XI.11 Energy Informatics: Support for Decision Makers through Energy, Carbon and Water Analysis

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Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2011 Objectives

- Depict energy use at the state and international level.
- Depict water use at the state level.
- Depict carbon emissions at the state level.
- Increase the fidelity of conceptual energy depictions in the residential and transportation sectors.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior

(D) Feedstock Issues

(E) Unplanned Analyses

Contribution to Achievement Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 1:** Complete evaluation of the factors (geographic, resource availability, existing infrastructure) that most impact hydrogen fuel and vehicles. (3Q, 2005)
- **Milestone 5:** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- **Milestone 11:** Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness. (2Q 2015)

FY 2011 Accomplishments

- Produced an "atlas" of 51 state-level energy flowcharts (50 states plus Washington, D.C.) using automated analysis of the Energy Information Administration's (EIA) State Energy Data System (SEDS).
- Published an "atlas" of 51 state-level carbon flowcharts (50 states plus Washington, D.C.) by combining expert analysis of EIA's Greenhouse Gas reports with automated analysis of SEDS.
- Created an "atlas" of 52 state-level water flowcharts (50 states plus Puerto Rico and the Virgin Islands) using automated analysis of Unites States Geological Survey (USGS) water use and disposition data.
- Compiled an "atlas" of 136 national-level foreign country energy flowcharts using automated analysis of International Energy Agency data.

Introduction

Energy informatics is the combination of expert knowledge of the energy system with data-science tools and information technology. The products of an informatics program are methodologies, tools, visualizations and reports that enable analysts and decision makers to better understand the energy system at multiple scales.

The Fuel Cell Technologies Program has enabled stakeholders to visualize critical commodity flows at geographic scales relevant to decision-makers. These commodities include energy, carbon and water. Adoption of hydrogen fuel may alter the structure of the energy system, shift or reduce the emissions of carbon dioxide, and place new demands on water infrastructure. In previous years, LLNL has analyzed the quantitative impacts of hydrogen's potential impacts on local water systems. This year, through a campaign of energy informatics, we have provided qualitative (structural visualizations) and quantitative (energy statistics) descriptions of energy, carbon and water systems at multiple scales.

Approach

The energy flowcharts (EFCs) (http://flowcharts.llnl.gov) have long been recognized for their importance in visualizing energy and material flows in a way that highlights

resources, carriers, transformations and services. But, like a map of the interstate system, the published EFCs provide only a high-level view of the country's energy infrastructure. The usefulness of this top-down view is limited by the level of detail that can be conveyed in a single image.

In order to provide a more detailed view of energy, carbon and water systems to state-level and international-level decision-makers, we have applied software tools developed here at LLNL to produce visually informative graphics from analytical reductions of publicly available statistical data sets.

Results

Although example charts are included in this report, the reader is encouraged to download each of the "atlases" of flowcharts from http://flowcharts.llnl.gov.

Flowcharts were produced depicting energy at the state level. This collection includes all 50 U.S. states as well as the District of Columbia, for a total of 51 charts. As an example, Figure 1 shows the energy use in the state of California. Because this report does not permit full-page figures, the reader is encouraged to download the entire "atlas" of state-level flowcharts from http://flowcharts.llnl.gov. The report, entitled "Estimated State-Level Energy Flows in 2008," explains how the 30 megabyte SEDS data archive [1] is compressed to ~40 critical energy indicators for each state. In these figures, stakeholders at the state level can view their consumption of various energy resources, and visually compare the energy intensity of various economic sectors within their states. These charts also include information on net electricity imports/exports across state lines. There are significant differences between states. For example, it is well known that Texas is one of the states with the highest overall energy use, but the flowchart depicts that much of this energy is consumed by industry. It is also easy to see Hawaii's dependence on petroleum.

Flowcharts were produced depicting carbon emissions at the state level. This collection includes all 50 U.S. states as well as the District of Columbia, for a total of 51 charts. As an example, Figure 2 shows the carbon emissions in the state of California. Because this report does not permit full-page figures, the reader is encouraged to download the entire "atlas" of state-level flowcharts from http://flowcharts.llnl.gov. The report, entitled "Estimated Carbon Emissions in 2008: United States" explains how the 30 megabyte SEDS data archive [1] is compressed to ~40 critical energy indicators for each state and combined with EIA's greenhouse gas emissions data [2,3] to determine CO_2 flows. In these figures, stakeholders at the state level can view their CO_2 emissions, and visually compare the carbon intensity of various energy-related activities within their states. For example, from these charts, it is clear that California's CO_2 emissions are dominated by transportation, whereas Wyoming's and West Virginia's emissions are dominated by coal-fired electricity. A quick glance at the energy flowcharts for these two states shows that they are also major electricity exporters.

Flowcharts were produced depicting water use at the state level. This collection includes all 50 U.S. states as well

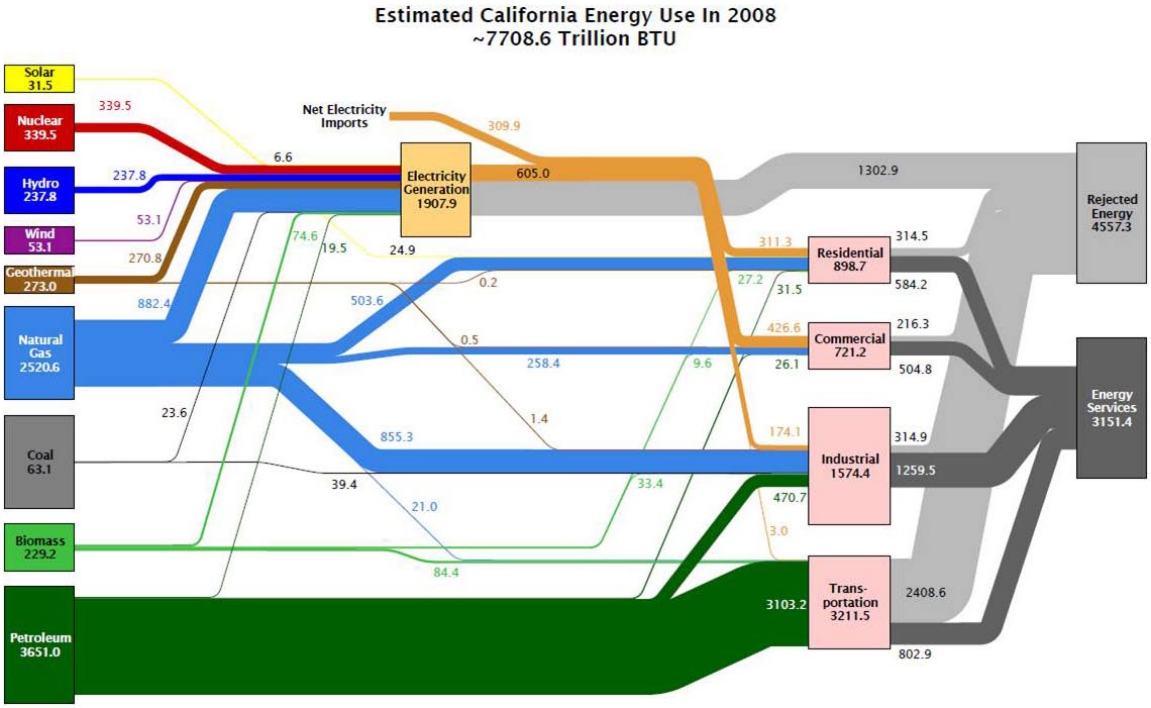

FIGURE 1. California Energy Flow in 2008

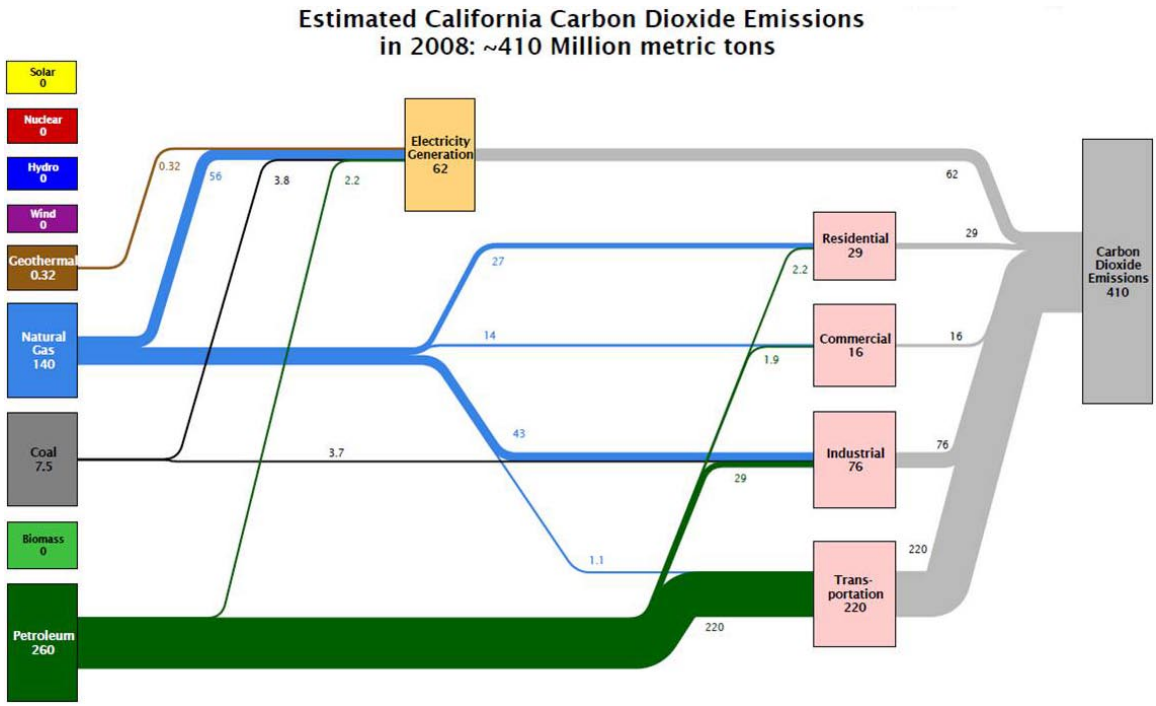

FIGURE 2. California Carbon Emissions in 2008

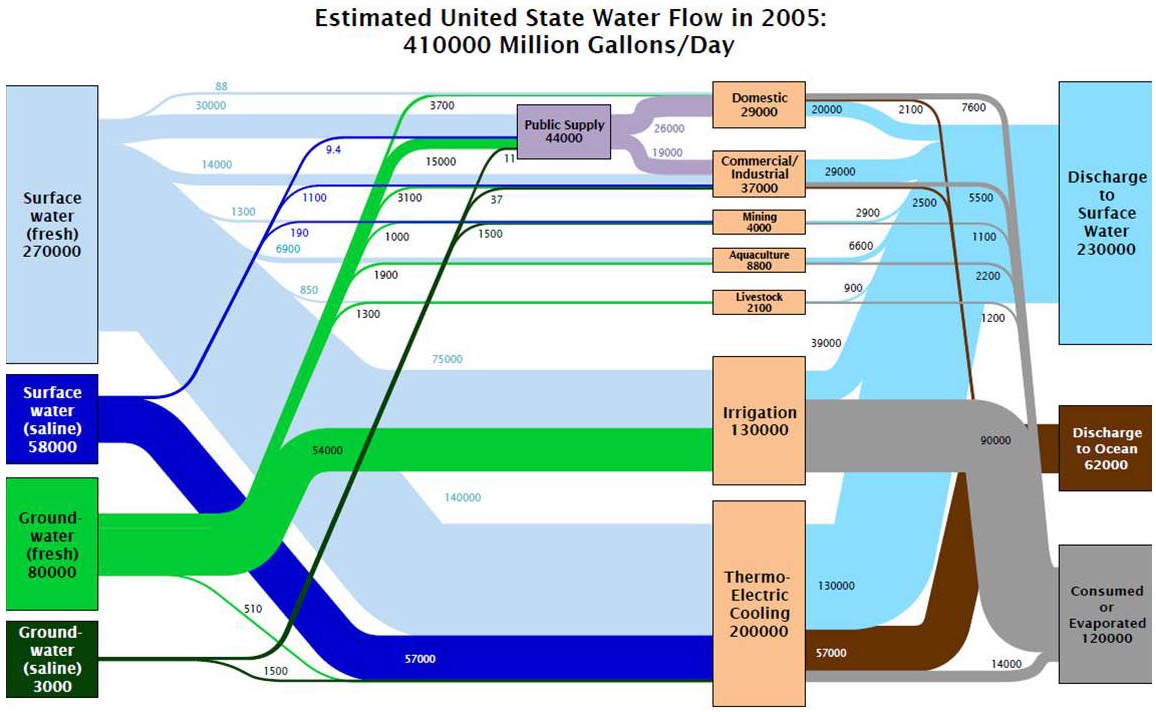

FIGURE 3. U.S. Water Flow in 2005

as the Puerto Rico and the Virgin Islands.. It also includes a composite national-level water flowchart for a total of fifty-three. As an example, Figure 3 shows the national-level water flowchart. Because this report does not permit full-page figures, the reader is encouraged to download the entire "atlas" of state-level flowcharts from http://flowcharts.llnl.gov. The report, entitled "Estimated Water Flows in 2005: United States" describes how the ~300,000 county-level water statistics compiled by the USGS [4] are reduced to ~40 critical water indicators for each state. These

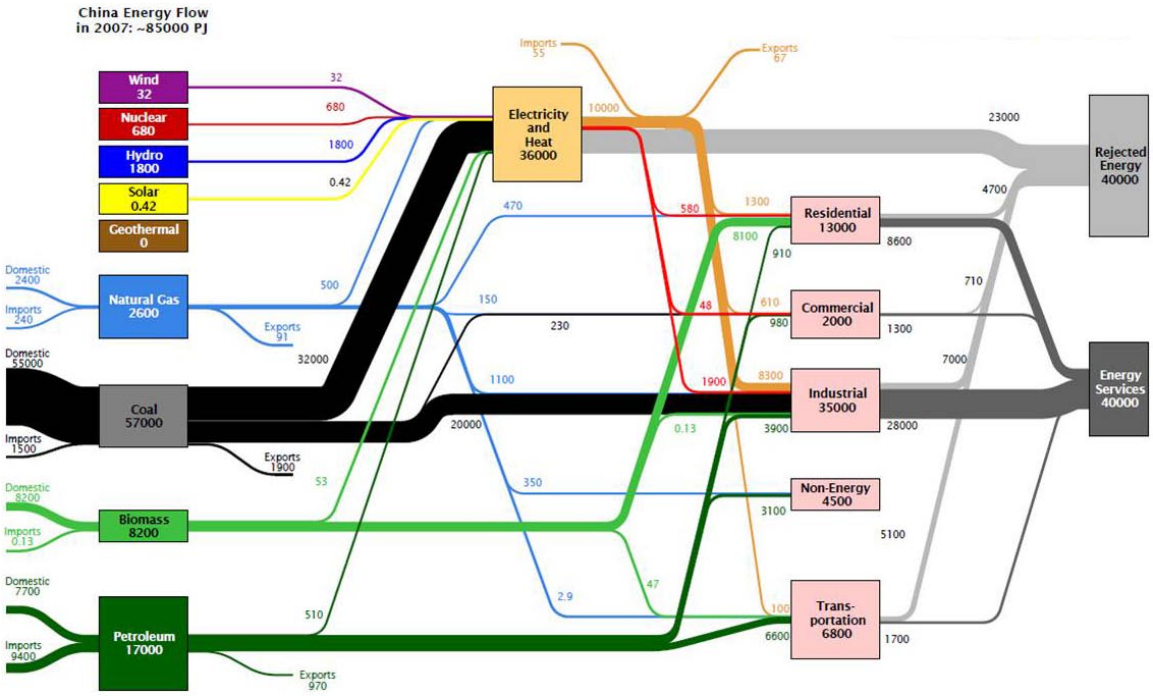

FIGURE 4. China Energy Use in 2007

figures allow a broad variety of stakeholders, including government, industrial, agricultural and environmental professionals, to quantitatively describe the structure of the water procurement, use and disposal systems. Of particular interest is the difference between western states and eastern states: managed water use in states such as Montana, New Mexico, Colorado and California tends to be dominated by irrigation, with power plant cooling as the only other water consumer at that magnitude. In the east, managed irrigation is significantly smaller due to more abundant rainfall.

One-hundred, thirty-six national-level energy flowcharts were produced depicting energy resources, use and disposition in foreign countries. This collection also includes a global-level aggregate energy flowchart for world energy use. As an example, Figure 4 shows the national-level energy flowchart for China. Because this report does not permit full-page figures, the reader is encouraged to download the entire "atlas" of state-level flowcharts from http://flowcharts.llnl.gov. The report, entitled "2007 Estimated International Energy Flows" describes how international energy data [5] are reduced from ~5,000 data points for each country to ~60 critical energy indicators. These figures enable visualizations of energy use patterns beyond the borders of the U.S., thereby giving stakeholders a quantitative and structural view of alternative energy infrastructures. Despite major differences between developed, transitional and developing economies, the resources, transformations and uses of energy as depicted are sufficient to capture all of the statistics. One major outlier is South Africa, whose coal liquefaction industry is large enough to warrant a separate transformation step.

Conclusions and Future Directions

Flowcharts, or "Sankey Diagrams" provide quantitative and qualitative information about flows of vital commodities within a defined geographical area or economic sector. As a result of this project, LLNL has produced flowcharts the three material flows most critical to the transformation of the energy economy.

- Decision makers now have access to a visual representation of state-level energy and carbon flows. Because environmental and technology regulations are often enforced at the state-level, these charts will empower the stakeholders closest to policy to better understand their energy use and environmental impact.
- Decision makers now have access to a visual representation of state-level water flows. Water is a fundamentally local commodity; water is used in such great quantity that the engineering of meaningful long-distance water conveyance is costly and therefore the rare exception. A quantitative and qualitative visual description of water supply, use and disposition at the state-level enables policy decisions at a geographic-scale comparable to that of many hydrologic basins.
- Decision makers now have access to a visual representation of national-level energy flows for most of the world's nations. Clearer intuition regarding foreign countries' energy use will enhance economic and security policymaking, as well as provide examples of alternative energy use patterns.

- Future directions of this research include visualizations of the details of energy use within the residential, transportation and industrial sectors. While we have demonstrated that flowcharts can be used to enable decision makers at finer geographic scales, we also intend to "zoom in" to finer structural details of the energy system.

FY 2011 Publications/Presentations

1. Simon, A.J. and Belles, R.D. "Estimated State-Level Energy Flows in 2008". LLNL-MI-410527. Available online at: https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2008/2008StateEnergy.pdf.

2. Smith, C.A., Simon, A.J. and Belles, R.D. "Estimated Carbon Dioxide Emissions in 2008: United States." LLNL-TR-480261. Available online at: https://flowcharts.llnl.gov/content/carbon/carbon_emissions_2008/2008StateCarbon.pdf.

3. Smith, C.A, Simon, A.J., and Belles, R.D. "Estimated Water Flows in 2005: Unites States." LLNL-TR-475772. Available online at: https://flowcharts.llnl.gov/content/water/water_flow_archive/2005USStateWater.pdf.

4. Smith, C.A., Simon, A.J. and Belles, R.D. "2007 Estimated International Energy Flows." LLNL-TR-473098. Available online at: https://flowcharts.llnl.gov/content/international/2007EnergyInternational.pdf.

5. Simon, A.J. and Smith, C.A. "Energy Informatics: Support for Decision Makers through Energy, Carbon and Water Analysis" Presented at DOE Hydrogen and Vehicle Technologies Annual Merit Review, Arlington, VA, May 10, 2011.

References

1. Energy Information Administration. State Energy Data System, 2008. Available online at: http://www.eia.doe.gov/states/_seds.html. DOE/EIA-0214(2008) June 2010.

2. Energy Information Administration. Annual Energy Review 2009. Available at: http://www.eia.gov/aer. DOE/EIA-0384(2009) August, 2010.

3. Energy Information Administration. U.S. Electric Power Industry Estimated Emissions by State. Available at: http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls DOE/EIA-767, EIA-906, EIA-920, and EIA-923. Revised January 4, 2011.

4. Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005. Available at: http://pubs.usgs.gov/circ/1344/ U.S. Geological Survey Circular 1344. Released October, 2009.

5. International Energy Agency. Extended World Energy Balances 2007. Available by subscription at http://data.iea.org August, 2010.