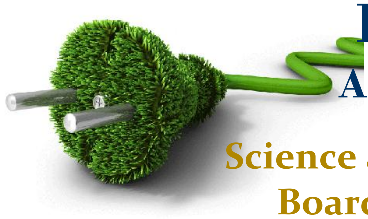
MEETING SUMMARY



ENERGY SUSTAINABILITY
A FOCUS ON WASTE HEAT RECOVERY

Science and Technology for Sustainability Program
Board on Energy and Environmental Systems
November 29, 2011

The industrial sector accounts for 30 percent of the total energy consumed in the United States, with much of that energy being lost as waste heat – heat generated from a process by way of fuel combustion or chemical reaction that is not reused for useful or economical purposes. Although waste heat recovery systems are frequently implemented, there continues to be a need and additional potential for their use[1]. Different systems are used to recover waste heat, depending on the type of industry generating the heat and the nature of the waste stream. Commonly used systems include heat exchangers, which transfer heat between gases or liquids; load preheating, which transfers the heat to the load entering furnaces; power generation, which uses waste heat to generate mechanical power or electricity; and low temperature technologies, which use waste heat with a heat pump to heat or cool facilities. The method selected depends on the end use of the recovered heat, as well as the temperature, phase, and chemical composition of the waste stream.

On November 29, 2011, the National Research Council's (NRC) Science and Technology for Sustainability Program (STS), in collaboration with the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems (BEES), convened a meeting of research leaders and technical experts in private industry as well as representatives from government and academia to discuss ways to recover waste heat and how it might contribute to energy sustainability. The meeting's purpose was to foster a focused discussion on the following topics:

- Opportunities to increase the use of waste heat;
- The technical, economic, and regulatory barriers in the U.S. to expanded implementation of waste heat programs, and ways these barriers can be reduced; and
- The role of federal agencies in supporting these programs.

[1] National Research Council. 2009. America's Energy Future: Technology and Transformation. Washington, DC. The National Academy Press.

Several overarching themes emerged from the participants' discussion at the meeting:

- Giving proper incentives, both internally in terms of clear productivity goals, and externally with appropriate credits for waste heat recovery
- Focusing on the big picture to find the major opportunities for energy efficiency within an industry instead of focusing on small energy losses
- Within an industry, focusing on optimizing the system at multiple scales, including optimizing use of energy, which is the energy potential of the waste stream
- Taking a regional perspective when managing energy demand, as there are major regional differences in available energy sources and prices
- Examining the U.S. energy infrastructure as a complex system and treating it from both a BTU (British Thermal Unit) perspective and an energy perspective
- Training and recruiting an incoming workforce with specialized skills for today's technology and new technology in the future

Ellen Williams, Chief Scientist at BP Inc., stated that world energy demand is clearly going to increase dramatically – by at least 25 percent in the next 20 years and perhaps 50 percent in the next 40 years – and that one of the key ways the world is going to meet its energy demand is by energy conservation. For big companies like BP, energy conservation in its activities and operations is very important; paying attention to energy conservation in the outside world must be part of the company's strategic future as well.

Mark Gilbertson, Deputy Assistant Secretary for Engineering and Technology in the Office of Environmental Management at the Department of Energy (DOE), stated that the DOE has about 127,000 people, manages over 2 million acres of property, and has 18,000 facilities, making it the second largest energy user in the federal government next to the Department of Defense.

Part of DOE's challenge is to move forward with trying to decommission aging infrastructure at older facilities, while at the same time supporting a long-term nuclear and hazardous waste clean-up program.

According to Gilbertson, DOE is also trying to work within the same constraints that private companies have and needs to take advantage of assets available to meet its goals for energy use at DOE facilities.

When looking forward at the need to meet energy demand and looking across programs at a site, across federal entities in a location, or across a region, different solutions become apparent, Gilbertson stressed. For example, hydro, nuclear, and wind power could be merged at a treatment site in Richland, Washington, because the region is naturally rich in water and wind resources. It is necessary to build these regional energy dynamics into national energy policy, he added. Gilbertson also emphasized the importance of public-private partnerships in furthering energy policy, and reiterated the importance of looking at these issues at different scales. Opportunities that might or might not exist on a small scale are different on a larger scale, changing the equation and economics.

Representatives from the corporate sector gave their impressions of energy efficiency as a sustainable energy practice. Tom Casten, Chairman of Recycled Energy Development, discussed opportunities and challenges associated with incorporating waste heat recovery systems. One challenge is that often the exergy – the energy potential of the waste stream to perform work on a system, such as driving turbines to produce electricity – is lost before it can be captured.[2] For example, an exhaust stream from making lime might be captured, but only after it has passed through pollution-control devices to trap particulates; this results in a significant drop in the stream's temperature and a loss of exergy. One area still to be explored, Casten said, is taking advantage of pressure drops along electric transmission lines, such as natural gas pipelines or steam lines. This is not technically waste heat, he added, although a little heat is taken out; mainly

[2] For an overview of how energy and exergy are related, please see: Lior, N. and N. Zhang. 2007. Energy, exergy, and Second Law performance criteria. Energy (32): 281-296.

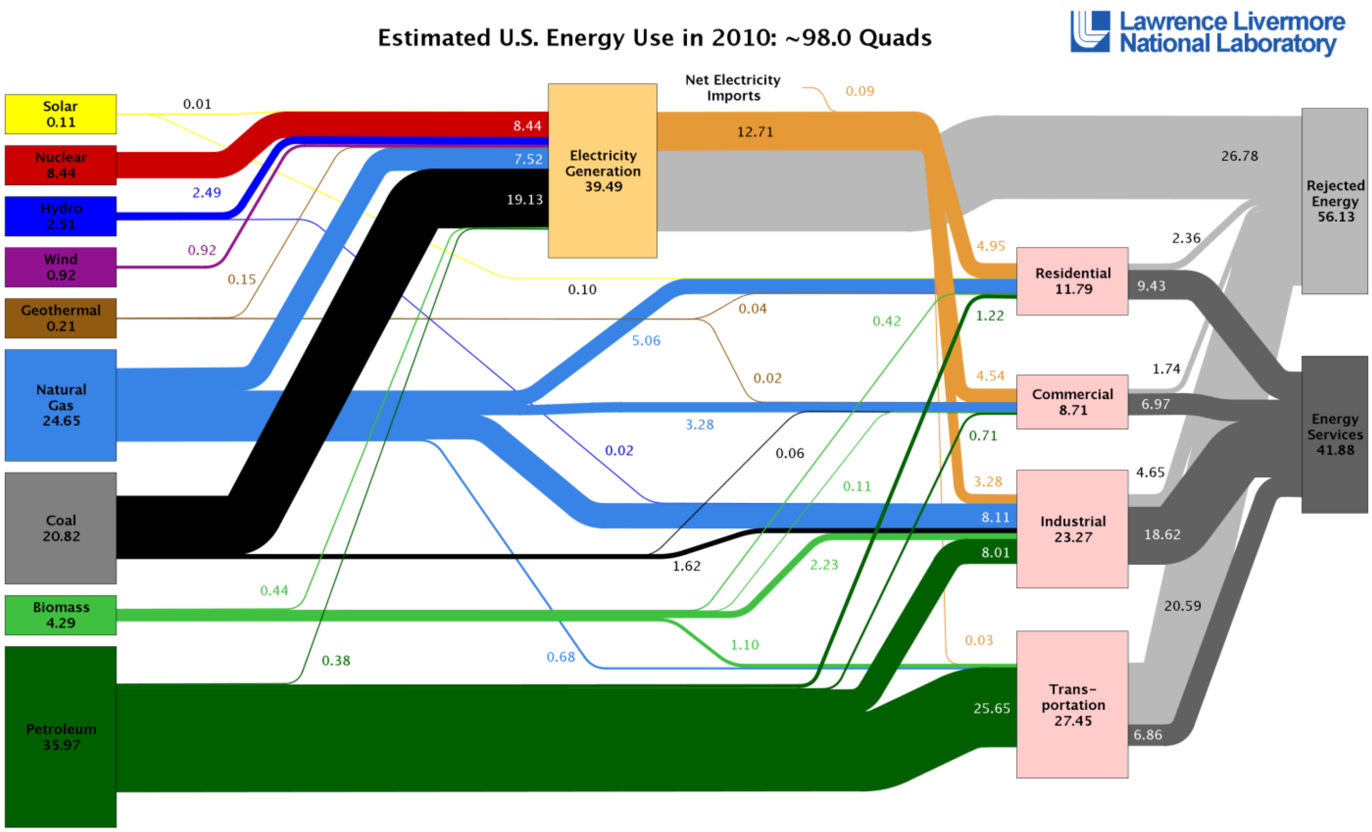


FIGURE 1 Estimated energy use in 2010. This energy flow chart shows the relative size of primary energy resources and end uses in the United States, with fuels compared on a common energy unit basis. SOURCE: LLNL 2011.

it is a pressure drop, and there are probably millions of applications in the United States where you could put a back-pressure turbine next to a pressure-reducing valve to capture this energy.

Casten noted that the DOE's well-known flow chart of energy use in the United States underestimates how much potential there is for energy efficiency (Figure 1). This chart assumes that all electricity turns into useful work, but if electricity is sent to an incandescent light bulb, only two percent efficiency is achieved[3], he said. Furthermore, the chart suggests that there is not much opportunity for efficiency gains; however, Dr. Robert Ayres has gone through 100 years of data and calculated the potential to do work in all the energy that we burn, Casten explained.

Electricity conversion was about three percent efficient in 1900, climbed as high as 13 percent about 15 years ago, and has now dropped back to 12.5 percent. We know how to be more efficient; Japan, the UK, and Austria are all over 20 percent efficient. With no change in technology, but with combined heat and power and local generation, we could double the efficiency of the United States, said Casten.

Discussing how to implement waste heat recovery systems, Jeff Yigdall, Director of Engineering & International Business at PPG Energy & Sustainability, stated that it is important to make energy part of the company culture, and that linking goals implementable on the factory floor to production can help overcome some of the barriers to implementation. Cutting down on energy cuts down on costs, and setting goals that are relevant to the manufacturing organization will help drive implementation, he said. While many statistics out there are good for external corporate reporting, he added, from a manufacturing standpoint you need to convert to units of energy per net ton of product to make it relevant to the people responsible for

[3] National Research Council. 2008. What you Need to Know About Energy. Washington, DC. The National Academy Press.

manufacturing, in order to justify it financially and drive implementation. Increasing output and having a return on the investment of only one or two years helps, he added. With limited capital distribution, it is hard to justify an investment with an eight-year payback.

Another important consideration is the stability of the manufacturing process, Yigdall noted. If there is a disruption in the system that slows or stops production, this can quickly cost as much as the expected energy savings. He gave an example of a float glass line, a typical line used in glass making, which may operate with an energy input of about 150 million BTUs an hour. About 40 million of those 150 million BTUs will ultimately be released via a stack or through other losses in the system. Using current technologies, such as a boiler, to recover this waste heat could generate two megawatts of electricity per year; however, when a boiler is installed, so are many controls and bypasses, safety devices, and systems to assure process stability because the primary mission is to make glass. Production people are not credited for producing electricity, and if the glass comes out poorly, that reflects poorly on production.
All of the extra systems to assure process safety and reliability and maintain glass quality ramps the cost of the system up to about $8 million or more. Producing two megawatts would generate a savings of about $1.4 million, which relative to $8 million dollars is an estimated six- or seven-year payback period. This is important to consider when units within companies are competing for limited capital distribution, he added. For example, this option needs to be competitive with the purchase of a new machine, which will better serve a customer and has only a one- or two-year payback period.
Yigdall concluded that there need to be proper incentives for waste heat recovery – both internally in terms of goals on productivity, and externally so that an organization gets appropriate credit for contributing a new source of energy. If this happens, then the organization has incentive to keep investing in these systems. All of this needs to be integrated into the organizational culture so that it is part of the primary job and work ethic, as opposed to an overlay on people who are already overloaded.
Pollution-control devices can be a barrier to capturing the waste stream, noted Casten and Yigdall. One example given was a unit being developed to meet requirements for controlling nitrogen oxide emissions (NOx). The catalyst in the selective catalytic reduction (SCR) unit requires 550-600 degrees Fahrenheit to operate – a requirement that inhibits whatever waste heat recovery one might do, because the stream must be held at 600 degrees F before it goes through the catalyst. It is less practical to capture the heat after the SCR because it is at a lower temperature, Yigdall noted. He also expanded on how the process of recovering heat exhaust can ruin a heat exchanger, and that no one has yet designed a system that can integrate capturing heat with addressing the contaminants in the exhaust stream. He noted that those contaminants pulled from a stream could also potentially be recycled back into the process, which would present a tremendous benefit; however, having a design that integrates recovering waste heat and trapping pollutants is needed.

Good technologies already exist for waste heat recovery but often are not used, said Thomas Mort, Global Program Manager for Energy Efficiency at Archer Daniels Midland Company. One strategy he employs is to find best practices and replicate them across many plants. He noted that it is important to look at the big picture and to focus on the biggest opportunities for energy efficiency rather than on small energy losses. It is necessary to look at how the cogeneration plants are running, what steam is going out, how a row of 24,000 horsepower air compressors are distributed, and how the parts are working together, he said. It would be the same thing, he added, if we stood back and looked at the United States to determine the biggest opportunities for energy efficiency.

Mort also discussed how energy loads in factories across the United States dramatically increase in the winter because of ambient heating requirements. Much of the heat is wasted and could be recovered for re-use in what he refers to as “people air.” For example, instead of letting cold air in at dock doors, where people tend to put in extra heaters, cold air can be blown down from the ceiling, which stops the ceiling exhaust and pressurizes the factory; in a sense, cold air is used to heat the factory. A pilot project was done at a spark plug factory in Columbus, Ohio; five tubes were installed to blow cold air into the factory, a step that warmed the factory. This approach, which did not require new technology, allowed the plant to shut down its two large boilers – which had been running since 1952 – and avoid running them for the past two years. This design was common in German factories in the 1930s, but it was forgotten as gas became cheaper.

There are other challenges, as discussed by Craig Walker, Director of Energy Systems at United Technologies Corporation. He discussed discontinuities in energy management, giving as example the tendency to focus too much on components rather than taking a step back and looking at the system as a whole before drilling into the details. Whether it is policy, energy flows or exergy optimization, too much focus is on trying to optimize the components, he stressed. In contrast, energy consumption in buildings has decreased substantially because they have been looked at as systems; energy efficiency has been improved by 50%, as opposed to incremental gains of only one or two percent with components.

To make major gains, Walker added, we need to step back and look at the energy infrastructure in the United States as a system, treating it from both a BTU perspective and an exergy perspective. Then, at every step of the way – whether on policy or environmental standards – take the system view and talk about things that make the system better. It is also necessary, he added, to have the tools available and studies in place that can communicate the root cause and corrective action of those system-level discontinuities in such a way that policymakers can understand it. Although the concept of BTUs is fairly simple, the concept of exergy, system optimization and incorporating exergy, emissions, and BTU energy is much more complex. This often results in rules and decisions that are made on a component scale instead of at a system-optimization scale. Walker also raised the point that retrofitting energy systems in industry is very difficult, and that the industrial infrastructure in the United States is old. It is very difficult in the U.S. to design better plants and then implement those designs. New facilities are incorporating better, more efficient technologies, but these new facilities are often built overseas – for example, in India or China. Because of our "component" thinking, we are driving the best solutions to other places, he said. What is needed is to focus on system optimization at multiple scales that incorporate the idea of exergy optimization. It is not about the individual technologies, because 90% of the technology to achieve this exists, he stated; it's really about putting together better systems for the technologies we already have. In addition, Walker stated that we do not yet have well-validated, easy-to-use multi-level system-optimization design tools for our energy systems that look at exergy, or at the interplay between environmental issues and economics.

Michael Carroll, President of NRG Thermal LLC and Vice President of NRG Energy Inc., discussed some of the economics of waste heat recovery, the value of waste energy, and the need to evaluate projects on an economic basis. The economic viability of any project is tied to the price of fuel and the volatility of prices. Inês Azevedo, Executive Director of the Center for Climate and Energy Decision Making and Assistant Research Professor, Department of Engineering and Public Policy, Carnegie Mellon University, said that in a case study she worked on for a small hospital in the Pittsburgh area, the key factor determining the viability of the project was the price of natural gas. She added that one of the ideas explored was using a feed-in tariff, similar to what is done in some European countries. A feed-in tariff is a long-term contract price that eliminates shorter-term price changes, providing a greater degree of certainty about the expected return on investment. This would guarantee certain revenue for investors in combined heat and power, she noted.

Thomas Mort discussed some of the differences between the United States and Europe in terms of energy pricing and use. He noted that the price of energy to consumers is far higher in Europe because of its energy taxes. These high prices make many energy efficiency investments more attractive. Mort noted also the difference in development patterns and attitudes, in that people live in closer proximity and use more public transportation. In contrast, the U.S. is a very independent country and spread out; people want their own cars and their own ability to control temperatures.

Casten offered another perspective. He agreed that in Europe they tax energy, while in the United States energy is subsidized through policies such as depletion allowances, keeping prices low and reducing incentives to reduce use. The National Academies, he added, stated in a recent report that coal on average created $32 a megawatt of hidden costs and that the

worst coal plants created $120 a megawatt hour, but that taxpayers -- not the coal industry – pay these costs.[4] These hidden costs include the cost of pollution control and damage to public health. If coal prices included these hidden costs, he said, there would be incentives to reduce use.

There may be some sociological explanations of why the United States and Europe differ in their patterns of energy use, but it is really economics that make the difference, he concluded. When it costs a person $150 to fill up the tank, they will drive a different kind of car than when it costs $30. In response, Walker added that the economics in Europe have been driven by their tolerance to some of the social decisions they made, like taxing and feed-in tariffs, which would not be tolerated as much in the United States. He agreed that it is economics that drives these differences.

Carroll noted that when a third-party company or an energy company is making a large capital investment, the reality of the payback period can be intimidating. If the company is in an energy market that is unregulated, such as Texas or the Northeast, there often is no guarantee that the company will recover the cash to justify its investment. This concern has been alleviated in states – California, for example – that actually establish capacity payments for the locational value, he observed.

Another challenge discussed was that posed by third-party capital investments. As Mr. Carroll explained, oftentimes an industry is purchasing electricity from a third-party or thermal energy producer. Under the Generally Accepted Accounting Principles, that industry is required to carry that capital investment on their balance sheet even though the industry does not own it. Casten noted that accounting practices changed after the Enron scandal to prevent companies from under-representing risk.[5]

Yigdall added that it is not just the case with electricity, but that PPG Industries converted a line to total oxygen firing, which uses 20 percent less natural gas and has about 80 percent less NOx emissions. The oxygen plant was built and run by a third party, and the oxygen is purchased under a 15-year contract. The result is that approximately $20 million is added to their capital base. Yigdall suggested that a possible solution would be to classify that particular capital differently, which would still allow for addressing the perceived problem of corporations under representing their capital or under representing liability.

The certainty of a company's ability to recover its investment from a generation perspective is critical, Carroll pointed out. The loan guarantees provided by DOE have enabled a lot of large-scale solar projects in California, Nevada, New Mexico, and Arizona, he noted, adding that the continued development of these projects is limited by the funds available for loan guarantees and the fact that the mandated renewable portfolio standards adopted by some states have been met[6].
Carroll discussed the need for financial models that look specifically at the value of energy in a particular region of the country and try to determine whether or not combined heat and power, or other renewable energy, would be economically viable. There are differences in terms of what makes sense economically, both

[4] National Research Council. 2010. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. Washington, DC. The National Academies Press.

[5] These changes refer to the Sarbanes-Oxley Act, which was the federal response to corporate accounting scandals at Enron, Tyco, and Worldcom in the early 2000s . This act, which became law in 2002, addresses complex and off-balance-sheet accounting practices for publicly traded companies through information disclosure. Companies traditionally completed clean energy installations through off-balance-sheet financing and now have to finance these projects in competition with other costly measures.

[6] Currently, there are 14 states that qualify CHP in their energy portfolio standards. See Brown, M.A., Jackson, R., Cox, M., Cortes, R., Deitchman, B., and M. Lapsa. 2011. Making Industry Part of the Climate Solution: Policy Options to Promote Energy Efficiency. Oak Ridge National Laboratory, ORNL/TM-2010/78, May, 275 pp.

on a regional basis and on an industrial basis, because industries have different energy requirements. In a broad swath of the middle part of our country, nuclear and coal plants exist and dominate the market, keeping energy costs low; combined heat and power systems will not be competitive there, he noted. However, such systems will be competitive in the Northeast, Florida, Louisiana, Texas and California, where energy costs are high and there are major opportunities to improve the efficiency of power generation.

Another challenge discussed by the participants is current environmental regulations, which do not consider energy efficiency as part of their regulatory mechanism. Mort elaborated with an example using a lump of coal. If a lump of coal is burned completely until it is all powder, there would be a certain amount of emissions, he explained. If a utility company burned that lump of coal, only 30 percent of the energy would be available as useful energy such as electricity. In contrast, a cogeneration plant burning the same amount of coal would have 70 percent of the energy available as useful energy. The penalty on cogeneration plants, is that they have the same emission constraints as the utility company, he said; there are no credits for extracting more energy out of the same amount of coal. Cogeneration plants are not able to compete with utility companies, and people running these plants are starting to consider closing them, even though they are almost twice as efficient. Permitting should be based on the amount of useful energy going out and not on the amount of coal coming in, he suggested[7].

Carroll continued that it is common to have a grandfathered permit and it not be clear whether or not making improvements would be considered a major modification to the facility; if so, this would require costly new permits. Casten offered an alternate paradigm, saying that industry could receive an allowance based on units of output; there would be one allowance for electricity and one for thermal. This would apply only to fixed sources, which account for two-thirds of the pollution, he said. Once the rules are set, continuous emissions monitoring would need to be installed by a certain date and meet the protocols prescribed by EPA. Industry would report the right number of allowances and pay for hidden costs. There would be some mistakes, he added, but if industry can address emissions in the way they want to, then even though it might not be perfect, he added, it would be much better than the current permitting system.

Carroll also talked about the importance of recognizing workforce needs. Forty percent of the workers at his company are eligible for retirement, which will result in a shortage of qualified people to operate the plants in the future. This raises issues such as how to train a workforce, what local resources are available in terms of trade schools or universities, and how to form partnerships with them. Right now, he added, there is no coherent approach to training the new workforce and ensuring that they recognize the value of energy sustainability.

[7] For more on permitting and regulations, see Brown, M.A. and S. Chandler, 2008. Governing Confusion: How Statutes, Fiscal Policy, and Regulations Impede Clean Energy Technologies. Stanford Law and Policy Review (19)3: 472-509.

Planning Committee: Ines Azevedo**,** Center for Climate and Energy Decision Making, Carnegie Mellon University; Steven Koonin, Former Under Secretary for Science, U.S. Department of Energy; Ellen Williams, Chief Scientist, BP, Inc.

DISCLAIMER: This meeting summary has been prepared by Dominic Brose, editor, as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the National Academies.

The summary was reviewed in draft form by Marilyn A. Brown, Georgia Institute of Technology to ensure that it meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

About Science and Technology for Sustainability (STS) Program

The National Academies' Science and Technology for Sustainability Program (STS) in the division of Policy and Global Affairs was established to encourage the use of science and technology to achieve long-term sustainable development. The goal of the STS program is to contribute to sustainable improvements in human well-being by creating and strengthening the strategic connections between scientific research, technological development, and decision-making. The program concentrates on activities that are cross-cutting in nature and require expertise from multiple disciplines; important both in the United States and internationally; and effectively addressed via cooperation among multiples sectors, including academia, government, industry, and non-governmental organizations (NGOs).

For more information about STS visit our web site at http://sustainability.nationalacademies.org
500 Fifth Street, N.W., Washington, D.C. 20001
sustainability@nas.edu