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Alphabet Energy

Matt Scullin, the founder and CEO of Alphabet Energy, sat staring out the window of his Berkeley office, but the sunny December day barely registered. He was lost in thought, wondering which market Alphabet should enter first. It was 2010, and the start-up had a working prototype of a thermoelectric device—a solid-state semiconductor that could turn heat into electricity. He had just closed on $1.5 million in seed funding. Scullin knew that his young business was at a crucial point: a misstep now could cost him the company.

Industry Background

Approximately 60 percent of energy generated in the United States is wasted as unutilized heat. Machines, electrical generators, and industrial processes throw off heat as a by-product in the same way that an old-fashioned incandescent light bulb gets hot to the touch as it shines. Different sources of waste heat are typically segmented based on temperature and production volume **(Exhibit 1)**.

Thermoelectric technologies could revolutionize energy efficiency by capturing that lost heat and putting it to work. Thermoelectrics have had a long history of use as both electricity generators and heat pumps. As generators, they convert heat into electricity. As heat pumps, they transfer heat from one side of a device to the other, serving in applications like car seat coolers and small refrigeration systems. In general, thermoelectric systems have been optimized to serve as either generators or heat pumps.

As solid-state devices, thermoelectrics have been more reliable than machines with moving parts, but also more complex and costly to manufacture. The most widely used material in earlier thermoelectric solutions was bismuth telluride (Bi_2Te_3), which contains the rare element tellurium. Some experts believe all of the gold produced in history could fit in less than three Olympic swimming pools. Tellurium, in contrast, is considered to be roughly three times *rarer* than gold. As a result, thermoelectric concepts have faced potential supply chain constraints.

Adam Boscoe, Mason Cabot, Phillip Dawsey, Luc Emmanuel Barreau, and Russell Griffith prepared this case study under the supervision of Professor Beverly Alexander as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

Company Background

Scullin, who received his doctorate in Materials Science and Physics from the University of California at Berkeley, had spent several years researching waste-heat harvesting technologies, including the organic Rankine cycle[1], one of the most widely used incumbent technologies. Recovering lost heat was not new—innovations like combined-cycle natural-gas turbines had increased power generation efficiencies 10 to 25 percent over previous levels—but Scullin was attracted to new developments that could prompt more widespread adoption.

Initially, he wasn't sure whether Alphabet should manufacture its own products or become a consultant on projects using thermoelectric products made by others. Trying to narrow the list of markets without a defined business model or technology proved difficult. Drawing on his technical expertise, Scullin decided to take on the challenge of producing a superior thermoelectric device. After extensive customer research, he found that "customers care about payback time, not efficiency, because in every case, we're competing with non-consumption of the waste-heat." After estimating the payback for various potential technologies, he zeroed in on a prototype close to home.

The Lawrence Berkeley National Laboratory, a member of the laboratory system supported by the United States Department of Energy, had been developing a novel silicon-based chemistry for several years that demonstrated promising performance at scalable costs. In early 2009, Scullin secured an exclusive license on the prototype, which offered a significant advance in energy conversion efficiencies, particularly for mid- to high-grade heat sources (greater than 250°C). Thanks to its silicon design, the device could be produced using 30-year-old semiconductor processes, and production would cost ten times less than current thermoelectric materials. Scullin projected it could be installed cheaply enough to give customers a one- to five-year payback time.

Shortly after licensing the technology, Scullin raised a round of angel funding. He then met Adam Lorimer in a Berkeley-Haas MBA class, and he hired Adam as Alphabet's first employee (to be followed by several more). In contrast to Scullin's nanotech background, Lorimer spent years building oil rigs before attending business school. Combining their complementary skills and knowledge, the two men began working hard on their business plan.

Market Entry Decision

Scullin and Lorimer needed a strategy for narrowing the vast number of potential applications for their product **(Exhibit 1)**. A start-up is an optimization problem: it has to solve for the optimal solution given limited time, cash, and labor. This meant not only identifying promising markets but also sequencing their market-entry strategy. The key question: which application should they attack first? As Scullin told a potential investor: "My goal is to position the company to pivot and to find a strong 'product-market fit.' Some of our work may never get to market, but that's okay because we will learn from it if we have to adapt."

They identified over 80 industries with medium and high-grade waste heat that could benefit from the efficiency brought by thermoelectrics, ranging from industrial equipment to camping stoves. Scullin and Lorimer ranked these applications based on the following operating criteria:

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[1] The organic Rankine cycle is a thermodynamic process where heat is transferred to a fluid at a constant pressure. The fluid is vaporized and then expanded in a vapor turbine that drives a generator, producing electricity. The spent vapor is condensed to liquid and recycled back.

- Was the heat source the right temperature?
- Was the heat source in a corrosive or dirty operating environment, with high maintenance and engineering costs?
- What was the total amount of waste heat generated annually in the industry?
- Was the customer currently paying a high price for electricity?

By using these questions in a screening process, they narrowed their potential targets to four major industries: automotive, aerospace and defense, power generation, and manufacturing.

Which one should Alphabet enter first? One of Scullin's mentors had given him advice that stuck: your entry market should be the one that values power the most (e.g., diesel for generators is very expensive in remote locations). Yet Scullin had to balance that priority against other considerations, including the need for waste-heat recovery in an industry. "I have just seen too many young energy companies run out of cash and momentum trying to push their technologies into markets without an obvious pain point," he recalled.

Alphabet would also have to commit to a product size that would be flexible enough to be used with smaller power systems first, but that later could be combined into larger ones. Scullin worried that combining modular electrical systems for greater capacity was always less efficient in practice than in theory, which might limit his ability to attack both system sizes simultaneously.

Automotive

About half of the Alphabet team was passionate about cars and motorcycles in their free time, so they were naturally drawn to the automotive market. Thermoelectric generators had the potential to increase vehicle fuel economy by converting engine waste heat to electricity. Conventional gasoline- or diesel-powered vehicles might use the extra electricity to reduce alternator loads and drive accessories such as power steering. This seemed promising given carmakers' recent market push toward more efficient vehicles. Hybrid electric vehicles might also feed the added electricity directly into propulsion. Several auto companies had begun funding thermoelectric research, and BMW, the earliest adopter, planned to incorporate thermoelectrics into a vehicle by 2012.

A typical automobile engine converts only 30 percent of fuel into propulsion; the rest is lost to road friction, engine cooling, and, more than anything else, waste heat. Thermoelectric prototypes in vehicles had primarily recovered heat from engine exhaust, which exits a vehicle at anywhere from 250-900°C. This large a temperature range can diminish the durability of a thermoelectric device. The National Renewable Energy Laboratory had tested a comparable thermoelectric system in vehicles, and they concluded that it improved fuel efficiency by around 10 percent on average. The value of power for automobiles, however, remained relatively low compared to other industries because (1) cars tend to operate less than other equipment (some manufacturing equipment runs 24 hours a day, 7 days per week), and (2) gas prices remain relatively low in the United States. Scullin's customer interviews suggested that power generation from waste heat in this market would be worth only around $1 per watt.

Still, the new vehicle market did present enticing opportunities for Alphabet in both the U.S. and abroad. The U.S. Bureau of Transit Statistics reported that some 256 million passenger-vehicles were on the road in 2008, and 12.2 million new vehicles were sold that year **(Exhibit 3).** In conversations with contacts in the auto industry, Scullin learned that global sales were expected to reach 50 million vehicles by 2010. Despite these large volumes, he worried about the size of the thermoelectric system required for automotive applications. It would be small (about 1 kW), which meant that Alphabet would have to scale up quickly for the mass production of relatively small units.

Alphabet also would have to sell to the large original equipment manufacturers (OEMs) like Ford, General Motors, and BMW. These companies were risk-averse and cost-conscious, as shown by their slow embrace of hybrid engines. Hybrids had been developed in the 1970s, but the first commercially successful models were not introduced until 2004. The sales cycle in the auto industry took approximately five to seven years from the introduction of a new technology to large-scale production, primarily due to the safety and quality checks required by OEMs and regulators (not to mention requirements for supply chain redundancy). Selling to an automotive OEM also required a partnership with big suppliers like Delphi, Dana, or Johnson Controls, which sold a wide array of products to OEMs. Selling through such suppliers would add transaction costs, lower Alphabet's profit due to at least one more layer of markups, and potentially deprive Alphabet of the direct customer feedback that is so critical during the early stages of a company's development. This was particularly true in the auto industry, where the upfront engineering and design work to integrate a thermoelectric device into the automotive system tends to be highly iterative.

On the positive side, Alphabet's product would have to be modular, in the way that other car parts are, and this would make it easier to scale up production. Gross margins in the automotive industry for equipment suppliers average around 8 percent. A superior product might beat that margin, but Scullin knew he had much to learn about the industry and therefore could not count on a higher number to start.

Aerospace and Defense

The aerospace and defense industry had been a pioneering market for thermoelectrics, including use in the Viking I space probe as early as 1976. Thermoelectrics had many applications in the military. They helped to power satellites, jet fighters, and personnel equipment such as GPS devices. They also contributed to distributed power generation in places like Afghanistan, where the cost of fuel could reach hundreds of dollars a gallon. Even such exotic applications as silent propulsion systems for submarines were feasible.

Economic cycles in this industry tended to be long due to the need for political authorization of the defense budget; two decades of fat budgets could be followed by two decades of lean ones. However the market was potentially large. The U.S. Department of Defense spent $160 billion on product-related contracts **(Exhibit 4)** and $80 billion on R&D contracts in 2010[i]. Estimates suggested that the market for thermoelectrics could reach $2 billion by 2020, although executives at Lockheed Martin cautioned Scullin that these estimates might be optimistic. In any case, Alphabet had relationships in the defense market and had received two research grants from the U.S. Air Force and Army.

The aerospace and defense market was a collection of highly profitable niches—gross margins in the defense sector had at times exceeded 80 percent—with specialized engineering requirements for each. Certification and "ruggedization" processes, although quite long, were relatively straightforward. And the industry was more focused on performance and weight than on economics and payback. It therefore could be an attractive "premium" market to start, while

Alphabet worked on reducing its manufacturing costs for more price-sensitive markets down the road.

But Scullin wondered whether the defense market aligned with the kind of corporate culture he was trying to foster. He knew that several recent defense industry start-ups had received lower valuations than they'd hoped because investors perceived the market as boring and slow growing. "Do we really want to sell weapons components?" he wondered. "Can we still attract the best minds and talent if that is our focus?"

Power Generation

In most electric power plants, fossil or nuclear fuel is used to produce heat, which is then converted to electricity in a turbine. Fossil-fueled plants tend not to operate at full capacity, instead throttling output to meet changing demand from the grid, which results in volatile waste-heat production.

Electric power generation tends to be centralized, with utility-scale plants generating over 90 percent of the world's electricity. The typical utility-scale plant operates for 30 to 50 years. Except for the advent of nuclear power, power-generation technology hasn't changed much over the past 100 years. Rather, plants have pushed to become more efficient and reduce operating costs. The U.S. Energy Information Administration projected that 25.5 GW of new power generating capacity would be constructed in the U.S. in 2011 **(Exhibits 5** and **6)**, but most of these new plants would not emit usable levels of waste-heat.[ii] Grid electricity is a commodity, and its wholesale price ranges greatly throughout the day (for a sample day, see **Exhibit 7**).

Given the temperature requirements for Alphabet's technology, simple-cycle natural-gas power plants presented the best opportunity, with the temperature of their waste heat measuring above 250°C. A simple-cycle plant is akin to a jet engine, in which gas burns in a turbine, and exhaust fumes discharge directly to atmosphere. The thermodynamic efficiency of a simple-cycle plant is around 33 percent, meaning that it wastes about 67 percent of the heat created from burning natural gas. At this level of efficiency, 2 MW of heat escapes for every 1 MW of electricity produced.

Scullin believed that 10 percent of the waste heat from a simple-cycle plant could be converted to electricity using Alphabet's technology. A combined-cycle plant also burns gas in a turbine, but it uses a heat-recovery steam generator to capture waste heat and increase efficiency. Recovery methods used in combined-cycle plants make these similar to other Rankine-cycle power plants, both nuclear and coal, in that there is little accessible waste heat above 250°C.

As a rule, power companies employ combined-cycle plants to generate electricity to cover their so-called base loads and simple-cycle plants to meet peak loads, which occur each day from approximately 3 to 9 p.m. as the use of household appliances spikes (exact times vary by location and season). In 2010, the U.S. had 162 GW of simple-cycle and 220 GW of combined-cycle natural gas-fired power generating capacity.[iii]

Scullin likened the power market to "elephant hunting": a single sale could finance Alphabet's operations for the entire year, but delivering a power-plant-sized system would require extensive engineering resources, enormous manufacturing capacity, and a long sales lead-time. On top of this, each plant's system would likely require some level of custom engineering because once a plant has been constructed, changing its design to incorporate new components tends to be difficult. Power plants therefore generally do not install new equipment after the fact unless they have a strong economic argument for doing so.

The key players in the power generation industry were electric utilities, independent power producers with their own power plants, and the engineering, procurement, and construction (EPC) firms that design, procure, and construct plants. There were many utilities and independent power providers, but relatively few EPC firms. The EPC firms were, potentially, a choke point. Alphabet would have to persuade them to incorporate thermoelectrics into their designs. For fossil-fuel plants, conceptual design normally took five years before a plant began operating, with more detailed designs firmed up in the final two years. Gross margins in the power market averaged around 20 to 40 percent.

Manufacturing

The industrial sector accounted for approximately one third of all energy used in the United States, consuming approximately 32 quadrillion BTU ($32x10^{15}$ BTU) of energy annually **(Exhibit 8)**. It emitted about 1,680 million metric tons of carbon dioxide associated with this energy use (1 BTU equals 0.0003 kW-h). Larger industrial customers generally had access to some of the cheapest electricity supply—averaging 6.77 cents per kW-h in 2010 (**Exhibit 9**).—but 20 to 50 percent of the energy used for manufacturing was lost as waste heat.

Eighty percent of industrial waste heat was low quality, but plenty of processes operated at higher temperatures. Many of them already included waste-heat recovery systems, but these technologies were often outdated and expensive—systems based on the organic Rankine cycle cost around $4 a watt to install—and their adoption had been limited. In general, manufacturers would invest in waste-heat recovery only if the savings paid for the investment in less than three years and the perceived risks were negligible. Cost mattered most to them.

Reaching manufacturers would be easier than reaching customers in the other markets. Because many of them were already capturing waste heat, Alphabet would not have to sell a new and unfamiliar idea. Additionally, their decision-making was often centralized. “This is a market where you find the person [who] buys equipment for the plant,” Scullin said, “and you can sell him on the payback time.” Although not critical, reaching this person could be accelerated by partnering with an industrial services company that specialized in fine-tuning manufacturing operations. TEAM Industrial Services was the largest such company in North America.

One problem was that each plant was different, and each customer would want a solution that could fit easily into its manufacturing line. Alphabet would need to create a base system that could be modified to fit the needs of each customer. That would make achieving economies of scale more challenging than in, say, the automotive market. Although gross margins for industrial equipment averaged 40 to 55 percent, gross margins for engineering and installation work were only 10 to 30 percent.

Another challenge was the chemical composition of the exhaust gas. Heat recovery was more common with clean exhaust, including that from boilers, ethylene furnaces, and hot blast stoves. It was less common when chemicals contaminated the exhaust, as happened with about 50 percent of the high quality heat from manufacturing.

Final Decision

Scullin knew that market entry could be a life-or-death decision for the young company. All four markets tempted him, but he wasn’t sure that Alphabet had the resources to pursue more than one initially. Which should he target first?

Case Discussion Questions

Evaluate Alphabet's market entry decision through the following market characteristics.

1. Which market looks most attractive for Alphabet's technology at this stage of the company's development, assuming no one can match Alphabet's price and performance? Consider customer demands, time to market, potential profits, and long-term strategic vision. How would viable competitors change your evaluation?

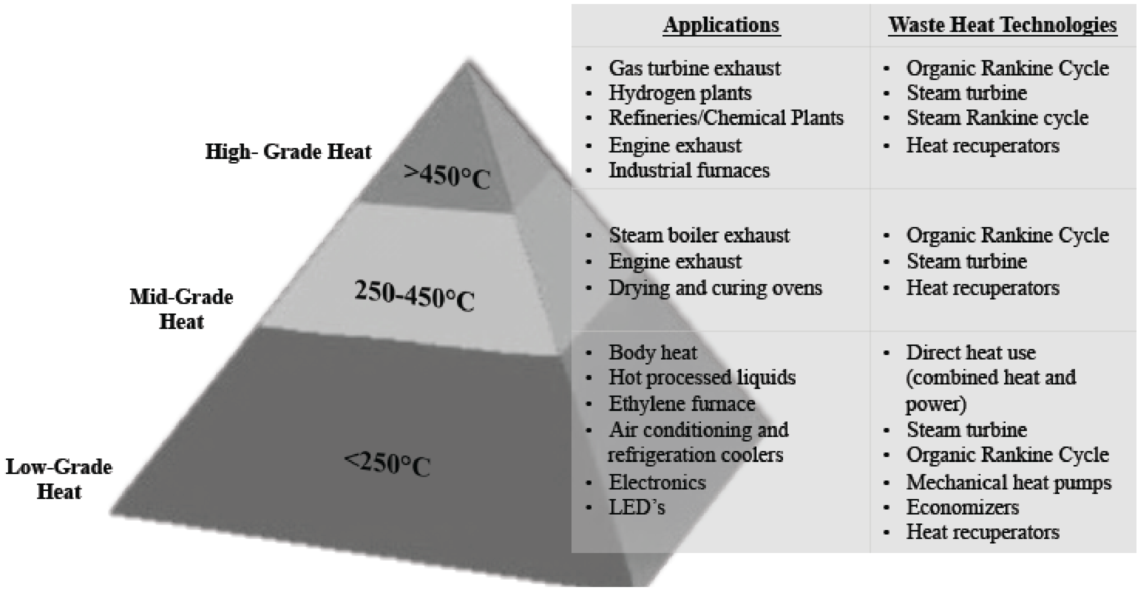
2. Which market would present the most competition? Who would Alphabet's main competitors be and how could Alphabet differentiate itself? What would be the main factors influencing the value of Alphabet's product and how might some of them change? What could Alphabet do to anticipate these changes?

3. Should Alphabet pursue a single market entry or develop a secondary option? Why? How?

4. How would you validate your market assumptions, and what other information would be helpful?

5. How should Alphabet measure the success of its market selection decision? Which criteria should it use to commit to or abandon a particular market? How would it maintain this agility?

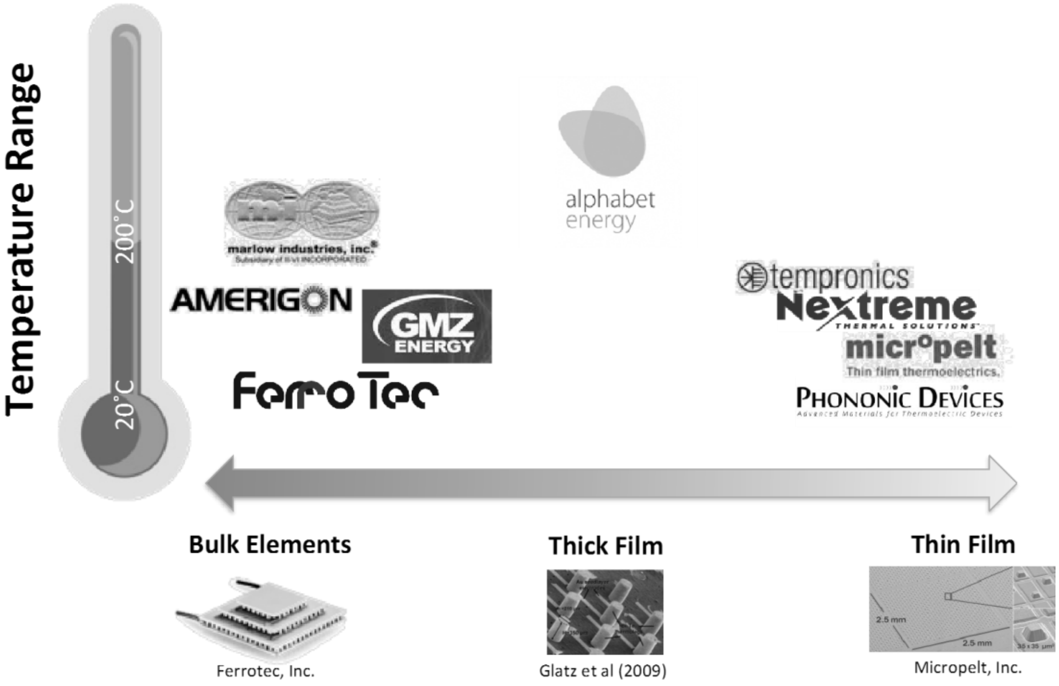
Exhibit 1 Applications Segmented by Heat Range



Applications	Waste Heat Technologies
• Gas turbine exhaust • Hydrogen plants • Refineries/Chemical Plants • Engine exhaust • Industrial furnaces	• Organic Rankine Cycle • Steam turbine • Steam Rankine cycle • Heat recuperators
• Steam boiler exhaust • Engine exhaust • Drying and curing ovens	• Organic Rankine Cycle • Steam turbine • Heat recuperators
• Body heat • Hot processed liquids • Ethylene furnace • Air conditioning and refrigeration coolers • Electronics • LED's	• Direct heat use (combined heat and power) • Steam turbine • Organic Rankine Cycle • Mechanical heat pumps • Economizers • Heat recuperators

Source: Author estimates and company research.

Exhibit 2 Thermoelectrics Landscape



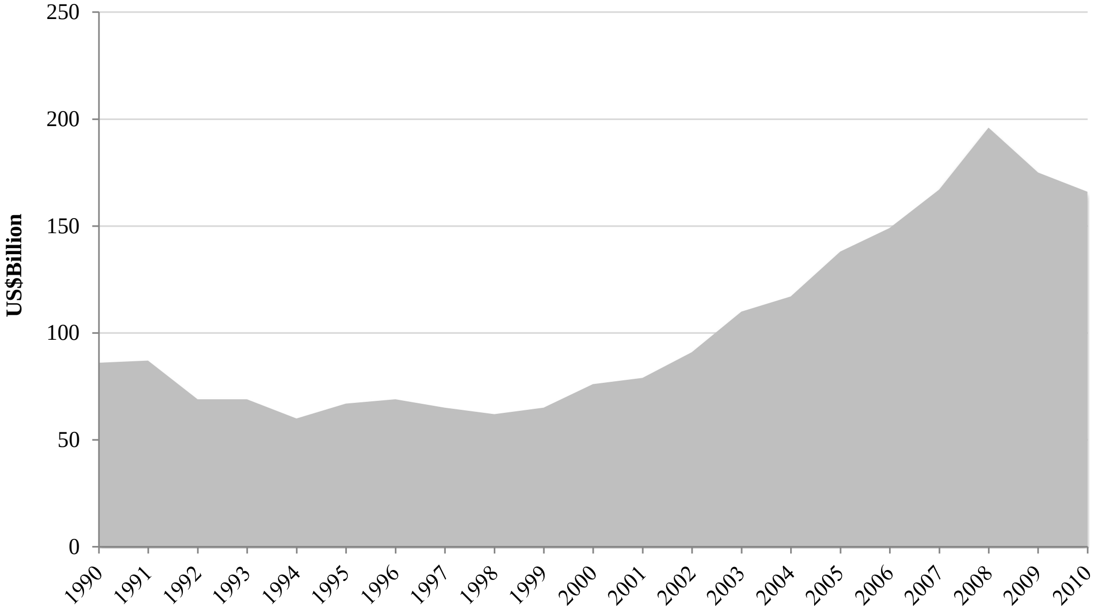
Source: University of California, Berkeley Cleantech-to-Market Program (2011).

Exhibit 3 New U.S. Vehicle Sales

1,000 units	**Passenger car**	**Motorcycle**	**Truck**	**Rec Vehicle**	**Total**
2007	7,618	1,124	6,201	354	15,297
2008	6,813	880	4,323	237	12,253
2009	5,456	522	3,107	166	9,251
3-yr Avg	6,629	842	4,544	252	12,267

Source: U.S. Department of Transportation, National Transportation Statistics.

Exhibit 4 Department of Defense Contract Spending for Products



Source: Author estimates from multiple industry sources.

Exhibit 5 New Power Generation Capacity in the United States

MW	**2007**	**2008**	**2009**	**2010**	**2011**
U.S. Total	**15,027**	**19,062**	**23,144**	**19,661**	**25,602**
Coal	1514	1651	2,021	5,836	4,873
Petroleum	268	95	93	1,001	548
Natural Gas	7587	8,700	10,760	7,544	11,256
Other Gases	--	--	--	101	--
Nuclear	--	--	--	--	--
Hydroelectric Conventional	0		26	22	33
Wind	12	18	9,581	4,565	7,972
Solar Thermal and Photovoltaic	5209	8,304	88	337	586
Wood and Wood Derived Fuels	0		99	94	155
Geothermal	90	32	199	24	31
Other Biomass	63		278	139	128
Pumped Storage	39	52	--	--	--
Other	245	56	--	1	20

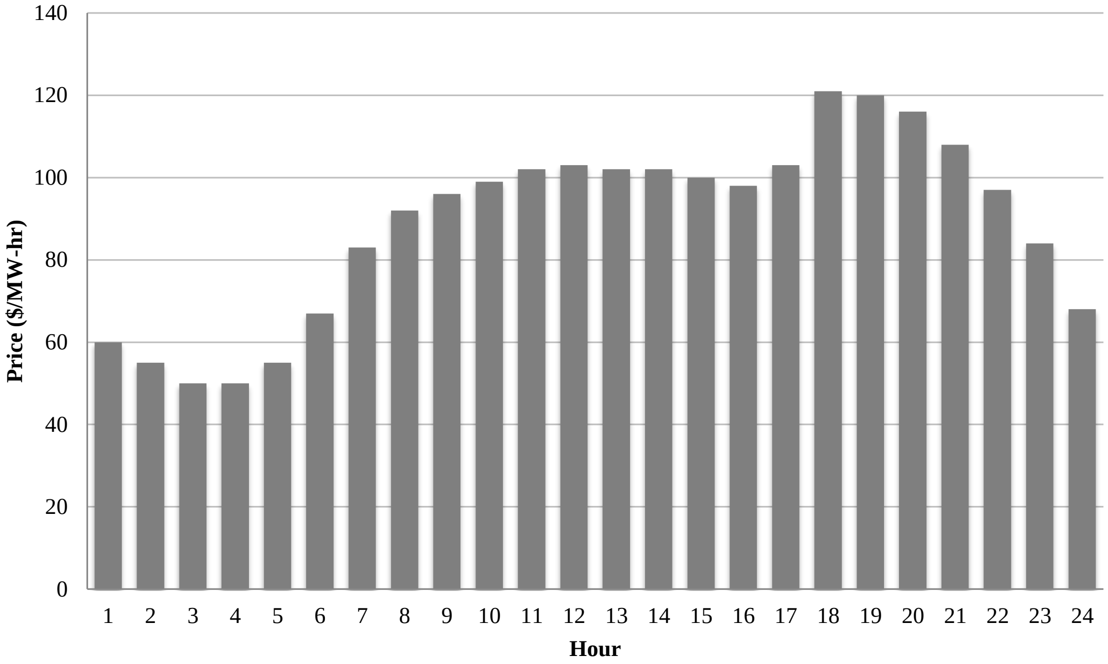
Source: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report.".

Exhibit 6 New Power Plants Built in the United States

Units	**2007**	**2008**	**2009**	**2010**	**2011**
U.S. Total	**314**	**433**	**382**	**418**	**521**
Coal	2	5	13	9	8
Petroleum	47	40	25	53	26
Natural Gas	63	94	76	106	89
Other Gases	--	--	--	2	--
Nuclear	--	--	--	--	--
Hydroelectric Conventional	0		8	7	26
Wind	2	7	120	69	92
Solar Thermal and Photovoltaic	48	101	20	61	171
Wood and Wood Derived Fuels	0		3	3	9
Geothermal	17	47	13	2	7
Other Biomass	3		104	105	92
Pumped Storage	4	3	--	--	--
Other	128	4	--	1	1

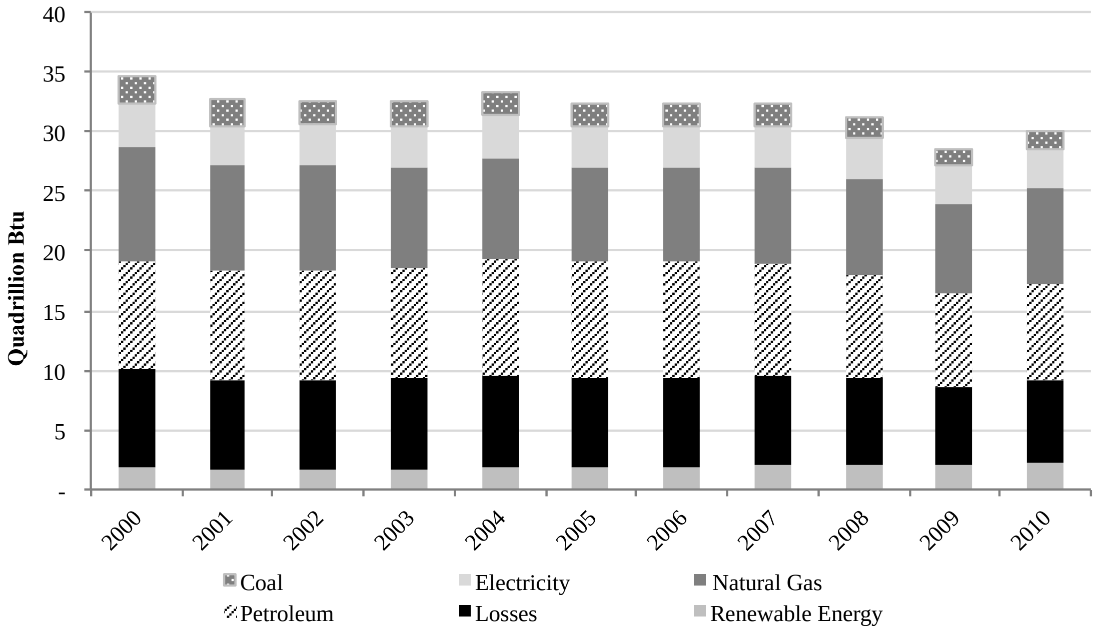
Source: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report.".

Exhibit 7 California Independent System Operator Grid Electricity Pricing for Nov. 30, 2011



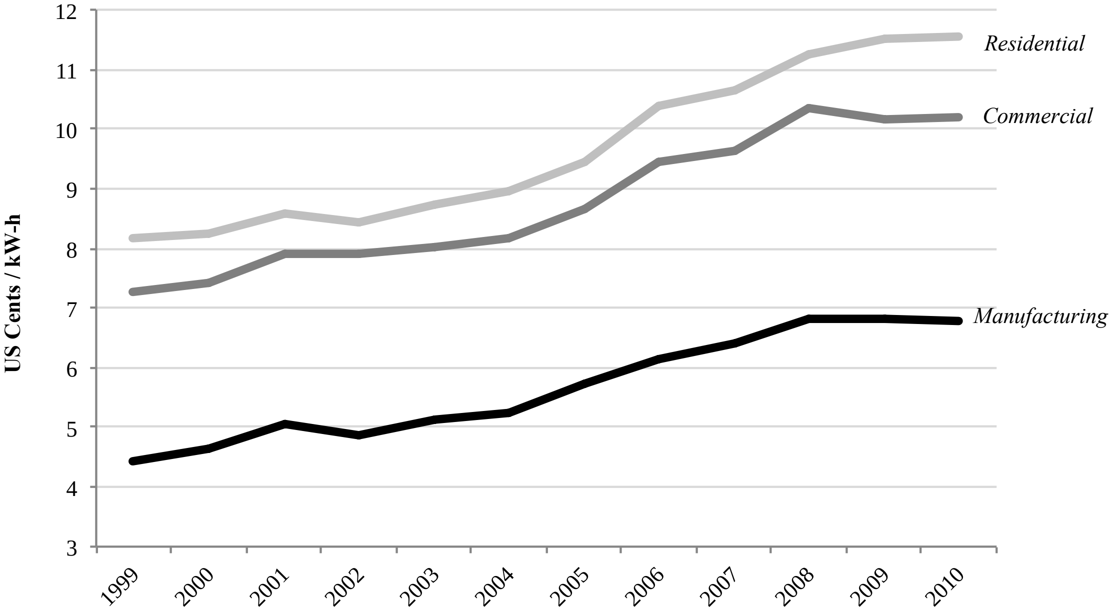
Source: U.S. Federal Energy Regulatory Commission.

Exhibit 8 U.S. Industrial Sector Total Energy Consumption Estimates by Major Source



Source: U.S. Energy Information Administration Annual Energy Review, Table 2.1d (all DOE material reproduced based on stated fair use policy: http://energy.gov/about-us/web-policies).

Exhibit 9 Average U.S. Electricity Retail Rates by Sector



Source: U.S. Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

References

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[i] CSIS. *Defense Contract Trends: U.S. Department of Defense Contract Spending and the Supporting Industrial Base*, May 2011. http://csis.org/files/publication/110506_CSIS_Defense_Contract_Trends-sm2.pdf.
[ii] Ibid.
[iii] Platts UDI World Electric Power Plants Database (September 2010).