Energy Goes with the Flow

LAWRENCE Livermore produced the first diagrams illustrating U.S. energy use in the mid-1970s. Portraying U.S. energy resources and their ultimate use, these diagrams, called energy flow charts, help scientists, analysts, and other decision makers to visualize the complex interrelationships involved in powering the nation. The charts continue to provide value, drawing widespread attention and praise from such organizations as the National Academy of Sciences and the President's Council of Advisors on Science and Technology.

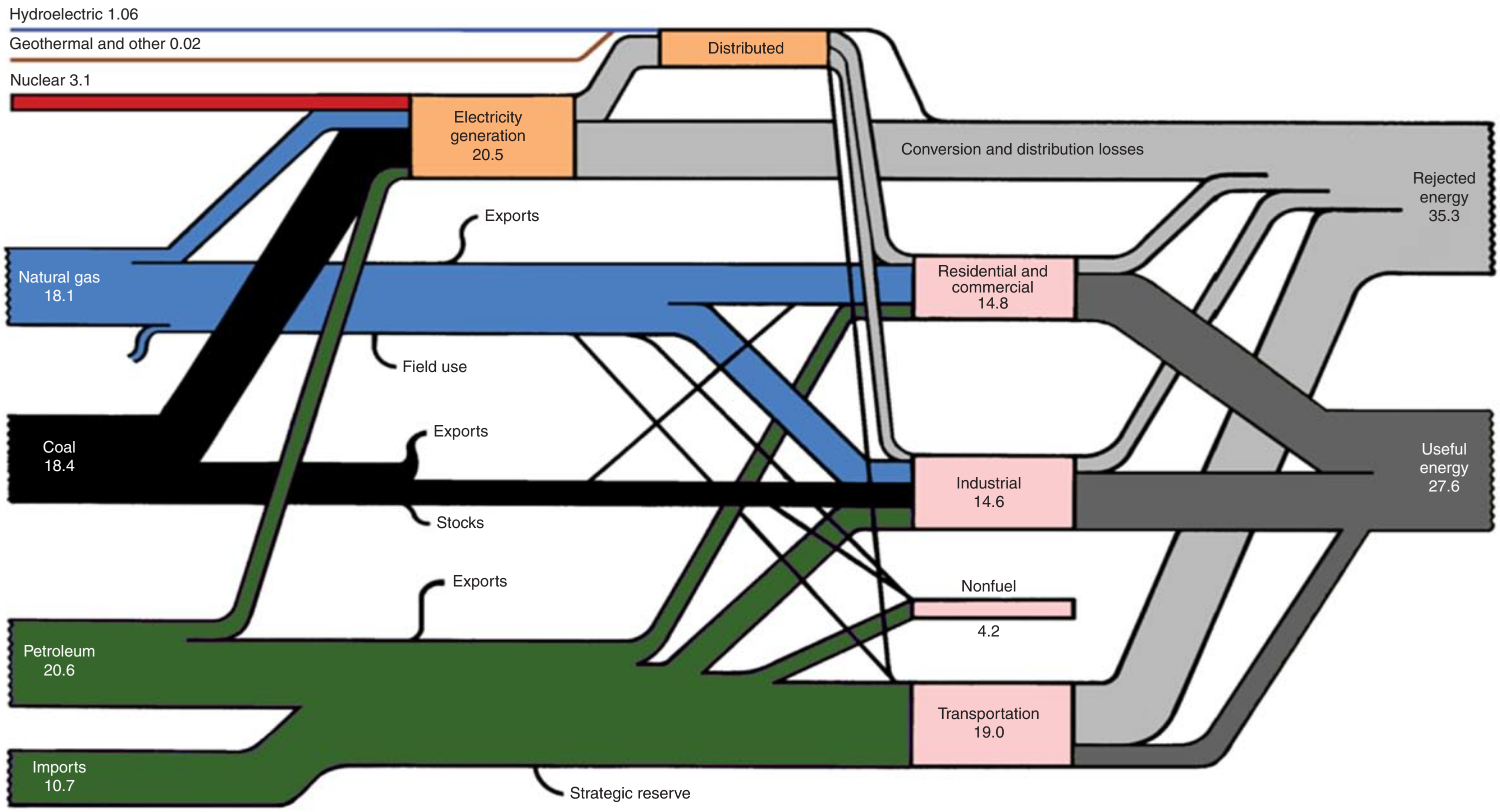
Nalu Kaahaaina, deputy project director for Energy and Environmental Security in the Global Security Principal Directorate, has overall responsibility for Livermore's development of the energy flow charts, and engineer A. J. Simon leads the analysis. The researchers, both previously lecturers at Stanford University, note that the Laboratory's work on the energy diagrams is one reason they chose to come to Livermore. "A huge community of experts is performing energy systems analysis," says Simon, "but Livermore is one of the few organizations that distills 'the big picture' into a concise visual representation." Because the Laboratory's staff includes a variety of experts working across disciplines, it is uniquely qualified to develop the charts.

A single energy flow chart for U.S. resources and their use represents vast quantities of data from the Department of Energy's Energy Information Administration (EIA). In 2007, for example, energy resources included solar, nuclear, hydroelectric, wind, geothermal, natural gas, coal, biomass, and petroleum. Fully 40 percent of the total resources expended produced electricity—to power hair dryers and coffee makers, run factory lines and agricultural irrigation systems, and keep the lights on. All nuclear energy and virtually all coal resources went toward electricity generation as well. The uses for natural gas, another major resource, were more varied. Petroleum, the largest single resource, representing almost 40 percent of total energy inputs, continued to be used primarily to fuel cars, planes, and other forms of transportation.

A Snapshot of Changing Technologies

Energy flow diagrams change over time as new technologies are developed and as priorities change. (See the figures on pp. 18–19.) Twenty-five years ago, the U.S. consumed 70 quadrillion British thermal units (or quads) of energy compared with 101.5 quads in 2007, an almost 50-percent increase. In 1982, a primary concern was whether energy sources were domestic or imported.

"Alternative" energy resources such as wind and solar did not figure into the 1982 diagram at all. Solar energy appears on the 2007 chart, but it is used almost exclusively by private homeowners. This detail reflects the expense of the technologies that collect solar radiation and transform it into electricity relative to the cost of systems that deliver other forms of energy. As a result, choosing solar energy as a power source is usually an individual decision.



The first energy flow diagrams such as this one from 1982 required a technical specialist to review data from the Department of Energy's Energy Information Administration and a graphics designer to produce the image.

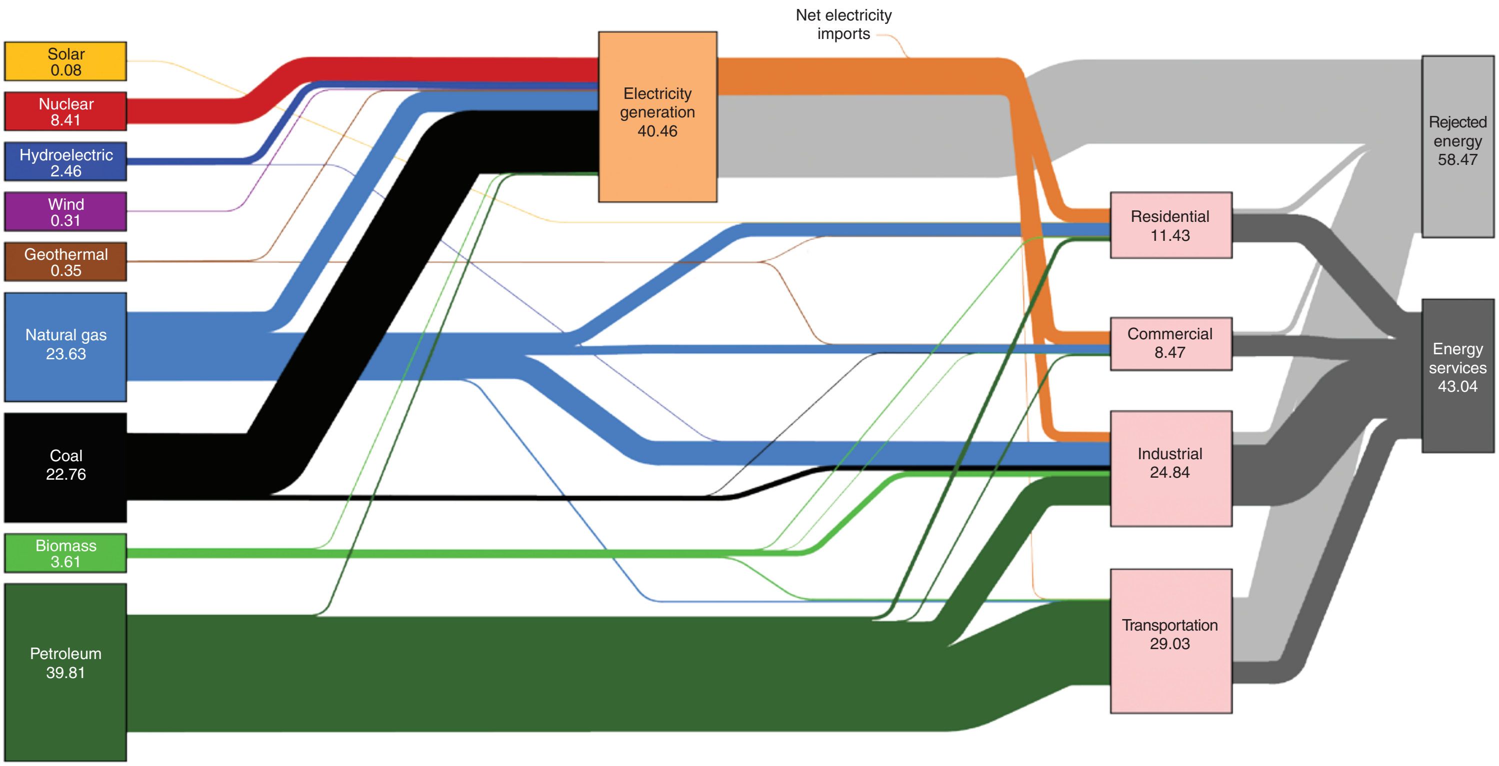
Considerable research and development is under way to make solar and other forms of energy less expensive and more available to the public. In fact, the newest charts, which are available online at publicaffairs.llnl.gov/news/energy/energy.html, show that this effort is producing results. Not only did Americans reduce their energy usage from 101.5 quads in 2007 to 99.2 quads in 2008, but also more of that energy came from renewable resources. Nuclear power continues to make small gains through increased reliability. Thus, if current clean energy policies are successful, the flow chart for U.S. energy sources and their use will look very different by 2032.

Capturing the Big Picture

An integrated approach to energy resources and how they are consumed must consider all scales across all disciplines. "For example," says Kaahaaina, "energy processes for a vehicle can be examined from the individual chemical reactions in a combustion engine to the mechanics of the drive train to the national demand for fuel. These problems affect engineers, physicists, and economists, all of whom speak different technical languages. By better representing energy networks, the Laboratory can help bridge these technical communities."

Simon has already harnessed Laboratory expertise in algorithm design, physics-based modeling, and system analysis to produce increasingly refined assessments of U.S. energy resources and consumption. "Originally, producing these charts required a member of our technical staff to review an EIA report and a graphics designer to produce the image," says Simon. "Now, we automate the routine data synthesis with a software engine that renders the image." Instead of having a person read through a 400-page report, the analysis tool calculates a set of intermediates, ultimately generating approximately 30 energy statistics. This greatly speeds the process—which once took a week—enabling the analyst to now spend a few hours interpreting the results after only a few seconds of processing.

"The relative simplicity of the diagrams sometimes belies the initial effort to build them," says Simon. "Ultimately, this effort is about taking complex systems and sharing them with broader audiences. The less daunting the information is, the more impact it can have. Simplicity is a compliment."



Comparing this 2007 energy flow chart with the 1982 diagram on p. 18 highlights the massive increase in energy consumption during that 25-year period, the new resources in use today, and the changing concerns about the origin of energy resources. The 2008 chart (available online at publicaffairs.llnl.gov/news/energy/energy.html) shows that U.S. energy usage dropped from 101.5 quadrillion British thermal units, or quads, in 2007 to 99.2 quads in 2008.

The next logical step for Kaahaaina and Simon is to apply the science of informatics to the less structured data, particularly data gathered from otherwise distinct technical fields. Such a step would reduce the barriers to optimizing large systems. Energy informatics would combine Livermore's substantial computational capability with expertise in energy technology to organize and process data in ways that make it more accessible.

"Examining information across scales and disciplines requires quick access to the data at many levels," says Kaahaaina. "Our national figures offer a high-level view of what energy means. In reality, the national energy network comprises many layers of technology, from microscale chemical mechanisms to mesoscale devices and macroscale infrastructure. Addressing all of these scales comprehensively requires both dexterity of information and the array of technical disciplines needed to process that data sensibly."

Energy informatics will improve the methods available for visualizing these types of data. As a result, says Simon, "We will be better able to answer the questions we receive from other researchers, and we can develop more useful products for a variety of users." The team is currently searching for a sponsor to support an energy informatics program at the Laboratory.

For Livermore's mission-related work on energy and environmental security, the flow charts are an ideal tool to analyze not only energy but also carbon, water, and other relevant "networks." One chart portrays the estimated carbon dioxide emissions associated with all energy resources. Such analyses provide insights that simultaneously enable system optimization, for example, identifying underused resources or the need for better technology, and reveal cross-system couplings, such as carbon embedded in energy or water demand for electricity generation.

"I think of the energy flow charts as yet another example of 'thought leadership' at the Laboratory," says Kaahaaina. "The diagrams contain so much data, they can be used in many different ways by a variety of groups."

—Katie Walter

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