply and conveyance systems across jurisdictional boundaries in California. |
| Treatment | Reduce the energy intensity of current water and wastewater treatment systems and processes, and develop options that reduce expected energy impacts of increasingly stringent water and wastewater quality requirements. |
| Distribution | Reduce energy demand in distribution systems through direct and indirect methods, and capture opportunities to reduce peak demand. |

| Water-Energy Target Research Areas and Objectives | |
|---|---|
| **Target Research Area** | **Objective** |
| End Use | Develop methodologies for valuing the total resource costs and benefits of water consumption and develop technologies, tools and techniques that enable optimizing savings of energy embedded in water. |
| Renewable Energy | Advance technologies that increase renewable energy potential in water and wastewater systems. |

The following sections describe each TRA in more detail, and include for each TRA a definition, objective, key opportunities and challenges, a preliminary set of RD&D needs, and example strategic RD&D initiatives.

### *7.4.1. Supply & Conveyance*

**Definition**
The Supply & Conveyance TRA is characterized by large water collection and transportation (conveyance) systems throughout the state. This TRA includes surface and sub-surface sources of water.

**Objective**
Research conducted under this TRA will focus on identifying opportunities that optimize energy use and reduce peak demand of water supply and conveyance systems throughout California.

**Key Opportunities and Challenges**
Next to End-Use, the Supply & Conveyance segment has the highest energy intensity and is the largest energy consumer in the water-use cycle. The greatest challenge in the Supply & Conveyance TRA will be to develop remedies to the significant obstacles to statewide optimization of water and energy created by existing policies, practices, rules and regulations that favor managing water and energy as two entirely separate resources and systems, and also make it difficult to optimize any resource or system beyond its jurisdictional boundaries.

**Preliminary Set of RD&D Needs**
Several RD&D needs were identified for the Supply & Conveyance TRA. These include:

- Changes to large water systems' design and operations
- Increased water storage to enhance operating flexibility (e.g., for load shifting)
- Changes to water resources (especially developing additional local sources, such as groundwater, or decreasing the energy intensity of alternatives such as desalination)

**Example Research Initiatives**
Potential research initiatives that would address these RD&D needs could include:

- Identifying changes to supply and conveyance design and operations that increase system flexibility for demand response and peak load reductions

- Identifying strategies that reduce climate change risks on supply and conveyance energy requirements
- Integrating renewable energy sources into existing systems
- Advancing energy efficient technologies that "make" water (i.e., increase water supplies)

### *7.4.2. Treatment*

**Definition**
The Treatment TRA is characterized by systems, processes and technologies to treat potable water, wastewater, storm water and urban runoff.

**Objective**
Research under the Treatment TRA will focus on reducing the energy intensity of current water and wastewater treatment systems and processes, and develop options that reduce expected water-related impacts on energy consumption from increasingly stringent water and wastewater quality requirements.

**Key Opportunities and Challenges**
Energy savings opportunities in Treatment lie in focusing on the increasingly stringent water quality rules for both drinking water and wastewater, which have increased the energy intensity of systems and technologies. Until fairly recently, treatment was comprised of primarily mature technologies. Today, concerns about disinfection byproducts and other carcinogens have produced new disinfection technologies and processes. In some cases, multiple points of treatment are required.

**Preliminary Set of RD&D Needs**
RD&D needs include:

- Reducing the energy intensity of treatment processes such as filtration, solids removal, disinfection and reverse osmosis
- Packaged plant solutions for distributed treatment

**Example Research Initiatives**
Potential research initiatives that would address these RD&D needs could include:

- Reducing the energy intensity of existing treatment systems, processes and technologies
- Mitigating barriers to the adoption of new, energy efficient technologies
- Modifying treatment systems' design and operations to reduce energy intensity and demand

### *7.4.3. Distribution*

**Definition**

The Distribution TRA is characterized by an extensive system of pipes, pumps, valves, motors, controls, pump stations and lift stations that use mature technologies to:

- Deliver potable water to end-users
- Deliver wastewater to sewage treatment plants
- Treat and discharge wastewater effluent
- Transport recycled water to approved end uses

**Objective**

Research under the Distribution TRA will focus on reducing the energy demand in distribution systems through direct and indirect methods, and capture opportunities to reduce peak demand.

**Key Opportunities and Challenges**

RD&D will focus on three key opportunities:

- Distributed treatment plants could reduce energy requirements for water and wastewater distribution by reducing both the volume and distance of transport.
- Reducing leaks in distribution systems can save substantial amounts of embedded energy.
- Small storage facilities (reservoirs, tanks and pipelines) could increase load shifting capabilities.

**Preliminary Set of RD&D Needs**

RD&D needs for the Distribution TRA include:

- New design approaches, such as distributed treatment that may reduce the quantity and distance of distributed potable water, wastewater and recycled water.
- Use of pipes for short-term detention of water, allowing interim storage that can provide load shifting capabilities.

**Example Research Initiatives**

Potential research initiatives that would address these RD&D needs could include:

- Achieving direct energy benefits by reducing the energy intensity of distribution systems
- Achieving indirect energy benefits by reducing system losses
- Increasing the ability of water and wastewater distribution systems to reduce peak demand

### 7.4.4. End-Use

**Definition**

The End-Use TRA focuses on end use applications that save water and associated indirect ("embedded") energy, and other end-use applications that directly reduce energy consumption by water end-users.

**Objective**

The primary objective of this TRA is to develop methodologies for valuing the total resource costs and benefits of water consumption, and to develop technologies, tools and techniques that enable optimizing savings of energy embedded in water.

**Key Opportunities and Challenges**

Embedded energy savings are currently a central area of policy and implementation review. However, valuation methodologies can be complicated by policy, regulatory and jurisdictional issues. Additionally, it will be important to focus on the incremental value of embedded energy savings separately from any direct efficiency savings.

**Preliminary Set of RD&D Needs**

Several RD&D needs were identified for the End-Use TRA. These include:

- Data, methods and tools for evaluating the energy benefits of water savings opportunities
- Direct energy reductions in hot water and pumping applications
- Understanding the potential benefits of TOU water metering to foster water demand reduction during summer peak periods[45]

**Example Research Initiatives**

Potential research initiatives that would address these RD&D needs could include:

- Developing models and tools to help evaluate the tradeoffs between water and energy consumption in joint applications
- Identifying changes in irrigation technologies and practices that reduce the energy intensity of agriculture
- Reducing cold water consumption to obtain embedded energy benefits

### 7.4.5. Renewable Energy

**Definition**

The Renewable Energy TRA is characterized by water-related renewable energy production, specifically biogas and in-conduit hydropower that occur primarily as a by-product of water and/or wastewater operations.

[45] Some stakeholders believe that there might be a peak demand benefit; however, since water deliveries are most often distributed from local storage facilities, no one yet knows if any such potential benefit is significant.

**Objective**
Research under the Renewable Energy TRA will focus on advancing technologies that increase renewable energy potential in water and wastewater systems.

**Key Opportunities and Challenges**
Technologies in the Renewable TRA are not unique to water sector applications. PIER can therefore benefit from research being conducted by other organizations. Additional RD&D investments in these areas will likely have marginal impact.

**Preliminary Set of RD&D Needs**
RD&D needs for the Renewables TRA include:

- Develop new/improved tools to optimize existing conventional hydropower generation
- Advance low-head hydropower technologies
- Identify modifications to wastewater treatment systems and processes that increase biogas production and renewable energy potential

**Example Research Initiatives**
Potential research initiatives that would address these RD&D needs could include:

- Maximizing energy recovery from water and wastewater collection, transport and treatment systems and operations (e.g., in-conduit hydro and biogas)
- Identifying ways that water and wastewater systems could be used to help meet the state's Renewable Portfolio Standard (RPS)

## 7.5. Technology Roadmap

The Technology Roadmap is comprised of priority research initiatives for each Target Research Area. Each research initiative seeks to answer a particular question that is deemed of great importance to optimizing the state's water and energy resources and infrastructure.

As noted previously, PIER decided to align its water-energy Target Research Areas (TRAs) with the water use cycle. Through stakeholder workshops, 3-5 priority research initiatives were selected for each TRA.

While following the water use cycle would tend to assure that there are no overlaps among the research initiatives, there are similarities among certain functions of the water use cycle. For example:

- Treatment technologies are used in both the Treatment and Supply & Conveyance segments to increase water supplies by enabling conversion of brackish water to potable water supplies.
- Storage is an essential concept for increasing operational flexibility and demand response capabilities in both Supply & Conveyance and in Distribution.
- Recycled water, an increasingly important water resource, is a by-product of [wastewater] treatment and also requires distribution energy to deliver recycled water to qualified end uses.

Some research initiatives will be combined in PIER's Water-Energy RD&D Portfolio for efficiency and cost-effectiveness.

This section will describe the 19 research initiatives that were identified with the assistance of key stakeholders and the criteria that were applied to qualify the RD&D opportunities in context of "best fit" with the state's water-energy policy goals. Their relative ranking and the bases for these determinations are also provided. The discussions about the rationale applied to determine their relative ranking are organized by TRA.

### *7.5.1. Water-Energy Research Initiatives*

The 19 research initiatives below were identified in consultation with knowledgeable water and energy stakeholders through interviews, webcasts and workshops.

The research initiatives were prioritized to develop a portfolio of low-risk, high energy efficiency potential, near-term activities that are deemed essential to meeting the State water-energy policy goals.

The following characteristics distinguish priority research initiatives with favorable timing and risk profiles:

- Successful implementation is likely
- Solution likely to be identified in the near-term
- Research results can be implemented within existing policies and regulations
- Champions ready to support and implement the initiative
- Many potential partners for collaborative development

Each research initiative was scored on two criteria:

- Potential impact on water-energy policy goals
- Need for PIER funding

"Potential Impact" was determined on the basis of several characteristics, including the approximate timing, magnitude and feasibility of potential energy benefits. Specifically, potential impact on water-energy policy goals refers to the likelihood that a particular research initiative can substantially reduce water-related energy consumption, peak demand and greenhouse gas creation.

Another important consideration for inclusion in PIER's RD&D portfolio is whether PIER's participation is "needed". In this context, PIER must ascertain which key stakeholders are already engaged, or likely to be engaged, in conducting research identified as high priority for California, and their potential levels and sources of funding.

The results of this identification and ranking process are shown in Table 7-6.

**Table 7-6: Water-Energy Research Initiatives by Target Research Area**

| Water-Energy Research Initiative by Target Research Area | | | |
|---|---|---|---|
| **Target Research Area** | **Water-Energy Research Initiatives** | | **Priority** |
| Supply & Conveyance | 1 | Design and Operations Changes: Identify changes to supply and conveyance design and operations that increase system flexibility for demand response and peak load reductions. | High |
| | 2 | Supply Switching: Identify opportunities for supply switching that reduce the energy intensity of the state's water supplies. | High |
| | 3 | Climate Change Risk Reduction: Identify strategies that reduce climate change risks on supply and conveyance energy requirements. | Low |
| | 4 | System Retrofits: Identify system retrofits that could reduce conveyance system energy requirements. | Mid |
| | 5 | Technologies to Make Water: Advance energy efficient technologies that "make" water. | High |
| Treatment | 6 | Energy Intensity Reduction: Reduce energy intensity of existing treatment systems, processes and technologies. | Mid |
| | 7 | Barriers Mitigation for Energy Efficient Technology: Mitigate barriers to adoption of new, energy efficient technologies. | Low |
| | 8 | System Design and Operation: Modify system design and operations to reduce energy intensity and demand. | Low |
| | 9 | Treatment to Create New Water Supplies: Develop energy efficient treatment technologies that create new water supplies. | High |
| Distribution | 10 | Energy Intensity Reduction: Achieve direct energy benefits by reducing the energy intensity of distribution systems. | Low |
| | 11 | System Loss Reduction: Achieve indirect energy benefits by reducing system losses. | Low |
| | 12 | Peak Demand Reduction: Increase the ability of water and wastewater distribution systems to reduce peak demand. | Low |
| End Use | 13 | Cold Water Reduction: Reduce cold water consumption to obtain the embedded energy benefits | High |
| | 14 | Hot Water Reduction: Reduce hot water consumption to obtain the direct and embedded energy benefits. | Mid |
| | 15 | Water-Energy Tradeoffs: Develop models and tools to help evaluate the tradeoffs between water and energy consumption in joint applications. | High |
| | 16 | Irrigation Energy Intensity: Identify changes in irrigation technologies and practices that reduce the energy intensity of agriculture. | Low |
| Renewable Energy | 17 | Water Energy Recovery: Maximize energy recovery from water and wastewater collection and transport systems (i.e., in-conduit hydropower). | Low |
| | 18 | Wastewater Energy Recovery: Maximize energy recovery from wastewater treatment operations (e.g., biogas from sewage digestion). | Low |
| | 19 | Support RPS: Identify ways that water and wastewater systems can be used to help meet RPS, including potential use of water-related renewable energy for integration of intermittent renewables such as wind and solar. | Low |

### *7.5.2. Supply & Conveyance*

The Supply & Conveyance segment of the water use cycle offers significant opportunities for reductions in both energy consumption and demand. In addition to opportunities to reduce the energy intensity of wholesale water systems through changes to design and operations, the Supply & Conveyance segment provides the opportunity to change the energy intensity of the state's overall water supply portfolio by displacing higher energy intensity water supplies with lower energy intensity supplies.

In addition, the Supply & Conveyance segment is most likely to be significantly impacted by climate change. Water managers throughout the state are preparing now for the significant changes in timing and magnitude of precipitation and temperatures that are expected to have a substantial impact on California's water supplies.

Examples of potential research projects are listed for each of the five Supply & Conveyance research initiatives in Table 7-7.

**Table 7-7: Research Initiatives for Supply & Conveyance**

| Research Initiatives for Supply & Conveyance | | |
|---|---|---|
| | **Research Initiative** | **Examples of Potential Research Projects** |
| 1 | Design and Operations Changes: Identify changes to supply and conveyance design and operations that increase system flexibility for demand response and peak load reductions. | • Evaluate opportunities to revise the design and operations of the state's large water storage and conveyance systems and their customers to increase the ability to significantly reduce peak water pumping loads.[46]<br>• Develop models and tools that evaluate groundwater storage capacity and simulate groundwater pumping operations to identify opportunities for shifting groundwater recharge and pumping to off-peak periods and seasons. |
| 2 | Supply Switching: Identify opportunities for supply switching that reduce the energy intensity of the state's water supplies. | • Evaluate the potential energy benefits achievable by increasing surface water storage capacity to displace higher energy intensity water supplies such as groundwater pumping and desalination.<br>• Develop a methodology for assessing the total resource costs and benefits of displacing higher energy intensity potable water supplies with local recycled/reclaimed water.<br>• Reduce reliance on highest energy intensity water supplies.<br>• Capture storm water to augment water supplies.[47]<br>• Increase efficiency of agricultural water use to make more surface and groundwater available to meet potable water demand, reducing need for very high energy intensity water supplies such as seawater desalination. |

[46] PIER is already coordinating future work with the State Water Contractors on the State Water Project's (SWP) East Branch retrofits project.

[47] Also under Research Initiative #5.

| Research Initiatives for Supply & Conveyance | | |
|---|---|---|
| | **Research Initiative** | **Examples of Potential Research Projects** |
| 3 | Climate Change Risk Reduction: Identify strategies that reduce climate change risks on supply and conveyance energy requirements. | • Assess the impacts of a multi-year drought, with and without climate change, on statewide energy consumption and energy production, and develop options for mitigating energy impacts of potential water supply shortages.<br>• Evaluate the relative energy intensity of drought risk mitigation measures, including ocean desalination.<br>• Evaluate the potential energy impacts of increased groundwater pumping under climate change scenarios. |
| 4 | System Retrofits: Identify system retrofits that could reduce conveyance system energy requirements.[48] | • Develop models & tools that evaluate the energy impacts of conveyance system options (e.g., reducing friction-related energy loss in large water conveyance systems such as tunnels, pipelines, aqueducts and canals; and/or maximizing gravity to reduce pumping energy loads).<br>• Integrate renewable energy (in-conduit hydropower) into existing conveyance systems, including consideration of pump-back systems that maximize power production during on-peak periods and use power during off-peak periods to replenish storage facilities.[49] |
| 5 | Technologies to "Make" Water: Advance energy efficient technologies that create new water supplies by enabling potable use of non-potable water resources (e.g., desalination).[50] | • Increase opportunities for creating additional sources of local water supplies through inland desalination by advancing zero liquid discharge (ZLD) and other technologies that enable safe concentrate disposal.<br>• Advance technologies that enable displacing potable supplies with water reclaimed from storm drains, irrigation ditches and other runoff capture systems. |

**Example Research Projects**

- **Energy Consumption for Potable Water Conveyance and Treatment in Southern California Region** – Alternative water supplies in Southern California require vastly different amounts of energy. This project would identify the current range of energy usage and energy costs for seawater desalination, and compare to the energy used to convey and treat imported and local supplies.
- **Cost and Value of Recycled Water** – The economic and environmental costs of discharge may become prohibitively expensive. The objective of this project would be to conduct a university-based study of the cost of delivering reclaimed water with the cost of desalination and other potential water sources.
- **Energy Consumption for Potable Water Conveyance and Treatment in Southern California Region** – Alternative water supplies in Southern California require vastly different amounts of energy. This project would identify the current range of energy usage and energy costs for seawater desalination, and compare to the energy used to convey and treat imported and local supplies.

[48] This research initiative overlaps with the Distribution TRA.

[49] Overlaps with research initiatives under the Distribution & Renewables TRAs.

[50] Similar to "Create New Water" in Treatment TRA.

### *7.5.3. Treatment*

The Treatment TRA includes both treatment technologies for potable water production and for treating wastewater. As noted previously, desalination also has a role in Supply & Conveyance, where it is used to convert brackish water and seawater to potable water supplies. For this reason, there is some overlap among those treatment technologies that can be used along multiple segments of the water use cycle.

Regulatory rules governing the quality of drinking (potable) water and safe discharge of effluent (non-potable water) are becoming increasingly stringent, with the result that the amount of energy used for treatment is increasing, and is expected to continue increasing for the foreseeable future. This segment of the water use cycle offers opportunities for reductions in energy consumption and demand through several primary strategies:

- Developing treatment technologies that meet strict federal and state water quality rules as energy efficiently as possible
- Reducing the amount of water and wastewater that needs to be treated with high energy intensity systems and technologies
- Integrating flexible design and operations into water and wastewater systems to enable their participation in demand response

The Treatment TRA also includes optimization of biogas production from wastewater treatment processes. The research initiative "Energy Intensity Reduction" thus overlaps with the Renewable Energy TRA.

The four Treatment research initiatives are described in Table 7-8.

**Table 7-8: Research Initiatives for Treatment**

| Research Initiatives for Treatment | | | |
|---|---|---|---|
| | **Research Initiative** | **Examples of Potential Research Projects** | **Comments** |
| 6 | Energy Intensity Reduction: Reduce energy intensity of existing treatment systems, processes and technologies | • Evaluate energy impacts of technology options for each major treatment process including:<br>• Clarification & Filtration (flocculation)<br>• Disinfection & Purification (UV, ozonation, reverse osmosis, chemical and other disinfection technologies, separately and in combination through integrated multi-stage disinfection processes)<br>• Contaminant Removal/Control (microfiltration, arsenic removal)<br>• Aeration/Oxidation (catalytic oxidation, micro-algae oxygenation)<br>• Digestion (thermophilic v. mesophilic)<br>• Advance options that reduce energy intensity and carbon footprint<br>• Optimize anaerobic digestion and alternative sewage treatment processes<br>• Develop models, tools and techniques for improving management of systems and processes, e.g.<br>• Benchmark energy performance of primary systems and processes<br>• Advance real-time monitoring & controls that optimize efficiency of treatment processes<br>• Develop modeling tools that improve treatment systems' hydraulics | The focus of this research initiative is on incremental changes to existing technologies.<br>PIER IAW currently has several projects underway with Awwa-RF through a collaborative RD&D agreement. |
| 7 | Barriers Mitigation for Energy Efficient Technology: Mitigate barriers to adoption of new, energy efficient technologies | • Identify barriers (policies, rules, regulations, practices, education, and training) to deployment of new, more energy efficient technologies; recommend changes | Support and advance innovative technologies. |
| 8 | System Design and Operation: Modify system design and operations to reduce energy intensity and demand | • Identify technologies and strategies for reducing peak (wet weather) treatment loads<br>• Evaluate energy and carbon costs & benefits of decentralized and small-scale wastewater treatment systems | System retrofits and re-operations. |
| 9 | Treatment to Create New Water Supplies: Develop energy efficient treatment technologies that create new water supplies | • Advance technologies that reduce the energy intensity of reverse osmosis (RO), electrodialysis reversal (EDR) and other desalination technologies that "make" water by converting non-potable water supplies to potable | This research initiative overlaps with Supply & Conveyance.<br>PIER IAW currently has several projects under development with WERF through a collaborative RD&D agreement. |

**Example Research Projects**

- **Identification and Evaluation of Innovative Water Treatment Processes** – Currently there is no process to actively identify innovative water treatment processes. Without this investment there will be no major advancement in treatment techniques. This project aims to identify innovative water research ideas, evaluate the potential advantages/disadvantages of these ideas based upon scientific principals, and assist in the demonstration of these processes.
- **Guidance Manual: Protecting Treated Water Quality While Reducing Energy Costs** – Many energy management techniques have the ability to negatively impact the quality of water within the treatment facility. This project addresses water quality risks at the treatment facility associated with energy management practices.
- **UV Optimization Guidance Manual** – As a new technology, most water and wastewater suppliers have only limited experience with the advantages, disadvantages and operating peculiarities of UV disinfection. This project would develop a UV optimization manual that could be used by planners, engineers, treatment plant operators, and energy managers to provide objective guidance for the successful implementation of UV technology in an energy efficient manner.
- **UV Disinfection: Develop Next-Generation Energy Efficient and Effective UV Disinfection Systems for Water and Wastewater Treatment** – UV disinfection provides cost-effective inactivation of waterborne pathogens including Cryptosporidium and Giardia, all without the formation of disinfection by-products but at high energy costs. The objective of this project would be the development or application of new equipment technologies, so as to explore other industry uses of UV applications for water and wastewater.
- **Use of Membranes for Treatment of Biosolids Processing Recycles** – The recycles generated from biosolids treatment processes contain high concentrations of ammonia, phosphorus, alkalinity, total dissolved salts, and hardness. Physical/chemical treatment processes such as the use of membranes, distillation, and ammonia stripping/neutralization options could be utilized for treatment of these.
- **Development of Anaerobic Treatment Technologies for Municipal Wastewater Treatment** – Wastewater treatment is presently achieved by using aerobic processes, such as air-activated sludge. This project would develop and operate an anaerobic treatment system, coupled with membrane filtration, for wastewater treatment to investigate energy savings and power generation potential.
- **Use of Membranes for Treatment of Biosolids Processing Recycles** – The recycles generated from biosolids treatment processes contain high concentrations of ammonia, phosphorus, alkalinity, total dissolved salts, and hardness. Physical/chemical treatment processes such as the use of membranes, distillation, and ammonia stripping/neutralization options could be utilized for treatment of these side streams and would result in treatment cost-savings while recovering these valuable nutrients.

- **Development of Anaerobic Treatment Technologies for Municipal Wastewater Treatment** – Wastewater treatment is presently achieved by using aerobic processes, such as air-activated sludge. This project would develop and operate an anaerobic treatment system, coupled with membrane filtration, for wastewater treatment to investigate energy savings and power generation potential.
- **Energy-Efficient, Carbon-Efficient Alternative Advanced Wastewater Treatment** – The objective of this study would be to demonstrate and quantify the energy efficiency and additional environmental benefits of advanced natural systems for primary, secondary and tertiary treatment. The project would also demonstrate water reuse, biogas recovery, power generation, and nutrient recovery and recycling.
- **Energy Consumption of Chlorine/Sodium Hypochlorite Disinfection and Dechlorination** – As the price and technology for low and medium pressure Hg UV are becoming more competitive, the need to benchmark the energy consumption of common alternatives becomes necessary for the identification of disinfection energy savings. This project would identify environmental, safety, and health impacts, quantify the impacts, if feasible, and compile a guidance manual.
- **Barriers to Using Fine Pore Aeration Systems at Smaller Treatment Plants** – Aeration is the most energy intensive aspect of secondary treatment. Typically 40 to 60 percent of the power consumption at a treatment plant is consumed by aeration. The project's objective is to determine which barriers (economic, technical or regulatory) prevent small plants from utilizing high efficiency fine pore aeration systems.

### *7.5.4. Distribution*

Distribution – the delivery of water and wastewater to/from customers – primarily relies on very mature technologies, primarily pumping. Consequently, opportunities to improve distribution system efficiency principally relate to optimizing hydraulics and pumping efficiencies. In addition, however, integrating flexible design and operations into distribution systems allows load shifting to reduce energy demand. Further, many mature water systems have significant leaks. To the extent that distribution system leaks can be quickly identified and cost-effectively repaired, energy savings are realized by increasing usable water supplies, thereby displacing potentially higher energy intensity water supplies that would be needed to replace the lost water.

**Table 7-9: Research Initiatives for Distribution**

| Research Initiatives for Distribution | | | |
|---|---|---|---|
| **Research Initiative** | | **Examples of Potential Research Projects** | **Comments** |
| 10 | Energy Intensity Reduction: Achieve direct energy benefits by reducing the energy intensity of distribution systems | • Continue to improve pumping efficiency (e.g., variable speed drives, Energy Star rated equipment).<br>• Develop models and tools that help optimize system hydraulics to reduce pumping loads.<br>• Evaluate the potential for new materials and design techniques to reduce friction and pumping loads in pipelines and canals. | Improving pumping efficiency is an on-going effort by multiple stakeholders, including PIER. |
| 11 | System Loss Reduction: Achieve indirect energy benefits by reducing system losses | • Assist in evaluating the energy benefits of technologies that reduce water supply losses (e.g., smart meters, acoustic listening devices).<br>• Evaluate the energy benefit of lining canals, covering open reservoirs, and other techniques that reduce water supply losses. | Since losses are so high (average 10% in mature municipal distribution systems), leak detection is low-hanging fruit.<br>EMBUD and PIER are conducting work in this area. |
| 12 | Peak Demand Reduction: Increase the ability of water and wastewater distribution systems to reduce peak demand | • Identify opportunities to incorporate interim storage (tanks, pipelines & other storage facilities) to increase operating flexibility and reduce peak energy demands.<br>• Develop forecasting tools that predict pumping water demands for improved energy management of water delivery systems. | IEUA is a very good example of how to do this – connected 4 wastewater treatment plants to rebalance loads for optimized processing; also are able to detain wastewater in pipelines during critical peak periods. |

**Example Research Projects**

- **Guidance Manual: Protecting Treated Water Quality While Reducing Energy Costs** – Many energy management techniques have the ability to negatively impact the quality of water within the treatment facility. This project addresses water quality risks at the treatment facility associated with energy management practices.
- **Process Optimization: Using Advanced Controls, and On-line Instrumentation to Increase Capacity, Improve Performance and Improve Energy Efficiency** – Many existing water and wastewater treatment facilities in the U.S. were constructed in the 1970's and are now outdated or have reached maximum capacity. Many treatment facilities are in need of improvements in asset management plans, system consolidation and innovative solutions. This project aims to provide alternatives to costly construction upgrades and could also provide some security enhancements.

### *7.5.5. End Use*

Energy utilities have many programs designed to assist water and wastewater agencies to reduce their direct uses of electricity and natural gas. The primary finding of the Energy Commission's 2005 Integrated Energy Policy Report (IEPR) was that the most significant

opportunity to reduce water-related energy consumption is likely indirect – i.e., saving water to save energy "embedded" in water.

Four research initiatives that were identified within the end-use sector are designed to work in concert to significantly reduce embedded energy in water by reducing water use. These research initiatives span both urban and agricultural uses. Two primary strategies are encouraged through these research initiatives:

- Significantly reduce water consumption by both the urban and agricultural sectors, reducing the need to produce high energy intensity supplies to meet growth in demand
- To the extent that water is needed, apply water supplies of appropriate quality to the use

For example, potable water is still used in many cases for non-potable purposes such as industrial cooling and landscape irrigation. Potable water supplies are often higher in energy intensity than non-potable sources that have not received the higher levels of treatment needed to ensure safe drinking water. Matching water supplies of lesser quality and lower energy intensities to non-potable uses would reduce the energy intensity of the state's overall water supply portfolio.

Table 7-10 contains descriptions of the four primary research initiatives that were identified for the End Use sector.

**Table 7-10: Research Initiatives for End Use**

| Research Initiatives for End Use | | | |
|---|---|---|---|
| **Research Initiative** | | **Examples of Potential Research Projects** | **Comments** |
| 13 | Cold Water Reduction: Reduce cold water consumption to obtain the embedded energy benefits | • Support development and widespread deployment of leak detection systems & technologies to access the embedded energy benefits of reduced water system losses.<br>• Advance options to reduce use of potable water for non-potable uses (e.g., landscape irrigation, power plant and other industrial cooling processes):<br>• Through technologies, and<br>• Through supply switching (e.g., switching to recycled water).<br>• Evaluate energy and peak demand reduction value of TOU water meters.<br>• Advance development of on-demand water heaters, structured plumbing, and other technologies and design approaches that reduce cold water waste. | This is the crux of the 2005 IEPR's new finding: that saving water saves energy. The fledgling nature of this area of study is a primary barrier. Policies and programs do not yet recognize value of energy embedded in water; nor do experts yet agree as to how this should be calculated. PIER IAW currently has a TOU water meter project underway with ACWA. |

| Research Initiatives for End Use | | | |
|---|---|---|---|
| **Research Initiative** | | **Examples of Potential Research Projects** | **Comments** |
| 14 | Hot Water Reduction: Reduce hot water consumption to obtain the direct and embedded energy benefits | • Identify, evaluate & demonstrate hot water reuse in commercial buildings, institutions, and industrial facilities.<br>• Identify and evaluate technologies that increase efficiency of hot water use in industrial processes. | PIER is currently doing substantial work in this area. |
| 15 | Water-Energy Tradeoffs: Develop models and tools to help evaluate the tradeoffs between water and energy consumption in joint applications | Develop methodology and tools for evaluating the tradeoffs among energy, water and societal values (e.g., GHG emissions) of existing water sector "best management practices" (i.e., "BMPs", or existing technologies) and other technologies, systems and processes that use both water and energy (e.g., the net societal cost vs. benefit of evaporative cooling). | PIER contracted with UC Berkeley to develop a water-energy sustainability tool (WEST) that evaluates life cycle costs and benefits of water-energy measures. |
| 16 | Irrigation Energy Intensity: Identify changes in irrigation technologies and practices that reduce the energy intensity of agriculture | • Assess the potential embedded energy benefits of optimizing agricultural water use efficiency by reducing salinity in agricultural water to increase crop yields per unit of water applied.<br>• Assess the direct and embedded energy impacts of increased drip/micro irrigation in agricultural applications. | PIER IAW has an Agricultural Water and Energy Efficiency Project underway with Cal Poly San Luis Obispo |

**Example Research Projects**

No research projects were analyzed in greater detail in this section.

### *7.5.6. Renewables*

The Renewables TRA focuses on increasing the renewable energy potential of water and wastewater systems. In particular, this TRA seeks to optimize development and use of biogas produced by the wastewater treatment process and in-conduit hydropower produced as a by-product of water and wastewater conveyance and distribution.

Table 7-11 shows the priority research initiatives that have been identified for the Renewables TRA, along with the scores that were used to evaluate their position in PIER's water-energy RD&D portfolio.

**Table 7-11: Research Initiatives for Renewable Energy**

| Research Initiatives for Renewable Energy | | | |
|---|---|---|---|
| **Research Initiative** | | **Examples of Potential Research Projects** | **Comments** |
| 17 | Water Energy Recovery: Maximize energy recovery from water and wastewater collection and transport systems (i.e., in-conduit hydropower) | • Develop tools for identifying and evaluating sites for in-conduit hydropower.<br>• Evaluate hydropower opportunities at outfalls and pressure reducing stations. | Focus is on renewable energy produced as a by-product of water and wastewater operations; i.e., in-conduit hydropower and biogas.<br>PIER conducted an evaluation of the potential for small hydropower in man-made conduits (2005).<br>PIER has conducted RD&D of innovative bio-feedstocks with IEUA.<br>PIER is working on projects that look at water-related renewable opportunities & is developing a software tool to evaluate the costs & benefits of different design options.<br>AB1969 removes a barrier to renewable development in the water sector by allowing water & wastewater agencies to sell excess renewable generation to the grid at TOU prices based on MPR. |
| 18 | Wastewater Energy Recovery: Maximize energy recovery from wastewater treatment operations (e.g., biogas from sewage digestion) | • Advance sewage treatment process improvements that increase biogas production (e.g., thermophilic anaerobic digestion).<br>• Develop technologies & processes that enhance biogas fuel value and production by combining with other bio-feedstock (e.g., forest biomass, agricultural waste, dairy and other animal wastes, food processing waste, etc.).<br>• Improve technologies that condition ("clean-up") biogas to pipeline quality gas.<br>• Develop models & tools that assist wastewater treatment operators in determining the optimal amount of on-site biogas storage capacity needed to meet peak electric demands with biogas generation. | |
| 19 | Support RPS: Identify ways that water and wastewater systems can be used to help meet RPS | • Identify opportunities to support grid integration of intermittent renewable resources (e.g., wind & solar) by:<br>• Increasing storage & peaking capacity (both water and biogas)<br>• Connecting pumped storage facilities with pipelines<br>• Assess potential of modifying existing surface storage facilities to maximize energy production & increase load following capabilities | |

**Example Research Projects**

- **Development of In-line, Continuous Thermal Hydrolysis for Improving Municipal Sludge Digestion** – The thermal hydrolysis systems currently employed consist of batch processes requiring steam injection, multiple tanks, and high operating pressures. This project would investigate the performance and cost of a continuous, in-line thermal hydrolysis system.
- **Development of High Solids, Vertical, Plug Flow Anaerobic Digestion** – Anaerobic digestion of biosolids generated from wastewater treatment results in generation of digester gas (typically used for co-generation) and reduction of the biosolids mass to

reuse/disposal sites. An unmixed or partially mixed, vertical, plug flow digester operating at a solids content of 12 percent to 20 percent could substantially reduce digester volume as well as mixing power and heating energy requirements.

- **Recovery and Use of Digester Gas at Small Wastewater Treatment Plants** – This research project is focused on increasing recovery of digester gas at small wastewater treatment plants. The project's objective is to determine barriers that prevent small wastewater treatment plants from recovering more energy from digester gas.
- **Cost-Effective Digester Gas Cleanup for Advanced Power Generations** – Wastewater treatment plant digester gas contains sulfur, halogenated hydrocarbons, and siloxanes that are harmful to post combustion emission control equipment. An important element to this project would be to show that the gas cleanup system would be cost effective and that the combined power cleanup and power-generating unit would produce electricity at competitive prices.

# 8.0 PIER Cross-cutting

Several cross-PIER RD&D opportunities emerged from the roadmapping processes undertaken by the IAW program area. This chapter documents high-level descriptions of these opportunities, the sectors in which they could be applied and the IAW and other PIER program areas to which they apply.

**Table 8-1: Collaboration Opportunities Across PIER Program Areas**

| Collaboration Opportunities Across PIER Program Areas | | | | |
|---|---|---|---|---|
| **RD&D Opportunity** | **Description of Need** | **Applicable Sectors** | **IAW Area** | **PIER Program Areas** |
| Energy storage | Expand use of electrical energy storage in industrial applications | Multiple industrial<br>Food processing | Industrial & Agriculture | Advanced Generation |
| | Improve efficiency of battery charging systems | | | |
| | Diurnal storage of digester gas for improved power production at peak times for plants with turbines and/or fuel cells | Wastewater facilities<br>Dairy farms<br>Multiple industrial | Industrial, Agriculture & Water | Renewables<br>Advanced Generation |
| CHP & Distributed Generation | Develop wider range of environmentally acceptable, high efficiency and reliable on-site generation systems | Energy intensive industries | Industrial | Advanced Generation |
| | Develop wider range of DG resources for large industrial applications | | | |
| Renewables | Tailor and improve renewable technologies for industrial applications | Multiple industrial, especially energy intensive industries | Industrial | Renewables |
| Digester gas | Install digester gas liquefaction system to prove technical and economic viability | Sources:<br>Wastewater treatment<br>Dairy farms<br><br>End-users:<br>Wastewater treatment<br>Dairy farms<br>Multiple industrial | Agriculture & Water | Renewables<br>Advanced Generation |
| | Recovery of methane produced during digestion may reduce the total energy demand of wastewater treatment plants and thus provide a means to lower the plant's operational costs | | | |
| | Cost effective digester gas clean up system | | | |
| | Improve conditioning of waste activated sludge prior to anaerobic digestion to enhance biogas production in digesters | | | |

| | | | | |
|---|---|---|---|---|
| | Determine lowest temperature needed for operation of thermophilic digesters to minimize energy use | | | |
| Alternative transportation fuels | Examine potential for biofuels in mobile/transportation equipment<br>Assess impact of different gasoline additives on environmental impacts | Transportation equipment for industrial & agriculture industry end-uses<br>Power generation | Industrial & Agriculture | Alternative Fuels |
| Lighting | Improve ballast efficiency for HID lamps<br>Development of and conversion to LED drivers and arrays to replace HID lamps | Multiple industrial<br>Food processing<br>Water system facilities | Industrial, Agriculture & Water | Buildings |
| Water | Improve water purification & desalting for industrial wastewater applications | Multiple industrial<br>Food processing | Industrial, Agriculture & Water | Unspecified |

1. **Energy Storage:** Expand the use of electrical energy storage to more industrial applications. Improve the efficiency of battery charging systems (e.g., UPS systems, electric vehicles, data centers, telecoms). Improve the efficiency of the charger, explore load shifting for peak load management / demand response, and explore non-interrupting peak load management / demand response opportunities enabled through improved battery charging technologies. Utilize ice storage. Collaborate with PIER Storage Program.

2. **CHP/Distributed Generation:** Medium need for a wider range of environmentally acceptable, high efficiency, reliable on-site generation options for industrial customers, including fuel diversity (back up, base load, peak shaving applications). Medium need for a wider range of DG resources (generation, storage, power delivery) for large industrial customers operating with independent microgrids. Near term need (0-3 years) for commercial demonstrations of gasification technology to produce onsite power and fuels, including electrification, gas to liquids projects, combining coke gasification with municipal waste disposal, IGCC and Black Liquor Gasifier Integrated Combined Cycle (BLCCC). Need RD&D in oil residue gasification. Also need enhanced interconnection technologies for generation systems at industrial facilities. Need the development and application of storage (large scale, thermal, DC power, alternatives to lead-acid batteries). Need to address regulatory barriers to use waste heat to generate power in the cement and refining industries (e.g., exit fees). Collaborate with PIER ESI, DER and EPAG programs.

3. **Renewables:** Tailor renewable technologies to industrial applications, and improve the integration of renewables into industrial applications. Collaborate with the PIER Renewables Program.

4. **Alternative Transportation Fuels:** Use biofuels in mobile / transportation equipment (e.g., diesel engines at mining operations in cement plants). Explore the use of biodiesel (e.g.,

feasibility, emissions, supply, and other implementation issues). Explore processes for producing biodiesel from algae (instead of Soybeans). Investigate how the use of different additives to gasoline may affect the environment (e.g., adding ethanol incrementally increases VOCs). Research on algae for biodiesel occurring at MIT and the University of New Hampshire. Collaborate with PIER transportation program.

5. **Lighting:** Short-term opportunity to improve ballast efficiency for HID lamps and convert HID lamps to LED drivers and arrays. Long-term opportunity to support the development of LED drivers and arrays. Long-term opportunity to quantify and set the stage to overcome barriers to LED; need more research to make LED drivers more efficient. DOE has conducted substantial research on LEDs. Collaborate with PIER Buildings.

6. **Water:** Need improved water purification and desalting technology for industrial waste water (e.g., examine upstream factors that impact desalter performance, use renewables). Collaborate with PIER IAW Program.
   - **Digester Gas Storage for Improved Peak Power Management** – Diurnal storage of digester gas can provide improved power production at peak times for plants with turbines and/or fuel cells. For plants that are considering turbines and/or fuel cells, this project will look at ways to optimize designs for peak shaving-optimization to improve return on investment and value to the grid of digester gas.
   - **Gas Enhancement During Anaerobic Process of Sewage Sludge by Co-Digestion of Organic Solid Waste** – Recovery of methane produced during digestion may reduce the total energy demand of wastewater treatment plants and thus provide a means to lower the plant's operational costs. One alternative to enhance methane production is by simultaneously digesting wastewater sludge with organic-rich wastes (co-digestion). This study evaluates the feasibility of co-digesting sewage sludge with other organic waste in order to enhance biogas production.
   - **Cost-Effective Digester Gas Cleanup for Advanced Power Generations** – Wastewater treatment plant digester gas contains sulfur, halogenated hydrocarbons, and siloxanes that are harmful to post combustion emission control equipment. An important element to this project would be to show that the gas cleanup system would be cost effective and that the combined power cleanup and power-generating unit would produce electricity at competitive prices.
   - **Conversion of Digester Gas to Liquefied Natural Gas (LNG) and Liquefied Carbon Dioxide (CO2) –** Often, anaerobic digester gas from wastewater treatment plants (WWTP) is not reused due to insufficient recovery, capacity, economics, or air pollution limits. Flaring of this excess gas wastes the fuel value of the gas and adds air pollutants and green house gases to the atmosphere. The objective of this project would be to install the first digester gas liquefaction system to prove the technology's technical and economic viability.
   - **Waste Activated Sludge Conditioning Prior to Anaerobic Digestion to Enhance Treatability and Dewatering** – Waste activated sludge is a problem at WWTPs. It is difficult to dewater, does not degrade easily in the digestion process, and produces large

volumes of residuals for disposal. Proper conditioning of this sludge prior to digestion could reduce the problems and enhance biogas production in digesters.

- **Enhancing Biological Oxygen Demand and Suspended Solids Removal Prior to the Energy Intensive Activated Sludge Process in Wastewater Treatment Plants –** There are large amounts of energy associated with the secondary processes in wastewater treatment plants. This project would investigate a variety of alternatives that could enhance the removal of BOD and SS prior to the secondary treatment process.
- **Energy Optimization of Thermophilic Anaerobic Digestion for Class A Biosolids Production –** Optimization of the digester temperature has a greater impact of the energy demand and cost of operation of wastewater treatment plants because of the large volume of waste sludge that needs to be treated. This project would determine the lowest temperature for operation of thermophilic digesters in order to minimize energy use.

# Appendices

## Appendix A: Cross-cutting & Miscellaneous

### 1. Title & Authors

Mike Gravely, Pramod Kulkami and Geoff Lesh, PIER Industrial End-Use Energy Efficiency RD&D and Implementation Plan. (2007)

### 2. Stakeholders

| Stakeholder Group | Organization | Names |
|---|---|---|
| Industry | Western States Petroleum Association | Tupper Hull, Joe Sparano |
| | Petroleum Technology Transfer Council | Iraj Ershaghi |
| | Industrial Equipment Heating Organization | Arvind Thekdi |
| | Cement Industry Environmental Consortium | Anne McQueen, Bob Kniss |
| | California League of Food Processors | Rob Neenan |
| | CSU Chancellor's Office – Capital Planning Design and Construction | Len Pettis |
| | Del Monte Foods | Glen Lewis |
| Research Organizations | LBNL – Industrial Analysis Group | Lynn Price, Marcy Beck, Aimee McKane, William Tschudi |
| | DOE EERE – Industrial Technologies Program | Paul Schieng, Sara Dillich, Jim Quinn, Gideon Varga, Harvey Wong, Bob Gemmer |
| | Electric Power Research Institute | Bill Howe, Brian Fortenbery, Jeff Crowe, Mark Stephens, Rich Menar, Chuck Thomas |
| | Gas Technology Institute | Bill Liss, Susan Paterson, Stephen Sikirica |
| | UC Davis | Jatal Mannapperuma |
| | CSU | Bob Smith |
| | California Energy Commission | Pramod Kulkarni, Geoff Lesh, Rajesh Kapoor, Ricardo Amon, John Sugar, Al Garcia, Mike Gravely, Clint Lowell |
| Utilities | Southern California Edison | Roger Sung, Babu Joseph, Brad Roberts |
| | Sempra Utilities | Cherif Youssef, Ed Becker |
| | Pacific Gas & Electric | Francois Rongere |
| | Los Angeles Department of Water & Power | Paul Costa, Krishna Verma |
| Other | Technology Insights | Harold Gotschall |
| | Beacon Power | Bill Capp |
| | Nextek Power Systems | Paul Savage |

| | | |
|---|---|---|
| | VRB Power Systems | Tim Hennessey, Janice Lin |
| | Advanced Micro Devices | Donna Shadowy |
| | Utility Savings & Refund | Charles Toca |
| | Consortium for EE | Ted Jones |
| | Distributed Utility Associates | Jim Eyer, Rick Winter |
| | SPAR Energy Solutions | Ernie Pasters |
| | Exar Corporation | Ralph Renne |
| | Silicon Valley Leadership Group | Frank Teng |
| | Global Energy Partners | Cecilia Arzbaercher |
| | Energy Movers and Savers | Mehdi Motameni |
| | CA Energy Circuit | Corky Templeton |
| | KSON International | Ammi Amarnath |
| | Kennedy/Jerks Consulting | Maria Tikkanen |

# Appendix B: Natural Gas

## 1. Title & Authors

Energetics Incorporated and E3M Incorporated, Technology for Reducing Natural Gas Use in California Industry: Research Investment Plan Fiscal Year 2008 to 2012. (2007)

## 2. Industrial Organizations & Technology Experts

### Organizations

The organizations listed below have both broad and specific interests relevant to natural gas technology and end-uses; their member companies encompass a wide range of expertise and products. These organizations can provide a conduit to their members for information on upcoming solicitations and potential partnering opportunities. Some of the member companies are equipped to conduct R&D, while others can participate in technology commercialization and demonstration.

**American Boiler Manufacturer's Association (ABMA)**
8221 Old Courthouse Road, Suite 207 Vienna, Virginia 22182
Voice: (703) 356-7172
Contact: W. Randall Rawson, President
randy@abma.com
Phone: (703) 356-7172 ext.15
*This organization has more than 40 members interested in R&D activities related to natural gas fired boilers, heat recovery steam generators, low to medium temperature heat recovery systems, controls, and related steam equipment.*

**American Gas Association (AGA)**
400 N. Capitol Street, NW Suite 400
Washington, DC 20001
Phone: (202) 824-7000
Contact: Research priorities and funding
Lori Traweek ltraweek@aga.org
Charles Fritts cfritts@aga.org
*The American Gas Association, founded in 1918, represents 200 local energy utility companies that deliver natural gas to more than 64 million homes, businesses and industries throughout the United States.*

**California League of Food Processors**
980 Ninth Street, Suite 230
Sacramento, CA 95814
Phone (916) 444-9260

Ed Yates, President/CEO ed@clfp.com
Bill Grigg, Vice President/Government Affairs
bill@clfp.com
*CLFP is devoted primarily to furthering the interests of the food processing industry before the State Legislature and regulatory agencies, and is also a major representative for the California industry at the Federal level. CLFP's purpose is to foster a favorable environment for the growth and strength of the industry within the state.*

**Council of Industrial Boiler Owners (CIBO)**
6035 Burke Centre Parkway, Suite 360
Burke, VA 22015
Contact : Robert D. Bessette
Phone: (703) 250-9042
E-mail: bessette@cibo.org
*This organization has more than 50 members interested in R&D activities related to natural gas fired boilers, heat recovery steam generators, emission control technologies, use of alternate fuels, low to medium temperature heat recovery systems, and related controls and other systems.*

**Industrial Heating Equipment Association (IHEA)**
1139 Fehl Lane
Cincinnati, Ohio 45230
Contact: Anne Goyer, Executive Vice President
Email: aygoyer@one.net ; ihea@ihea.org
Phone: (513) 231-5613
*This organization has more than 50 members interested in R&D activities related to natural gas fired furnaces, ovens, medium to high temperature heat recovery systems, controls, and related heating equipment.*

**Gas Technology Institute (GTI)**
1700 South Mount Prospect Road
Des Plaines, IL 60018-1804 USA
(847) 768-050
Contct: Steve Sikirica
steve.sikirica@gastechnology.org
*GTI is a research organization with a long history (since 1941) of conducting R&D on natural gas fired systems, burners, alternate energy use, and emission controls. This includes an emphasis on improving natural gas and energy use in residential, commercial, industrial, power generation, and transportation markets.*

**Western U. S. Food Processing Efficiency Initiative**
Oregon Department of Energy (ODOE)
625 Marion Street, NE
Salem, OR 97301-3737

(503) 378-6043
Contact: Mark W. Kendall
Email: mark.w.kendall@state.or.us
*This is a multi-year collaboration of the Oregon Department of Energy (Oregon), Washington State University (WSU) Energy Program, California Energy Commission (Energy Commission), and Idaho Department of Water Resources Energy Division (Idaho), in cooperation with the Northwest Food Processors Association (NWFPA), the California League of Food Processors (CLFP), Northwest Energy Efficiency Alliance (Alliance), Lawrence Berkeley National Laboratory (LBNL), and Del Monte Foods.*

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| **Broad Interest Organizations and Associations** | | | | | | | | | | | | | | | |
| American Boiler Manufacturer's Association (ABMA)<br>8221 Old Courthouse Rd, Suite 207 Vienna, Virginia 22182<br>W. Randall Rawson, President<br>randy@abma.com<br>(703) 356-7172 ext.15 | X | X | X | X | X | X | X | | | | X | | | | |
| American Gas Association (AGA)<br>400 N. Capitol Street, NW Suite 400<br>Washington, DC 20001<br>(202) 824-7000<br>Research priorities and funding<br>Lori Traweek<br>ltraweek@aga.org<br>Charles Fritts<br>cfritts@aga.org | | | | | | X | X | X | X | X | X | | | | |
| Council of Industrial Boiler Owners (CIBO)<br>6035 Burke Centre Parkway, Suite 360<br>Burke, VA 22015 Robert D. Bessette<br>(703) 250-9042<br>bessette@cibo.org | X | X | X | X | X | X | X | | | | X | | | | |
| Gas Technology Institute (GTI)<br>1700 South Mt Prospect Road<br>Des Plaines, IL 60018-1804<br>(847) 768-0500 | X | X | X | X | X | X | X | X | X | X | X | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| Steve Sikirica<br>steve.sikirica@gastechnology.org | | | | | | | | | | | | | | | |
| Industrial Heating Equipment Association (IHEA)<br>1139 Fehl Lane<br>Cincinnati, Ohio 45230<br>Anne Goyer, Executive Vice President<br>aygoyer@one.net ;<br>ihea@ihea.org<br>(513) 231-5613 | X | X | X | X | X | X | X | | | | X | X | X | | X |
| **Companies, Laboratories, and Individuals** | | | | | | | | | | | | | | | |
| G. Anand<br>Energy Concepts Co.<br>627 Ridgely Ave.<br>Annapolis MD 21401<br>(410) 266-6521<br>GAnandG@aol.com | X | X | | | | | | | | | | | | | |
| Bob Boucher<br>Alstom<br>robert.boucher@power.alstom.com | | | X | | | | | | | | | | | | |
| Robert K Cheng<br>Lawrence Berkeley National Laboratory<br>RKCheng@lbl.gov | X | X | X | | | X | X | | | | | | | | |
| James Chumley<br>DesChamps Technologies<br>(540) 291-1111<br>jchumley@des-champs.com | X | X | X | | | | | | | | | | | | |
| Ena Cratsenburg<br>Amyris Biotechnologies, Inc.<br>5980 Horton Street, Suite 450 | | | | | | | | | | | | | | X | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| Emeryville, CA 94608<br>(510) 450-0761<br>partners@amyrisbiotech.com *{Expertise: biotechnology}* | | | | | | | | | | | | | | | |
| John Cuttica<br>University of Illinois at Chicago<br>Energy Resources Center<br>851 South Morgan Street<br>Chicago, Illinois 60607<br>cuttica@uic.edu | X | X | X | | | | | | | | | | | | |
| Dr. Subodh Das<br>President, Secat, Inc.<br>1505 Bull Lea Road<br>Lexington, KY 40065<br>skdas@secat.net<br>***{Expertise: metals, metal casting}*** | X | X | X | | | | | | | | | | | | |
| Robert De Saro, President<br>Energy Research Company<br>2571-A Arthur Kill road<br>Staten Island, NY 10309<br>(718) 608-8788<br>rdesaro@er-co.com | X | X | X | X | X | X | | | | | X | | | | |
| Leonard R. Devanna,<br>Executive Vice President<br>Clean Energy Systems, Inc.<br>11330 Sunco Drive<br>Rancho Cordova, CA 95742<br>(916) 379-9143 | | | | | | | | | | | | X | | X | X |
| John Dormire<br>Bloom Engineering<br>(412) 653-3500<br>jdormire@bloomeng.com | | | | X | | | | | | | | | | | |
| Michael Greenman<br>GMIC Executive Director | | X | X | | | | | | | | | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| 735 Ceramic Place, Suite 101<br>Westerville, OH 43081<br>mgreenman@gmic.org<br>***{Expertise: glass manufacture}*** | | | | | | | | | | | | | | | |
| Glenn Hahn<br>Spirax Sarco<br>Ghahn@Spirax.Com<br>{***Expertise: petroleum industry}*** | | X | X | | | X | X | | | | | | | | |
| Larry Harger<br>Callidus Corporation<br>Tulsa, OK<br>lharger@chicagobridge.com<br>***{Expertise: petroleum industry}*** | | X | X | | | X | X | | | | | | | | |
| Dr. Klaus Hemsath<br>5120 Beacon Road<br>Palmetto, FL 34221<br>khemsath@tampabay.rr.com | X | X | | | | | | | | | | | | | |
| Dr. Evan Hughes<br>30 Rondo Way<br>Menlo Park, CA 94025<br>(650) 796-6301<br>evanhughesphd@aol.com<br>***{Expertise: biopower and geothermal energy}*** | | | | | | | | | | | | | | X | X |
| Terry L. King, Sales Manager<br>Thermal Transfer Corp.<br>50 North Linden Street<br>Duquesne, PA 15110<br>(412) 460-4004<br>(412) 466-2899<br>terry.king@hamonusa.com | | | X | | | | | | | | | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| Steve Kurosawa, Ph.D.<br>Program Manager<br>NineSigma, Inc.<br>23611 Chagrin Blvd.<br>Cleveland, OH 44122<br>kurosawa@ninesigma.com | | X | X | X | X | X | X | | | | X | X | X | | |
| John Liviakis<br>Pacific Ethanol<br>(415) 389-4670<br>www.pacificethanol.net<br>***{Expertise: biofuels}*** | | | | | | | | | | | | | | X | |
| Dr. Richard Martin<br>AZTEC Engineering Inc<br>3807 South Victor<br>Tulsa, OK 74105<br>richardmartin@aztecengineering.com<br>(918) 495-6253<br>***{Expertise: petroleum industry}*** | | X | X | | | X | X | | | | | | | | |
| Ken May, President<br>Industrial Solar Technology Corporation<br>4420 McIntyre St. Golden, CO. 80403<br>www.industrialsolartech.com<br>Ph: 303-279-8108<br>industrialsolar@qwest.net | | | | | | | | | | | | | | | X |
| Bruce McKenna, President<br>Exothermics<br>(419) 729-9726<br>bmckenna@exothermics.com | | | X | | | | | | | | | | | | |
| George Mochnal<br>Forging Industry Association<br>gmochnal@earthlink.net | X | X | X | | | | | | | | | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| {Expertise: metals forging, casting}<br>Note: FIA has several members in CA (aluminum, steel, titanium forging); can be instrumental in demonstration of heating and heat recovery systems. | | | | | | | | | | | | | | | |
| Riyaz Pappar<br>Hudson Technologies<br>14 Split Rail Place<br>The Woodlands, TX 7738<br>rpapar@hudsontech.com<br>(281) 298-0975 | | | | | | | | X | X | | | | | | |
| David Parrott<br>Industrial Microwave Systems, LLC<br>3000 Perimeter Park Drive, Building I, Morrisville, NC 27560<br>(919) 990-9900<br>info@industrialmicrowave.com | | | | | | | | | | | | X | X | | |
| Lori Perine<br>American Forest & Paper Association<br>(202) 463-2700<br>1111 19th St. NW Suite 800<br>Washington, DC<br>Lori_perine@afandpa.org<br>***{Expertise: pulp and paper industry}*** | | | | | | | | | | | | | | X | |
| Robert M. Purgert<br>Energy Industries of Ohio<br>purgert@msn.com<br>***{Expertise: metals manufacture}*** | | X | X | | | | | | | | | | | | |
| Roberto Ruiz<br>JohnZink | | X | X | | | X | X | | | | | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ruizr@kochind.com ***{Expertise: petroleum industry}*** | | | | | | | | | | | | | | | |
| Mike Skillingberg<br>The Aluminum Association<br>mhskilli@aluminum.org<br>(202) 862-5121 ***{Expertise: metals manufacture}*** | | X | X | | | | | | | | | | | | |
| Larry Slominski<br>Vice President & Director of Western Region<br>Quantum Energy Group<br>*subsidiary of WorldWater & Power, Inc.*<br>265 Applegate School Road<br>P.O. Box 158<br>Applegate, Ca. 95703<br>530-878-4585 | | | | | | | | | | | | X | | | X |
| Jim Taylor, Manager of Business Development<br>Wilson TurboPower Inc.<br>Jim.Taylor@WilsonTurboPower.com | X | X | X | | | | | | | | | | | | |
| Arvind Thekdi<br>E3M, Inc.<br>(240) 715-4333<br>athekdi@e3minc.com | X | X | X | X | | | | | X | X | | | | | |
| **Utilities: General Technology Development and Demonstration** | | | | | | | | | | | | | | | |
| Pacific Gas and Electric Company<br>77 Beale Street, B27P<br>San Francisco, CA 94105-1814<br>Phone Number: (415) 973-6436<br>Fax Number: (415) 973-2510 | | | | | | | | | | | | | | | |

| Technology Specific Experts and Organizations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry Contact | Industrial Energy Systems | | | | | | | Process Measurement, Diagnostics, Innovation | | | | | | Renewable Energy | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| Christopher T. Goff<br>Southern California Gas Co.<br>9240 E. Firestone Blvd<br>ML SCERC5<br>Downey, CA 90241<br>(562) 803-7362<br>(562) 803-7420<br>cgoff@semprautilities.com | | | | | | | | X | X | X | | | | | |
| Bryan Warren<br>Southern California Gas Company<br>(562) 803-7332<br>Bwarren@semprautilities.com | | | | | | | | X | X | | | | | | |
| Cherif Youssef<br>Sempra Energy, San Diego or Southern California Gas Company in LA, CA.<br>cyoussef@semprautilities.com<br>(213) 244-5325 | | | | | | | | X | X | | | | | | |

## 3. Relevant Government Policies and Programs

A summary of key point from California policies and programs related to the natural gas industry are summarized in the table, "Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms."

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***Warren-Alquist Act*** | | | | | | | | | | | | | | | |
| ***§ 25007. State policy; reduction in certain 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…"* <br><br> ***§ 25401. Continuous studies, projects*** *"…The commission shall… carry out studies, technical assessments, research projects, and data collection directed to reducing wasteful, inefficient, unnecessary or uneconomic uses of energy…including…comparisons in efficiencies of alternative methods of energy utilization."* | X | X | X | X | X | X | | X | X | X | X | X | X | | |
| ***§ 25400. Assessment of forms of energy; encouragement of balanced use of resources*** *"…The commission shall encourage the balanced use of all energy sources to meet the state's needs…and avoid undesirable consequences of reliance on a single source of energy."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***§ 25008. State policy; alternative energy supply sources*** *"…policy of the state to promote all feasible uses of alternative energy…resources and process which may be used to substitute for traditional energy … supplies, including…biomass, wind, vapor compression… and solar..."* | | | | | | | | | | | | | X | X | X |
| ***§ 25216. Duties; research and development*** *"…the commission shall ...(c) Carry out… research and* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| *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. "* | | | | | | | | | | | | | | | |
| ***§ 25601. Development and coordination of program; priorities***<br>*"The commission shall develop and coordinate a program of research and development in …energy consumption and conservation…. and give priority to those forms of research and development which are of particular importance to the state, including, but not limited to ...(a) methods of energy conservation….(c) expansion and accelerated development of alternative sources of energy..."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***§ 25602. Technical assessment studies***<br>*"The commission shall carry out technical assessment studies on… energy and energy-related problems…to be informed on future energy options…including (b) total energy concepts…(f) measures to reduce wasteful and inefficient uses of energy…(i) expanding recycling of materials and its effect on energy consumption…(k) utilization of waste heat…(m) use of agricultural products, municipal wastes, and organic refuse as an energy source."* | X | X | X | X | X | X | | X | X | | X | X | X | X | |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***§ 25685. Energy technology projects*** *"…projects considered for funding under Chapter 7.1 …include (e) advanced oil or gas combustion systems. (i) biomass gasification. (j) low and medium Btu gas technologies for electric generation. (k) other alternative energy technologies.* | X | X | X | | | X | X | | | | X | | X | X | X |
| ***Integrated Energy Policy Report November 2005*** | | | | | | | | | | | | | | | |
| *(p. 130) "…. Additional savings may be available from the use of… flared gas [sic. Waste gas], and "recycled energy," in which energy is recovered from industrial off-gases."*<br><br>*(p. 134) "...the state can examine the feasibility of increasing natural gas production from...innovative sources….California is rich in biomass resources…suitable as a feedstock for gasification technologies. Landfills...currently produce natural gas...agricultural waste can be converted to synthetic natural gas."* | X | X | X | X | X | | | | | | | X | X | X | X |
| *(p.145) "…Industrial water-related energy use represents 45 percent of natural gas use…including process hot water and steam; process chilling; equipment cooling; and cooling towers. Recommendations for Energy Savings…..includes assessing energy efficiency improvements in hot and cold water use in ….businesses [e.g., industries].* | X | X | X | | | | | | | | | X | X | | |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***Energy Action Plan 2005*** | | | | | | | | | | | | | | | |
| *"…meet California's energy growth needs while optimizing energy conservation and resource efficiency…"*<br><br>*"…Make continuing progress in meeting the state's environmental goals…including minimizing the energy sector's impact on climate change."*<br><br>*"…optimize strategies for increasing conservation and energy efficiency to minimize increases in…natural gas demand."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *"… California can reduce its greenhouse gas emissions, moderate its increasing dependence on natural gas, and mitigate the associated risks of electricity price volatility by aggressively developing renewable energy resources to meet the Renewables Portfolio Standard (RPS) requirements.*<br><br>*"…Establish a program to encourage solar hot water heating to reduce the reliance on natural gas for water heating…"* | | | | | | | | | | | | | | X | X |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***Governor's Executive Order S-3-05*** | | | | | | | | | | | | | | | |
| *" ….mitigation efforts will be necessary to reduce greenhouse gas emissions…. "*<br><br>*"…. 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…"*<br><br>*"..California-based companies…have taken leadership roles by reducing GHG emission...related to their operations and developing programs that will reduce…emissions."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***Western Regional Climate Action Initiative*** | | | | | | | | | | | | | | | |
| *"…agree to collaborate in identifying, evaluating and implementing ways to reduce GHG emissions in our states collectively... This collaboration shall include (no limited to):*<br><br>*… Promoting the development and use of clean and renewable energy within the region; Increasing the efficiency of energy use within our jurisdictions..."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***AB 32, California Global Warming Solutions Act of 2006*** | | | | | | | | | | | | | | | |
| *38501. "…investing in development of innovative and pioneering technologies will assist California in achieving the 2020 statewide limit on emissions of GHGs…*<br><br>*…the State Air Resources Board [will] design emissions reduction measures to meet the …statewide emissions limits for GHGs…"*<br><br>*38560. "…state board shall adopt rules and regulations to…achieve maximum technologically feasible and cost-effective greenhouse gas emission reductions from sources…"* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***Self-Generation Incentive Program, AB 970, AB 2778*** | | | | | | | | | | | | | | | |
| *(2007 SGIP Handbook, p. 2-3, Table 2-1) "…Eligible Technologies include: renewable, non-solar fuel cells operating on renewable fuel,…microturbines, internal combustion engines, and gas turbines operating on renewable fuel; and microturbines, internal combustion engines and gas turbines operating on non-renewable fuel or waste gas fuel, meeting the minimum operating efficiency requirement, the reliability and emissions criteria as applicable..."* | X | X | X | | | | X | | | | | | | X | X |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***California Solar Initiative Incentives (2007)*** | | | | | | | | | | | | | | | |
| *"…The California Public Utilities Commission, through its California Solar Initiative, provides incentives over the next decade for … new commercial, industrial, and agricultural properties…"*<br><br>*'…program funds only solar electricity (photovoltaic) systems…systems up to 5 Megawatts are eligible…"* | | | | | | | | | | | | | | | X |
| ***California Energy Commission Natural Gas RD&D Program, CPUC R.02-10-001 Resolution G-3394*** | | | | | | | | | | | | | | | |
| *"…. Research Area 1. Affordable, comfortable, and energy-smart choices for daily life and a strong California economy…*<br><br>*a. increase efficiency of existing industrial processes… (replacement/retrofit products, improve operational strategies, identify intervention tactics)*<br>*b. reduce first costs and operating costs of energy efficient technologies and systems for…industries…*<br>*c. reduce and optimize hot water use in … industrial operations… by developing technologies that…provide cost-effective alternate thermal energy sources…"* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| Natural Gas State Policies and Legislation: Language Relevant to Technology Platforms | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Industrial Energy Systems** | | | | | | | **Process Measurement, Diagnostics, Innovation** | | | | | | **Renewable Energy** | |
| | Heat Recovery | | | | | Com-bustion | | Energy Management | | | Process Innovation | | | | |
| **State Policy or Legislation** | Very Low Grade Heat Recovery | Low Grade Heat Recovery | Mid to High Grade Heat Recovery | Heat Loss Reduction | Enhanced Heat Transfer | Advanced Burners | Fuel Flexibility | Energy Metering | Efficiency Assessments & Analysis | Financial Analysis Tools | Advanced Controls | Innovative Processes | Non-Thermal Energy Alternatives | Alternative Fuels | Renewables for Heat and Power |
| ***California Energy Commission Public Interest Energy Research Program (PIER) 2007-2011 Natural Gas Research Investment Plan*** | | | | | | | | | | | | | | | |
| *"…Strategic objectives…1. Reduce cost and improve performance of efficiency systems for…industrial processes. 2. Develop energy-efficient technologies for unique California conditions and industries."* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| ***California Energy Commission Energy Innovations Small Grant (EISG) Program*** | | | | | | | | | | | | | | | |
| *"…EISG Program provides up to $95,000 for hardware projects and $50,000 for modeling projects to businesses, non-profits, individuals, national laboratories, utilities, and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts.*<br><br>*Research projects must target … PIER program areas, address a California energy problem and provide a potential benefit to California natural gas ratepayers. ... eligible program areas…: Industrial/Agriculture/Water End-use Efficiency; … Renewable Generation; Energy-Related Environmental Research; Energy Systems Integration (ESI)…"* | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

4.

# Appendix C: Petroleum Refineries

## 1. Title & Authors

Energetics Incorporated, Energy Efficiency Roadmap for Petroleum Refineries in California. (2004)

## 2. Stakeholders

| Stakeholder Group | Organization | Names |
|---|---|---|
| Industry | Shell Oil Products US | Frank Bela |
| | Kern Oil and Refining | Tony Butlig |
| | Chevron Texaco | Alan Gorski, Tim Nelson |
| | Paramount Petroleum | Gary Grimes |
| | Valero | Susan Gustofson |
| | BP | Matthew Lemmons |
| | ExxonMobil | David Light |
| | San Joaquin Refining Company | Ed Starbuck |
| | Tesoro Petroleum | Chuck Waitman |
| | ConocoPhillips | Michael Weidlein |
| | American Petroleum Institute | Ron Chittim |
| | Western States Petroleum Association | Ron Wilkins |
| Research | U.S. Department of Energy | Chris Cockrill |
| | LBNL | Donald Foster |
| | California Energy Commission | Pramod Kulkarni |
| Utilities | Pacific Gas and Electric Company | Mike Martin |
| | Los Angeles Department of Water and Power | Said Nikkhah, Patrick Umeh |
| | Southern California Edison | Ed Southerland, Ray Strong |
| | Southern California Gas Company | Joe Sullivan |

# Appendix D: Data Centers

## 1. Title & Author

William Tschudi, Xu Tengfang, Dale Sartor and Jay Stein (LBNL), Roadmap for Public Interest Research For High-Performance Data Centers. (2003)

# Appendix E: Electronics

## 1. Title & Authors

G. Wikler, P. Hurtado, G. Hirsch, and I. Bran (E2I and Global Energy Partners), Plan and Roadmap for Enhancing Energy Efficiency and Supply Reliability for California's Electronics Industry. (2003)

## 2. Stakeholders

| Stakeholder Type | Organization |
|---|---|
| Industry | Applied Materials |
| | Applied Micro Circuits Corporation |
| | Advanced Micro Devices |
| | Affymetrix, Inc |
| | ALZA Corporation |
| | Automated Power Exchange |
| | Cargill Salt |
| | CISCO Systems |
| | California Manufacturing Technology Association |
| | Communications and Power Industries |
| | Cubic Defense Systems of San Diego |
| | Electroglas Inc. |
| | GE Nuclear |
| | General Dynamics |
| | GKN Aerospace |
| | Gordon Biersch |
| | Granite Rock Company |
| | Hewlett Packard - Palo Alto |
| | Hewlett Packard - San Diego |
| | Honeywell |
| | iControl Inc. |
| | Inktomi Corporation |
| | Intel Corporation |
| | Intuit Inc. |
| | Kinetics Group, Inc. |
| | Lifeguard, Inc. |
| | Lawrence Livermore National Laboratory |
| | Lockheed Martin |
| | LSI Logic Corporation |
| | M3iworks, Inc |
| | Manpower Staffing Services |
| | Naval Facilities Engineering Command |

| | |
|---|---|
| | Network Appliance |
| | Nortel Networks |
| | New United Motor Manufacturing, Inc. |
| | Oracle |
| | Philips Electronics |
| | Pacific Industrial & Business Association |
| | Powerlink Corporation |
| | Pulse Engineering, Inc. |
| | Roche Bioscience |
| | San Diego Chamber of Commerce |
| | San Jose Medical Center |
| | Sharp Healthcare |
| | Solar Turbines, a Caterpillar Company |
| | Solectron Milpitas |
| | Sony Electronics |
| | Sure Power |
| | Tessera Technologies |
| Research | Lawrence Livermore National Laboratory |
| | San Jose State University |
| | Santa Clara University |
| | Stanford University |
| | Silicon Valley Manufacturing Group |

# Appendix F: Agriculture

## 1. Title & Authors

Sabine Brueske and Fred Hansen (Energetics Incorporated), Energy Efficiency Roadmap for the California Food Processing and Beverage Industry. (2009)

Sharon Shoemaker (California Institute for Food & Agricultural Research), Technology Roadmap: Energy Efficiency in California's Food Industry. (2006)

## 2. Stakeholders

| Stakeholder Groups | Organization | Names |
|---|---|---|
| Industry | Campbell Soup Supply Company | John Batura |
| | The Wine Group | Louis Dambrosio |
| | Ingomar Packing Company | Tim Durham |
| | Manufacturers Council of Central Valley | Jan Ennebga |
| | Del Mar Food Products | Lee Haskin |
| | Kagome Inc. | Ron Lema |
| | Sensient Dehydrated | Joe Martins |
| | Del Monte Foods | Mike Maulhardt, Jim Motensen, Glen Lewis |
| | Liberty Packing | Mark Przybyla |
| | Sunsweet Growers | Steve Rasmussen |
| | Grimmway Farms | David Roney |
| | Hilmar Cheese Company | Tedd Struckmeyer |
| | Stanislaus Food Products | Rick Vargas |
| | Pacific Cost Producers | Jerry Cordy |
| | Blue Diamond Growers | Sam Cunningham |
| | General Mills | Jenny Wright |
| | King & Associates | Walter King |
| | Gilroy Foods | Abizer Khairullah |
| | Foster Farms | Phillip Greene |
| | Harter Tomato Products | Todd Harter |
| | E & J Gallo Winery | Sa Ho |
| | Lyons Magnus | Bob Smittcamp |
| | International Fresh-Cut Produce Association | Jim Gorny |
| | Dairy Institute of CA | Rachel Kaldor |
| | California Beef Council | Bruce Berven |
| | National Meat Association | Rosemary Mucklow |
| | National Food Processors Association | Keith Ito |
| | California League of Food Processors | Rob Neenan, Ed Yates |
| Research Organizations | Gas Technology Institute | Yaroslav Chudnovsky |
| | CA Dairy Research Foundation | Joe O'Donnell |

| | | |
|---|---|---|
| | Valley Research | Tom Wong |
| | UC Davis | Zhongli Pan, Jim Thompson, David Reid, Sharon Shoemaker |
| | California Energy Commission | Rajesh Kapoor, Pramod Kulkarni, Ivin Rhyne, Ricardo Amon |
| Utilities | Southern California Edison | Henry Mak, Armen Abrahamian |
| | Pacific Gas & Electric Company | Ryan Matley, Patsy Dugger, Grant Dugon |
| | Sacramento Municipal Utility District | Mark Jagodzinski, Rich Guthrie |
| Other | Kennedy/Jenks Consultants | Sharon Melmon |
| | ChemFile | Richard Machado |
| | Creative Research Management | Dilip Chandarana |
| | R & D Enterprises | Dee Graham |
| | Department of Food & Agriculture | Lourminia Sen |
| | Technology, Trade & Commerce Agency | Gregory Hribar |

| Stakeholder Groups | Organization | Names |
|---|---|---|
| Industry | Campbell Soup Supply Company | John Batura |
| | The Wine Group | Louis Dambrosio |
| | Ingomar Packing Company | Tim Durham |
| | Manufacturers Council of Central Valley | Jan Ennebga |
| | Del Mar Food Products | Lee Haskin |
| | Kagome Inc. | Ron Lema |
| | Sensient Dehydrated | Joe Martins |
| | Del Monte Foods | Mike Maulhardt, Jim Motensen, Glen Lewis |
| | Liberty Packing | Mark Przybyla |
| | Sunsweet Growers | Steve Rasmussen |
| | Grimmway Farms | David Roney |
| | Hilmar Cheese Company | Tedd Struckmeyer |
| | Stanislaus Food Products | Rick Vargas |
| | Pacific Cost Producers | Jerry Cordy |
| | Blue Diamond Growers | Sam Cunningham |
| | General Mills | Jenny Wright |
| | King & Associates | Walter King |
| | Gilroy Foods | Abizer Khairullah |
| | Foster Farms | Phillip Greene |
| | Harter Tomato Products | Todd Harter |
| | E & J Gallo Winery | Sa Ho |
| | Lyons Magnus | Bob Smittcamp |
| | International Fresh-Cut Produce Association | Jim Gorny |
| | Dairy Institute of CA | Rachel Kaldor |
| | California Beef Council | Bruce Berven |
| | National Meat Association | Rosemary Mucklow |
| | National Food Processors Association | Keith Ito |
| | California League of Food Processors | Rob Neenan, Ed Yates |
| Research Organizations | Gas Technology Institute | Yaroslav Chudnovsky |
| | CA Dairy Research Foundation | Joe O'Donnell |
| | Valley Research | Tom Wong |
| | UC Davis | Zhongli Pan, Jim Thompson, David Reid, Sharon Shoemaker |
| | California Energy Commission | Rajesh Kapoor, Pramod Kulkarni, Ivin Rhyne, Ricardo Amon |
| Utilities | Southern California Edison | Henry Mak, Armen Abrahamian |
| | Pacific Gas & Electric Company | Ryan Matley, Patsy Dugger, Grant Dugon |
| | Sacramento Municipal Utility District | Mark Jagodzinski, Rich Guthrie |
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| | | |
|---|---|---|
| | ChemFile | Richard Machado |
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| | R & D Enterprises | Dee Graham |
| | Department of Food & Agriculture | Lourminia Sen |
| | Technology, Trade & Commerce Agency | Gregory Hribar |

## 3. California's Food Processing Industry Review (SIC 20), Prepared by Catherine M. Sullivan, California Energy Commission

***The food processing industry (SIC 20) consists of companies that manufacture or process meat products, dairy products, canned and preserved fruit and vegetables, grain mill products, bakery products, sugar and confectionery products, fats and oils, beverages and miscellaneous food preparations (canned fish, coffee, salty snacks, ice and macaroni).***

California's total food processing output, defined in this analysis as the total value of shipments, was $41.8 billion dollars in 1996. California's food processing industry leads the U.S., a position California has held for the last half-century. In 1996, the state accounted for more than 10 percent of U.S. food processing output. California accounts for more than 20 percent of national output in the preserved fruit and vegetable industry and 18 percent of U.S. output in the beverage industry. California's output is 10 percent or greater than the nation in three other sectors: bakery products, sugar and confectionery products and miscellaneous food preparations.

**Table 1. Food Processing Output for California and the U.S. (1996)**

| SIC | Description | California Output (Millions 1987 $) | U.S. Output (Millions 1987 $) | CA Share |
|---|---|---|---|---|
| 201 | Meat Products | 3,576 | 93,670 | 3.8% |
| 202 | Dairy Products | 4,081 | 45,368 | 9.0% |
| 203 | Preserved Fruit & Vegetables | 8,800 | 41,342 | 21.3% |
| 204 | Grain Mill Products | 2,863 | 42,007 | 6.8% |
| 205 | Bakery Products | 2,933 | 27,129 | 10.8% |
| 206 | Sugar & Confectionery Products | 2,489 | 21,552 | 11.6% |
| 207 | Fats & Oils | 1,348 | 18,429 | 7.3% |
| 208 | Beverages | 11,351 | 61,226 | 18.5% |
| 209 | Misc. Food & Kindred Products | 4,417 | 33,914 | 13.0% |
| | Total Food & Kindred Products | 41,858 | 384,637 | 10.9% |

Source: Standard & Poor's DRI, 2/98

This review concentrates on the economics of the food processing industry, particularly on its growth, employment and energy use. The discussion begins with an industry overview, and then focuses on individual sectors. Recent data and forecasts indicate this California industry is characterized by slow employment growth, modest output growth and rising energy use.

**Figure 1: Historic and Forecasted Employment and Shipments in California**

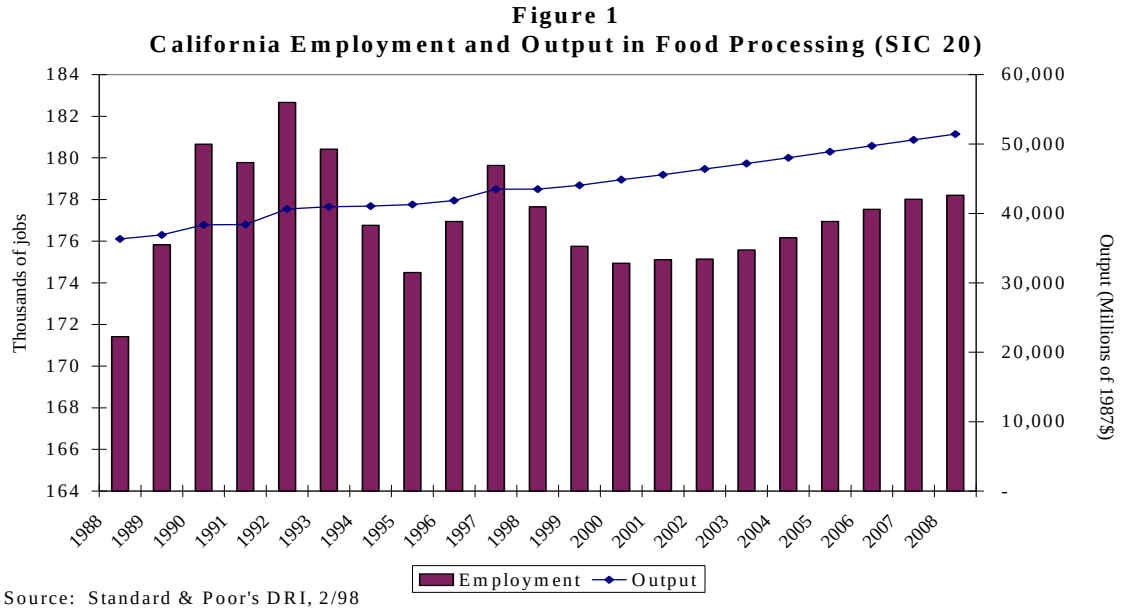



Figure 1 shows historic and forecasted employment and shipments in California. Historical employment is cyclical since the industry is dependent on weather and crop yields. Employment is forecast to improve a modest 0.3 percent from 1998 to 2008 despite the decline in employment through 2000. However, the value of shipments (in 1987 dollars) has increased 1.46 percent annually from 1998 to 1997 and is forecasted to increase 1.69 percent annually through 2008. Output is expected to increase because of improved labor productivity, increased competition among food processors and growth in the state's population. Mergers and acquisitions normally affect this industry's employment because of layoffs and plant closures. The sectors hit the hardest by mergers and acquisitions from 1990 to 1997 are preserved fruit and vegetables and fat and oil products.

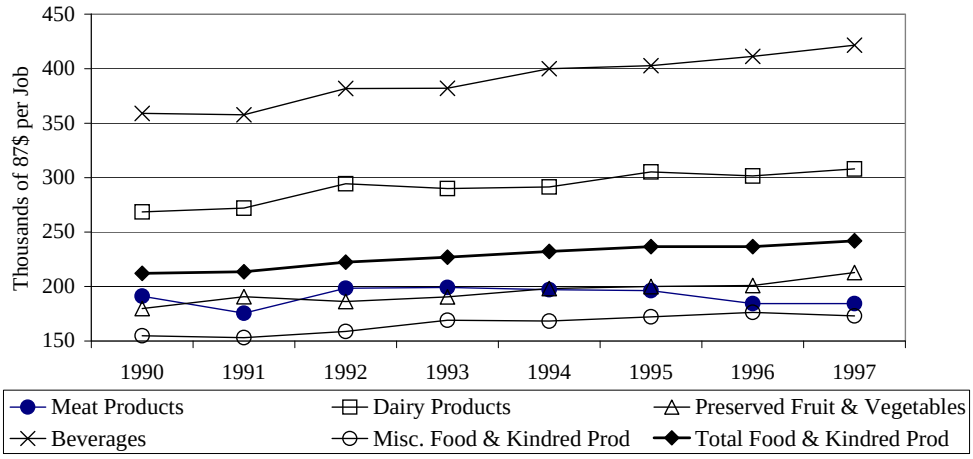
Table 2 shows 1996 three digit SIC data for California's food processing industry. More than 25 percent of the industry's output is produced by the beverage industry, which also has the largest number of establishments and the second highest employment. Of these establishments, 62 percent are in California's wine business. The canned and preserved fruit and vegetable sector also produces more than 20 percent of total industry output and has the most employment of any food processing sector. The large share of output is primarily due to California's extensive fruit and vegetable crops.

**Table 2. 1996 California Food Processing Industry**

| SIC | Description | Establishments | Jobs | Calif. Output (Millions $1987) | Share of CA Output |
|---|---|---|---|---|---|
| 201 | Meat Products | 230 | 17,734 | 3,576 | 8.5% |
| 202 | Dairy Products | 203 | 13,503 | 4,081 | 9.8% |
| 203 | Preserved Fruit & Vegetables | 541 | 47,030 | 8,800 | 21.0% |
| 204 | Grain Mill Products | 212 | 7,907 | 2,863 | 6.8% |
| 205 | Bakery Products | 635 | 22,974 | 2,933 | 7.0% |
| 206 | Sugar & Confectionery Products | 164 | 10,591 | 2,489 | 6.0% |
| 207 | Fats & Oils | 65 | 2,424 | 1,348 | 3.2% |
| 208 | Beverages | 662 | 31,927 | 11,351 | 27.1% |
| 209 | Misc. Food & Kindred Products | 591 | 22,016 | 4,417 | 10.6% |
| | Total Food & Kindred Products | 3,303 | 176,106 | 41,858 | 100.0% |

Source: California Trade and Commerce Agency, Standard & Poor's DRI, 2/98

**Figure 2**
**California Food Products Output per Job**



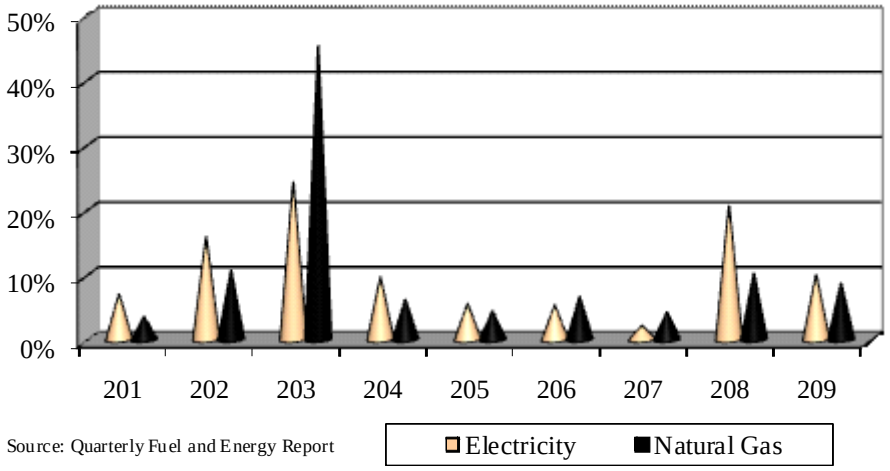

Standard & Poor's DRI 2/98

Labor productivity, as measured by output per employee, improved in each sector except meat products from 1990 to 1997. Increasing labor productivity is the result of investment in new equipment and plants. Also, corporate merger activity and increased competition has resulted in the closure of older, smaller and less productive facilities. This trend is expected to continue throughout the food processing industry, though not equally among all sectors. Figure 2 shows California output per employee for five selected food processing sectors. Compared to overall industry labor productivity, output per job is higher in beverages (74 percent) and dairy products (27 percent). The rate of productivity growth in these two sectors is 2.3 and 2.0 percent

per year, slightly greater than the 1.9 percent per year growth in productivity for the entire industry. Although productivity in meat products is somewhat lower than the entire industry, output per job was 3.5 percent lower in 1997 than in 1990.

Food processing companies convert raw agricultural output into food products that are easily transported and stored and have a longer shelf life. Process energy is used for washing, cooling, freezing, cooking, dehydrating and canning. In 1996, California food processors used 11.3 percent of the electricity consumed by industrial customers. Figure 3 shows 1997 electric and natural gas consumption in the California food processing industry by individual sector. Preserved fruit and vegetables (SIC 203), dairy products (SIC 202) and beverages (SIC 208) account for 58 percent of the electricity use in food processing. Preserved fruit and vegetables alone account for 44 percent of the natural gas used in the industry. This large amount of energy use in one sector of the industry is due to the energy intensity of canning, dehydration and freezing.

**Figure 3**
**1997 Electricity and Natural Gas Consumption**
**by Food Processing Industry**




Source: Quarterly Fuel and Energy Report

Table 3 shows the growth in real output, electricity use and natural gas use for individual industries. For the entire industry, electricity usage has grown faster than real output, whereas natural gas use has declined. For seven out of nine sectors within the industry, growth in electricity use outstripped growth in real output. However, only in grain mill products has natural gas usage grown faster than real output and in five sectors, gas use has declined. The largest decline in energy usage is in sugar and confectionery products. The three industries identified in Figure 2 as large energy users are each a little different. In the preserved fruits and vegetables sector, the data shows that electricity and natural gas use are both rising more slowly than output. In the beverages and dairy products industries, electricity use is rising much faster than output, whereas gas use is rising more slowly (beverages) or declining (dairy products).

**Table 3. Rates of Growth of Output and Energy Use (1990-1997)**

| SIC | Description | Real Output | Electricity Use | Natural Gas Use |
|---|---|---|---|---|
| 201 | Meat Products | -0.19% | 0.10% | -1.42% |
| 202 | Dairy Products | 1.95% | 3.68% | -5.93% |
| 203 | Canned & Preserved Fruit & Vegetables | 1.65% | 1.28% | 0.36% |
| 204 | Grain Mill Products | -0.53% | 1.57% | 0.61% |
| 205 | Bakery Products | 1.84% | 2.73% | -0.93% |
| 206 | Sugar & Confectionery Products | 0.81% | -0.40% | -11.49% |
| 207 | Fats & Oils | 2.53% | 2.58% | 0.71% |
| 208 | Beverages | 3.51% | 6.29% | 1.06% |
| 209 | Misc. Food & Kindred Products | 1.64% | 3.24% | -5.43% |
| 20 | Total Food & Kindred Products | 1.90% | 2.68% | -1.55% |

Source: Standard & Poor's DRI, Quarterly Fuel and Energy Report (QFER)

*Meat Products (SIC 201)*

The meat products sector includes processing of beef, pork, poultry, sausages and other prepared products. The industry is heavily dependent on weather, costs of feed and demand for meat products. In the past decade, the demand for red meat has declined and demand for poultry has steadily increased because of health concerns about cholesterol intake.

Table 4 shows electricity and natural gas usage, number of establishments and jobs in the meat products industry. The meat products industry uses about seven percent of total food processing industry electricity and 3.5 percent of the total natural gas. Electricity and natural gas use per establishment is slightly higher for poultry slaughtering and processing plants compared to meat packing plants. If consumers continue to substitute poultry for beef (the forecast projects the share of poultry processing to rise from 1998 to 2008 from 28 percent to 35 percent), electricity use in the meat products industry should gradually increase.

**Table 4. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**

***Meat Products Industry***

| SIC | Description | Electricity (million KWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2011 | Meat Packing Plants | 159.8 | 8.0 | 61 | 3,708 |
| 2013 | Sausages & Other Prepared Products | 95.5 | 3.7 | 125 | 4,135 |
| 2015 | Poultry Slaughtering & Processing | 134.7 | 10.7 | 44 | 9,891 |

Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 4 shows employment and output for meat products. Before 1998, employment was variable but output was relatively constant because output and employment in beef processing fell as poultry processing output increased. From 1988 to 1998, output of poultry products doubled. After 1998, employment in the industry is expected to increase 0.5 percent per year and output 2.1 percent per year. Beef and pork processing has had very low profit margins,

about .7 to 1.5 % over the last decade, suggesting that only the most efficient companies will continue (Standard and Poor's, 1998).

*Dairy Products (SIC 202)*

Individual sectors within the dairy products industry include butter, cheese products, frozen desserts and fluid milk. California is a leading producer of dairy products, with nine percent of U.S. dairy output coming from California. In the early 1980's, dairy farmers in California expanded their production capacity and efficiency by establishing new dairy farms and new processing plants. Nationally, the last decade has witnessed a 20.8 percent decline in the number of firms in the industry due to mergers and acquisitions and closures of older plants (Standard and Poor's, 1998).

In California, the fluid milk sector uses the most electricity and natural gas, and has the most companies and jobs within the dairy products industry. The large amount of energy used in fluid milk production is due to refrigeration requirements, pasteurization and the large number of plants (Table 5). About 58 percent of all California dairy industry jobs are in the fluid milk sector. Employment within the fluid milk industry has fallen in recent years, due to improved efficiency and consolidation. Since consumption levels per person do not change much over time, demand for fluid milk should rise at the rate of population growth. The U.S. cheese industry has steadily increased employment because of rising demand for cheese products.

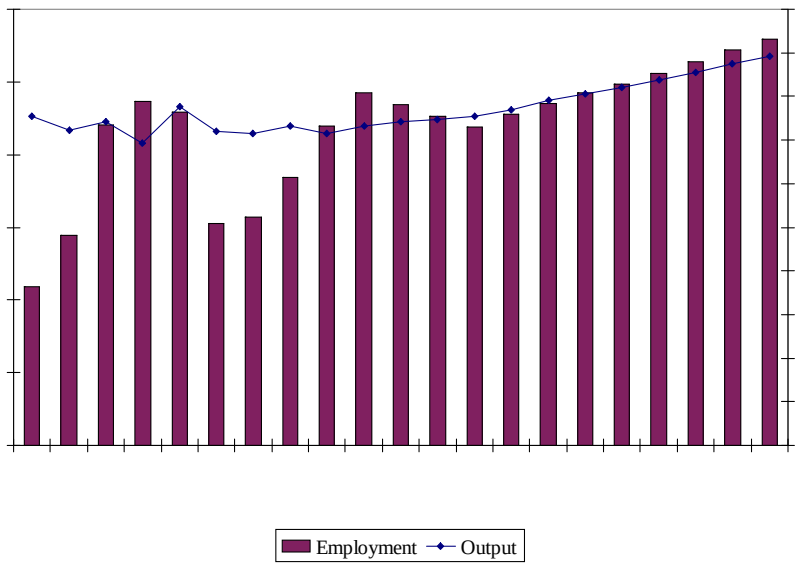


**Table 5. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Dairy Products Industry***

| SIC | Description | Electricity (million KWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2021 | Creamery Butter | * | * | * | * |
| 2022 | Cheese, Natural and Processed | 250.0 | 21.1 | 51 | 2,724 |
| 2023 | Dry, Condensed and Evaporated Prod | 96.7 | 4.9 | 19 | 847 |
| 2024 | Ice Cream and Frozen Desserts | 171.7 | 1.6 | 58 | 2,073 |
| 2026 | Fluid Milk | 363.0 | 33.5 | 74 | 7,859 |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

**Figure 5**
**Employment and Output in Dairy Products (SIC 202)**

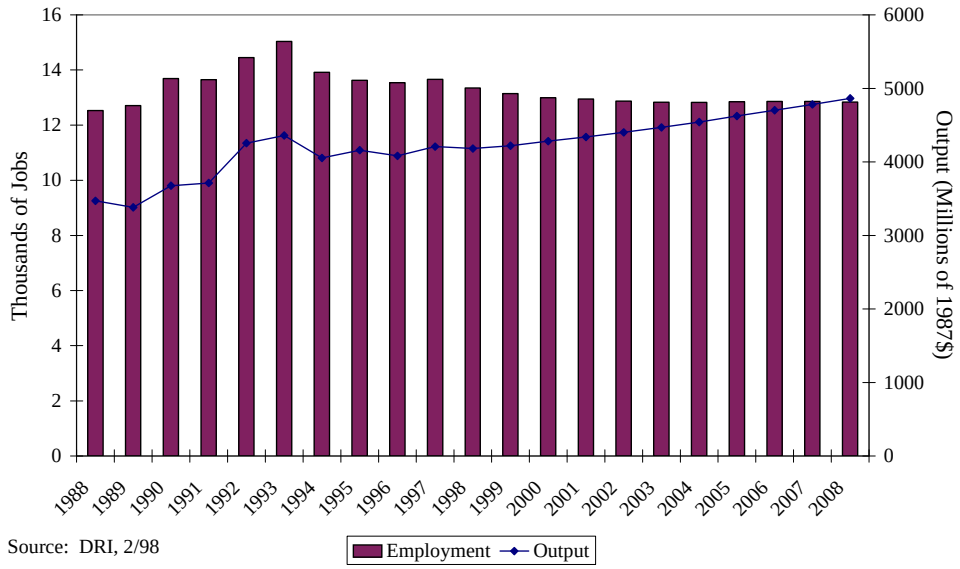



Figure 5 shows that the value of output rose 1.9 percent per year from 1988 to 1998, and employment was up 0.6 percent per year. However, employment has been falling since 1993. From 1998 to 2008, employment is expected to decrease 0.4 percent per year while output is expected to increase 1.7 percent per year.

*Preserved Fruit and Vegetables (SIC 203)*

Businesses in this sector produce several different types of fruit and vegetable products that are canned, dehydrated or frozen. Table 7 shows that the largest sector in terms of shipments is canned fruits and vegetables (SIC 2033). While there has been a decline in consumption of canned fruits and vegetables, the industry also includes catsup, pizza sauce and salsa, whose consumption has been growing in recent years.

The heaviest concentration of fruit and vegetable processors is in California. For example, California produces approximately 90% of the U.S. output of processed tomato products. There has been a significant drop in the number of fruit and vegetable canneries, except for firms producing catsup and other tomato products. California has also experienced a significant drop in establishments freezing vegetables because the operations have been moved to Mexico. Table 6 shows electricity use, natural gas use, number of establishments and jobs in the preserved fruit and vegetables industry. The sector with the largest energy use, the most establishments and 41 percent of all employment in the industry is canned fruit and vegetables. This is a major California industry because of the state's strong agricultural base.

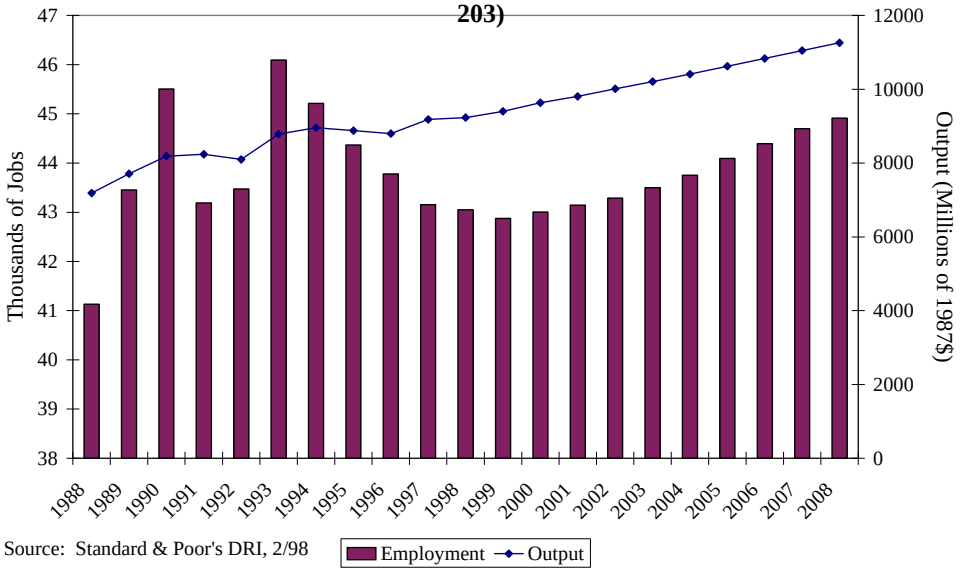
**Table 6. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Preserved Fruits and Vegetables Industry***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2032 | Canned Specialties | 72.8 | 9.9 | 28 | 3,417 |
| 2033 | Canned Fruits and Vegetables | 550.2 | 171.4 | 173 | 19,446 |
| 2034 | Dehydrated Fruits, Vegetables & Soups | 268.2 | 60.2 | 154 | 8,925 |
| 2035 | Pickles, Sauces & Salad Dressing | 30.2 | 2.4 | 66 | 2,536 |
| 2037 | Frozen Fruits &Vegetables | 329.8 | 38.7 | 48 | 6,722 |
| 2038 | Frozen Specialties | 105.1 | 3.5 | 72 | 5,984 |

Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 6 shows a modest increase in employment of 0.5 percent per year and a 2.5 percent per year increase in output from 1988 to 1998. Through 2008, employment is expected to continue to increase at 0.5 percent per year while output growth slows down to 2.2 percent per year.

**Figure 6**
**Employment and Output in Preserved Fruit and Vegetables (SIC 203)**




Source: Standard & Poor's DRI, 2/98

*Grain Mill Products (SIC 204)*

This sector includes grain mill products, cereal, flour, corn and rice milling, pet food and prepared feeds. Grain mill products constitute 6.8 percent of California food processing output. The largest end-user of grains is the livestock sector, accounting for about 59 percent of the market.

Table 7 shows electricity use, natural gas use, number of establishments and jobs in the grain mill products industry. The largest electricity and natural gas user is prepared feeds. Flour and other grain mill products use the largest amount of electricity. However, prepared feeds (SIC 2048) has the largest number of establishments. Businesses in this sector produce feed for farm and ranch animals, such as cows, horses and pigs.

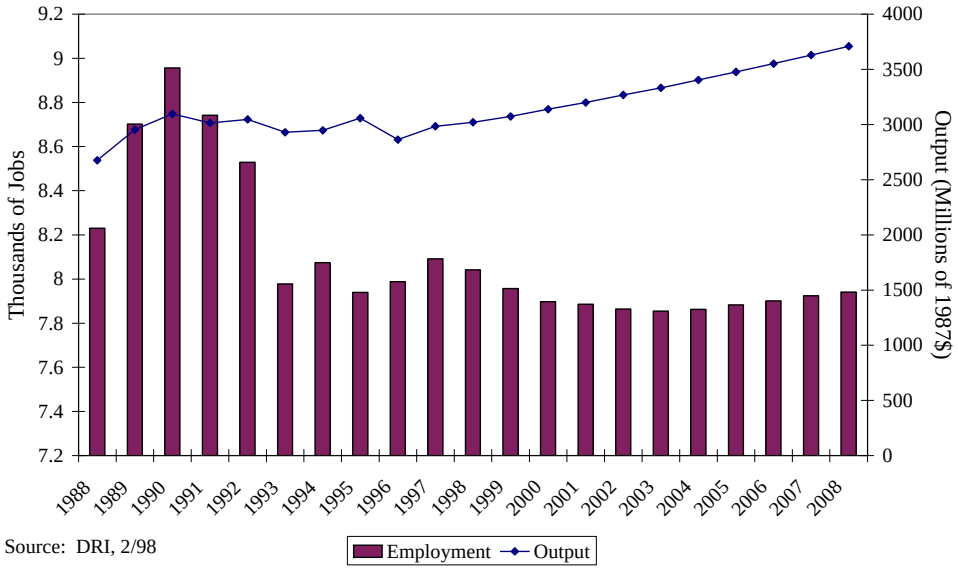
**Table 7. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Grain Mill Products***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2041 | Flour and Other Grain Mill Products | 131.4 | 1.7 | 27 | 841 |
| 2043 | Cereal Breakfast Foods | 70.2 | 6.2 | 12 | 1,083 |
| 2044 | Rice Milling | 87.7 | 1.1 | 19 | 1,188 |
| 2045 | Prepared Flour Mixes and Doughs | 8.8 | * | 23 | 846 |
| 2046 | Wet Corn Milling | * | * | 5 | * |
| 2047 | Dog and Cat Food | 49.5 | 8.3 | 20 | 1,719 |
| 2048 | Prepared Feeds, NEC | 117.1 | 17.2 | 106 | * |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 7 shows that while output has remained steady, employment in the industry dropped in the first part of the 1990's. After 1997, employment is forecast to decline 0.1 percent per year through 2008 and output is expected to increase 2.3 percent per year.

**Figure 7**
**Employment and Output in Grain Mill Products (SIC 204)**




Source: DRI, 2/98

*Bakery Products (SIC 205)*

The bakery products industry consists of establishments involved in producing and processing bread and bakery products such as bread, cake, cookies and crackers and frozen bakery products. California is also a leading shipper of bakery products to other states. Except for beverages, the number of establishments in this industry exceeds that of any other food processing industry.

Traditionally, the bakery products industry has been split into three sectors: wholesale, retail and in-store sales. Wholesale bakers supply retail outlets. Retail outlets sell their own products along with goods purchased from wholesale bakeries. In-store bakeries are part of a large retail establishment, like a grocery store. The number of in-store bakeries grew 85% from 1985 to 1989, reflecting the addition of in-store bakeries in membership warehouse clubs (EPRI, 1994). Since 1990, mergers and acquisitions are the major causes for a 58 percent decline in the number of establishments in the industry.

Table 8 presents the electricity use, natural gas use, number of establishments and jobs in the bakery products industry. The businesses in bread, cake and related products (SIC 2051) have 85 percent of all bakery establishments, 81 percent of all jobs in bakery products and use 68 percent of the electricity. The prominence of this segment of the industry within bakery products is not expected to change.

**Table 8. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**

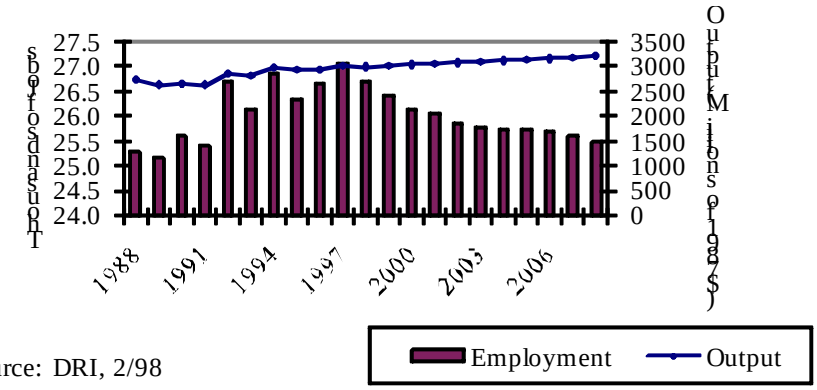
***Bakery Products***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2051 | Bread, Cake and Related Products | 211.9 | 22.9 | 541 | 18,618 |
| 2052 | Cookies and Crackers | 39.7 | 4.9 | 73 | 3,217 |
| 2053 | Frozen Bakery Products, exc. Bread | 54.1 | * | 21 | 1,139 |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Productivity (output per employee) increased 14% from 1977 to 1986 (EPRI, 1994). As competition for market share compels industry participants to continue cutting margins, there will be industry-wide pressure for continued productivity improvements. Employment is forecast to decline by 0.5 percent per year from 1998 to 2008, with output anticipated to rise 0.8 percent per year (Figure 8).

**Figure 8. Employment and Output in Bakery Products (SIC 205)**




Source: DRI, 2/98

*Sugar and Confectionery Products (SIC 206)*

The sugar and confectionery industry consists of establishments involved in the manufacture and sale of raw and refined sugar, chocolate and non-chocolate candy, chewing gum, nuts and seeds. While the consumer trend towards healthy foods has affected almost all food product industries, it appears to have had little impact on the confectionery products industry. One explanation is that there are few healthy substitutes for candy, confectionery products or

chocolate. In 1987, four of the top ten SIC 206 companies were mainly involved in refining cane sugar. California has more SIC 206 companies than any other state (EPRI 1991).
Table 9 shows the highest ratio of employees per establishment is in sugar related businesses. Sugar cane refining establishments average 156 jobs per firm and beet sugar producers average 178 jobs. The highest electricity use is in chocolate and cocoa products, indicating that the process of converting cocoa beans to cocoa is highly energy intensive. The largest natural gas user is beet sugar, which also uses 28 percent of the industry's total electricity (including those sectors for which data cannot be disclosed). The chocolate and cocoa sector has the largest number of companies and employees.

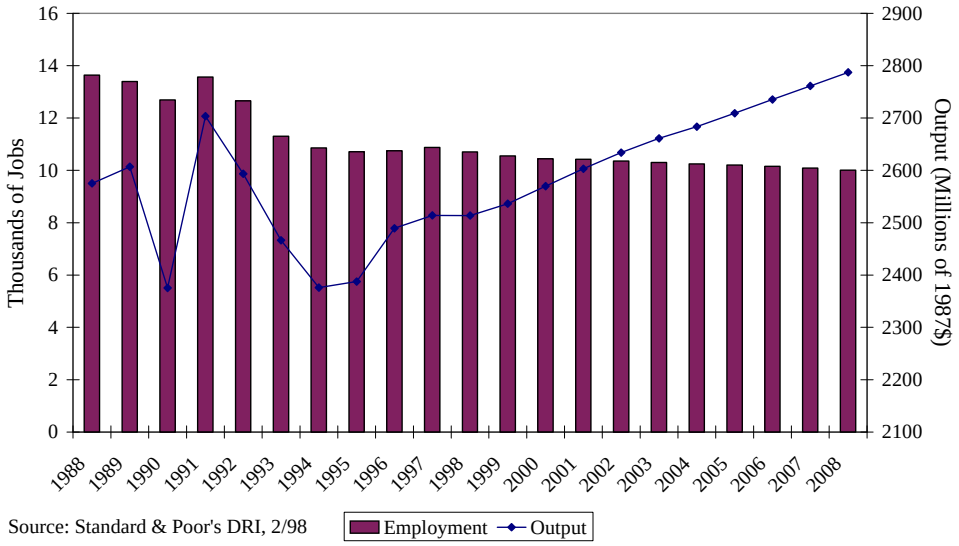
**Table 9. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Sugar and Confectionery Products***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2061 | Raw Cane Sugar | * | * | 1 | * |
| 2062 | Cane Sugar Refining | * | * | 4 | 625 |
| 2063 | Beet Sugar | 82.2 | 33.2 | 7 | 1,250 |
| 2064 | Candy and Other Confectionery Prod | 32.9 | 2.7 | 106 | 3,796 |
| 2066 | Chocolate and Cocoa Products | 91.3 | 2.7 | 16 | 1,570 |
| 2067 | Chewing Gum | * | * | 2 | * |
| 2068 | Salted and Roasted Nuts and Seeds | 20.7 | 1.4 | 28 | 2,806 |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Employment historically has been gradually going down, while output has been variable. From 1998 to 2008, employment is expected to continue to decline at 0.8 percent per year, while output is expected to rise 1.2 percent per year (Figure 9).

**Figure 9**
**Employment and Output in Sugar and Confectionery Prod (SIC 206)**




*Fat and Oil Products (SIC 207)*

Establishments in SIC 207 produce fats and oils from oilseeds, animal products and vegetables. Because transportation costs can represent as much as five to ten percent of production costs, fat and oil refineries tend to be located in the Midwest, nearest to the growing regions for key raw materials.

In California, fats and oils is the smallest sector within the food processing industry group, accounting for 3.2 percent of shipments in 1996. Although soybean oil mills are predominant nationally, California has more cottonseed oil mills than soybean and vegetable oil mills combined. Nationally, the edible fats and oils group accounts for 28% of shipments in SIC 207, but this could increase because consumer demand is shifting to oils low in saturated fats and with lower caloric content.

Table 10 presents electricity use, natural gas use, number of establishments and jobs. Over 90 percent of this industry's electricity and natural gas usage is in edible fats and oils and in animal and marine fats and oils. These two sectors also have the largest number of jobs in fat and oil products.

**Table 10. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**

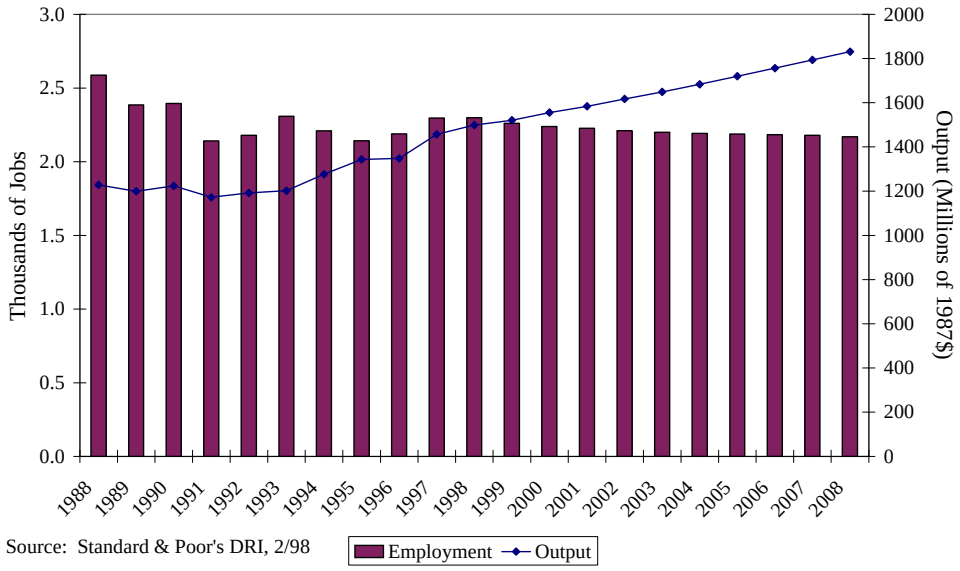
***Fats and Oils***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2074 | Cottonseed Oil Mills | 10.9 | * | 16 | 567 |
| 2075 | Soybean Oil Mills | 2.2 | * | 7 | 195 |
| 2076 | Vegetable Oil Mills | * | 1.7 | 6 | 171 |
| 2077 | Animal and Marine Fats and Oils | 39.2 | 18.5 | 15 | 700 |
| 2079 | Edible Fats and Oils | 58.6 | 4.2 | 21 | 791 |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 10 shows steady employment and increasing output through 1997. From 1998 until 2008, employment is forecast to decrease 0.6 percent per year and output is expected to rise by 2.3 percent per year.

**Figure10**
**Employment and Output in Fats and Oils (SIC 207)**




*Beverages (SIC 208)*

Beverages include alcohol, soft drinks, and flavorings. Alcoholic beverages are the largest energy user and have the most establishments and employees in California. The alcoholic beverage industry has three distinct sectors: malt beverages, wines and brandy and distilled spirits. Between 1989 and 1995, the amount of malt beverages produced nationally declined 0.4 percent, and distilled spirits dropped 12.5 percent because baby boomers are drinking less and the number of people in the prime age drinking group (21-40) has decreased (Standard and Poor's, 1998). From 1989 to 1995, U.S. wine production, of which California's share is 90 percent,

increased 2.7 percent. Wine exports, also dominated by California wineries, increased 400 percent between 1988 and 1997 (Wine Institute, 1998).

Table 11 shows that 84 percent of the electricity and 88 percent of the natural gas is used in the production of alcoholic beverages. Because of the internationally recognized wine country in the Napa Valley and other wine growing regions in California, alcoholic beverages also comprise the largest share of companies and jobs.

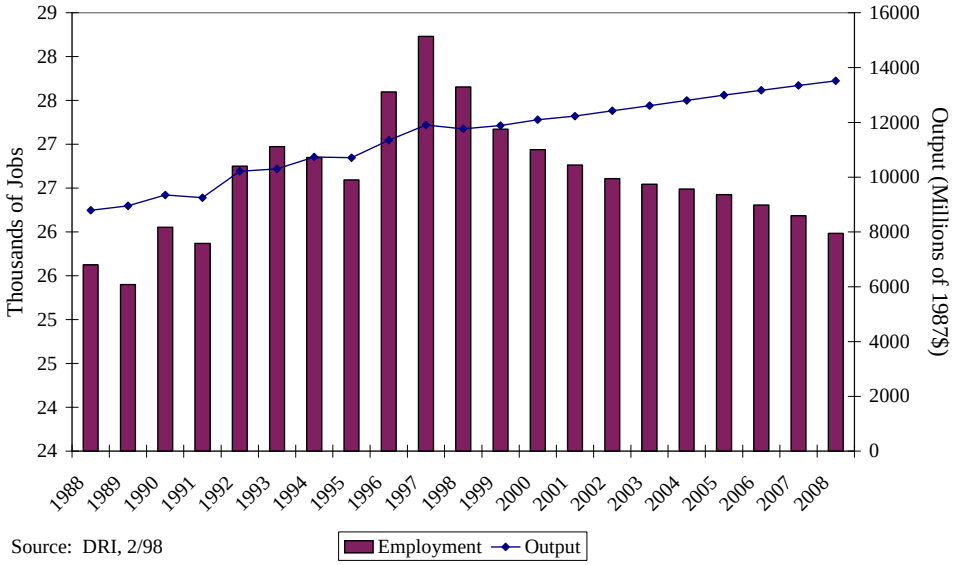
**Table 11. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Beverages***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2082 | Malt Beverages | 300.7 | 28.6 | 60 | 3,819 |
| 2083 | Malt | * | * | 2 | * |
| 2084 | Wines, Brandy and Brandy Spirits | 642.7 | 25.7 | 428 | 16,339 |
| 2085 | Distilled and Blended Liquor | 6.0 | 0.3 | 7 | * |
| 2086 | Bottled and Canned Soft Drinks | 180.4 | 6.8 | 97 | 9,854 |
| 2087 | Flavoring Extracts and Syrups | 10.5 | 0.9 | 68 | 1,548 |

* Confidentiality agreements do not allow public release of energy data in industries with less than 10 utility accounts.
Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 11 shows increasing employment and output through 1997. While output is expected to rise from 1998 to 2008, employment is forecast to decline by .7 percent per year. This forecast implies rising productivity in the industry, due mostly to a 3.3 percent per year increase in output per job in the production of non-alcoholic beverages from 1998 to 2008. Productivity in the alcoholic beverage sector is also expected to improve but only at 1.8 percent per year.

**Figure 11**
**Employment and Output in Beverages (SIC 208)**




Source: DRI, 2/98

*Miscellaneous Food Preparations and Kindred Products (SIC 209)*

This category encompasses canned, cured, fresh and frozen fish, coffee, salty snacks, ice, macaroni and miscellaneous food preparations. Table 12 shows that food preparation (not elsewhere classified) is the largest electricity and natural gas user in this industry and has the largest number of companies and jobs. However, this segment of the industry is highly diverse and it serves as a classification "catchall", thus its "large" size.

Other segments of the industry are roughly of comparable size in terms of number of establishments, jobs and energy use. California's coastal location promotes its seafood processing industry (SIC 2091 and 2092). The preparation of canned fish and seafood and fresh fish accounts for more than 3,600 jobs. However, the industry is not likely to grow because some commercial fisheries are experiencing declining numbers of fish.

California also has 42 establishments in the potato chips and similar snacks sector. Although Frito-Lay tends to dominate the business nationally, and operates plants in California, the state has several other companies in this market. Many of these plants are producing corn chips to meet California's taste for Mexican cuisine. The U.S. industry has seen consolidation and exit in the 1990's, as Keebler left the industry and Eagle Snacks sold its business to Frito-Lay. The market in California is no less competitive than the national market but its diversity can support several independent companies.

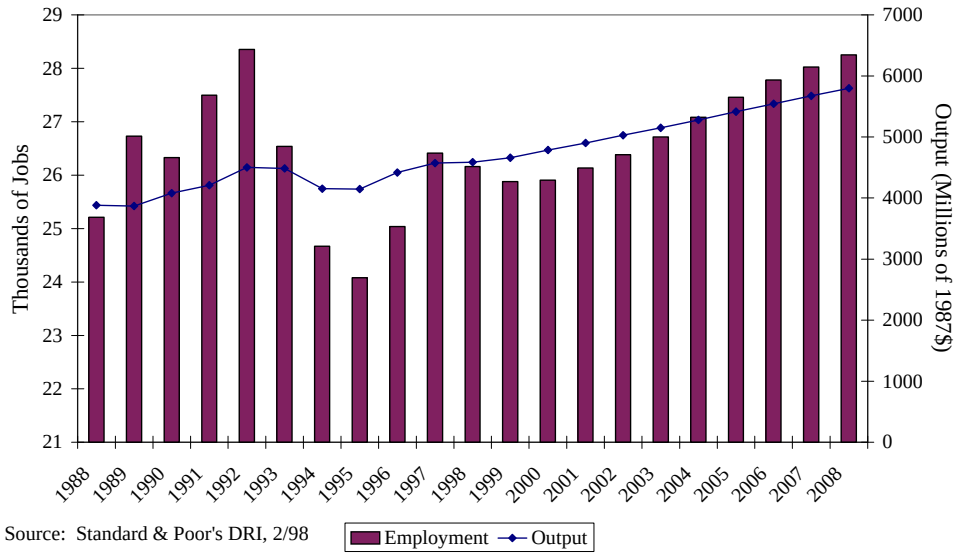
**Table 12. California Electricity and Natural Gas Consumption (1997), Establishments and Jobs (1996)**
***Miscellaneous Food Products***

| SIC | Description | Electricity (million kWh) | Natural Gas (million therms) | Establishments | Jobs |
|---|---|---|---|---|---|
| 2091 | Canned and Cured Fish & Seafoods | 44.2 | 1.5 | 29 | 1,519 |
| 2092 | Fresh or Frozen Prepared Fish | 45.0 | 0.3 | 47 | 2,109 |
| 2095 | Roasted Coffee | 22.1 | 2.4 | 35 | 1,015 |
| 2096 | Potato Chips and Similar Snacks | 60.2 | 9.3 | 42 | 2,814 |
| 2097 | Manufactured Ice | 65.0 | 0.1 | 45 | 677 |
| 2098 | Macaroni and Spaghetti | 38.7 | 8.1 | 51 | 1,472 |
| 2099 | Food Preparation, NEC | 278.5 | 33.9 | 342 | 12,410 |

Source: Quarterly Fuel and Energy Report (QFER) and California Trade and Commerce Agency

Figure 12 shows employment rising through 1992 and then falling until 1995. Employment has recently recovered some of the lost jobs and is expected to level out before increasing through 2008 by 0.9 percent annually. Output has been slowly increasing through 1998 and is forecasted to increase 2.6 percent per year from 1998 through 2008.

**Figure 12**
**Employment and Output in Miscellaneous Food Products (SIC 209)**




Source: Standard & Poor's DRI, 2/98

*References*

Standard and Poor's Data Resources, Inc., *U.S. Industry and Trade Outlook 1998*.
Electric Power Research Institute, "Industry Brief, Dairy Industry," Palo Alto, 1991.
Electric Power Research Institute, "Industry Brief, Sugar and Confectionary Products," Palo Alto, 1991.
Electric Power Research Institute, "Industry Brief, Bakery Products," Palo Alto, 1994.
Wine Institute, "U.S. Wine Exports Climb to $425 Million in 1997," press release, San Francisco, 1998

# Appendix G: Water-Energy

## 1. Titles & Authors

Edward Means III (McGuire Environmental Consultants), Water and Wastewater Industry Energy Efficiency: A Research Roadmap. (2004)

Navigant Consulting, PIER Water-Energy Strategic Plan and Technology Roadmap. (2008)

## 2. Stakeholders

| Stakeholder Type | Organization | Name |
|---|---|---|
| Industry | San Francisco Public Utilities Commission | Andrew DeGraca, Bill Idzerda |
| | California Department of Water Resources | Mark Cowin, Manucher Alemi, John Andrew, Dave Todd, Ralph Torres |
| | Inland Empire Utilities Agency | Martha Davis, Wyatt Troxel |
| | East Bay Municipal Utility District | Richard Harris, Joe Young |
| | Metropolitan Water District of Southern California | Silvia Orozco-Perez, Bill McDonnell, Eddie Rigdon, Brad Coffey |
| | U.S. Bureau of Reclamation | Leslie Cleveland, Mike Finnegan, Kevin Price |
| | State Water Resource Control Board | Caren Trgovich, Bob Languell |
| | City of San Diego Wastewater | Thomas Alspaugh |
| | King County Department of Natural Resources | Rick Butler |
| | Orange County Water District | Shivaji Deshmukh |
| | Las Vegas Valley Water District | Kevin Fisher |
| | Contra Costa Water District | David Huey |
| | City of Los Angeles Sanitation Bureau | Reza Iranpour, Omar Moghaddam, Ed Wheless |
| Research | American Waterworks Association Research Foundation | Rick Karlin, Linda Reekie, Jennifer Warner |
| | Electric Power Research Institute | Bob Goldstein |
| | Irrigation Technology and Research Center | Charles Burt |
| | Lawrence Berkeley National Laboratory | Mirka della Cava, Camilla Whitehead, F. Bailey Green |
| | Sandia National Laboratories | Dr. Glenn Kuswa, Tom Hinkebein |
| | Water Environment Research Foundation | Roy Ramani |
| | State Water Resource Control Board | Caren Trgovich, Bob Languell |
| | NYSERDA | Janet Joseph |
| | UCLA Department of Engineering | Michael Stenstrom |
| | UCSB | Robert Wilkinson |
| | California Energy Commission | Pramod Kulkarni, Rich Sapudar, Paul Roggensack, Joe O'Hagan, Shahid Chaudry, Ricardo Amon, Martha Krebs, Lorraine White |

| Stakeholder Type | Organization | Name |
|---|---|---|
| Utilities | Sacramento Municipal Utility District | Jim Parks |
| | Southern California Edison | Lory Larson |
| | Pacific Gas & Electric Company | Stephen Folk |
| Other | State Water Contractors | Terry Erlewine |
| | GEI Consultants | Ray Hart, Bill Bennett |
| | Navigant Consulting | Chuck Haddon, Ron Nichols, Craig McDonald, Laurie Park |
| | MEC | Edward Means, Michele Matthes |
| | Water Systems Engineering | David Beyer |
| | Global Energy Partners | Keith Cairns |
| | Sherman May Consulting | Sherman May |
| | Damon S. Williams Associates | Dale Newkirk |
| | HDR Engineering | David Reardon |
| | CH2M Hill | Fred Soroushian |
| | Natural Resources Defense Council | Barry Nelson |