Energy Systems Integration

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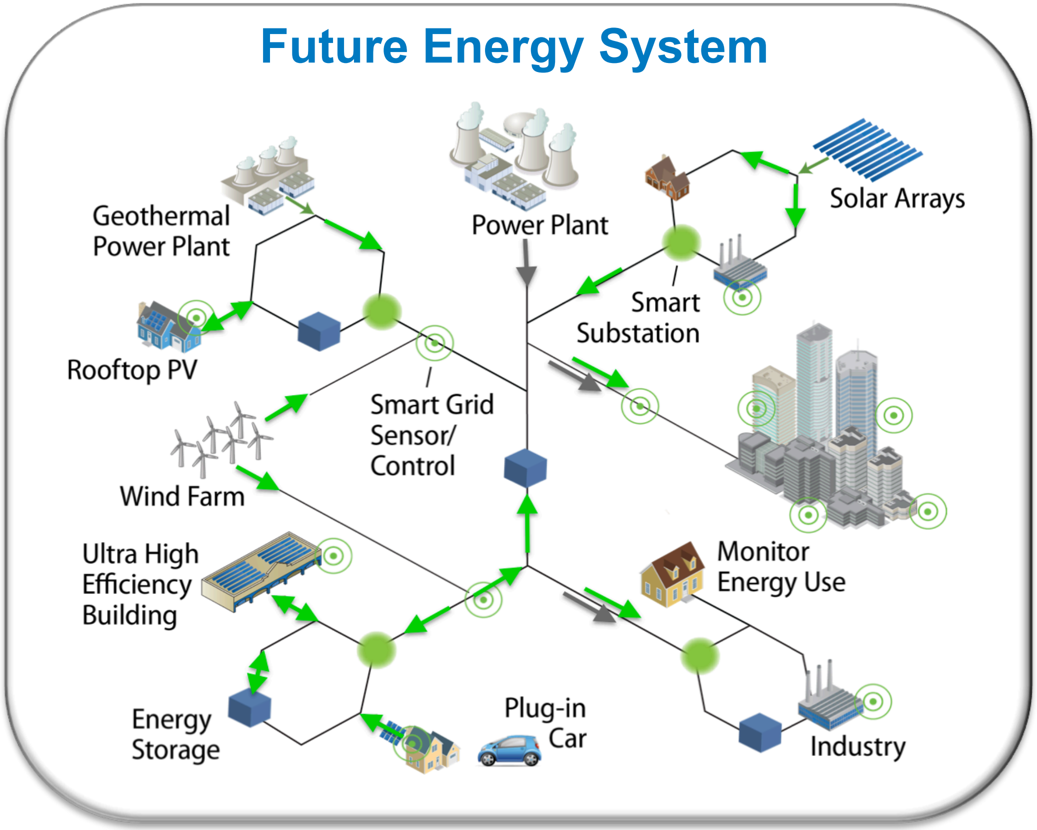
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

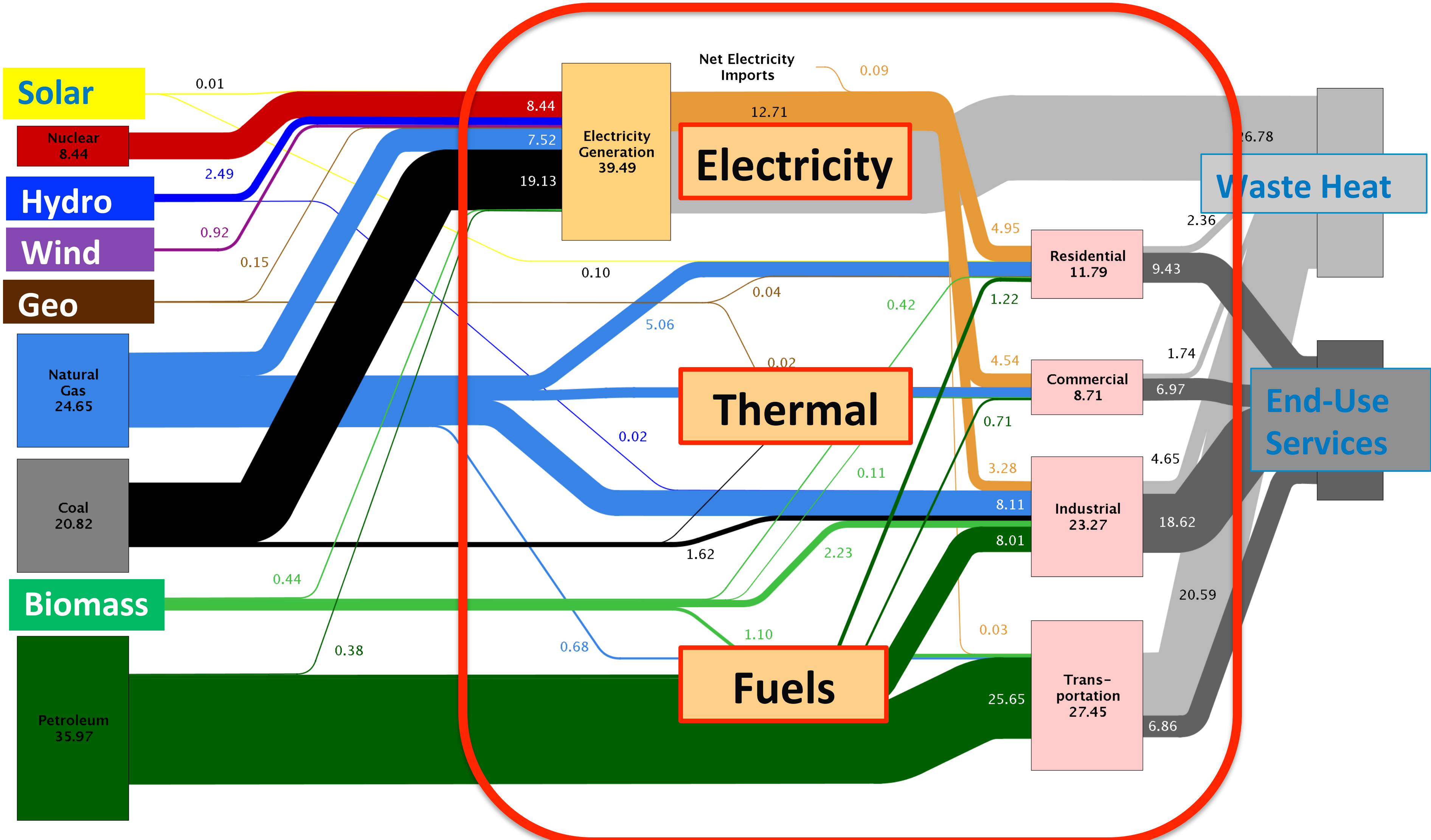
What is an Energy System?

- **Energy system =** a set of interacting or interdependent resources, infrastructures and individuals organized specifically for the production, delivery or consumption of energy

- **Examples:**
  - Buildings
  - Vehicles
  - Distribution feeders
  - Fueling stations
  - Communities
  - T&D grids
  - Pipeline networks

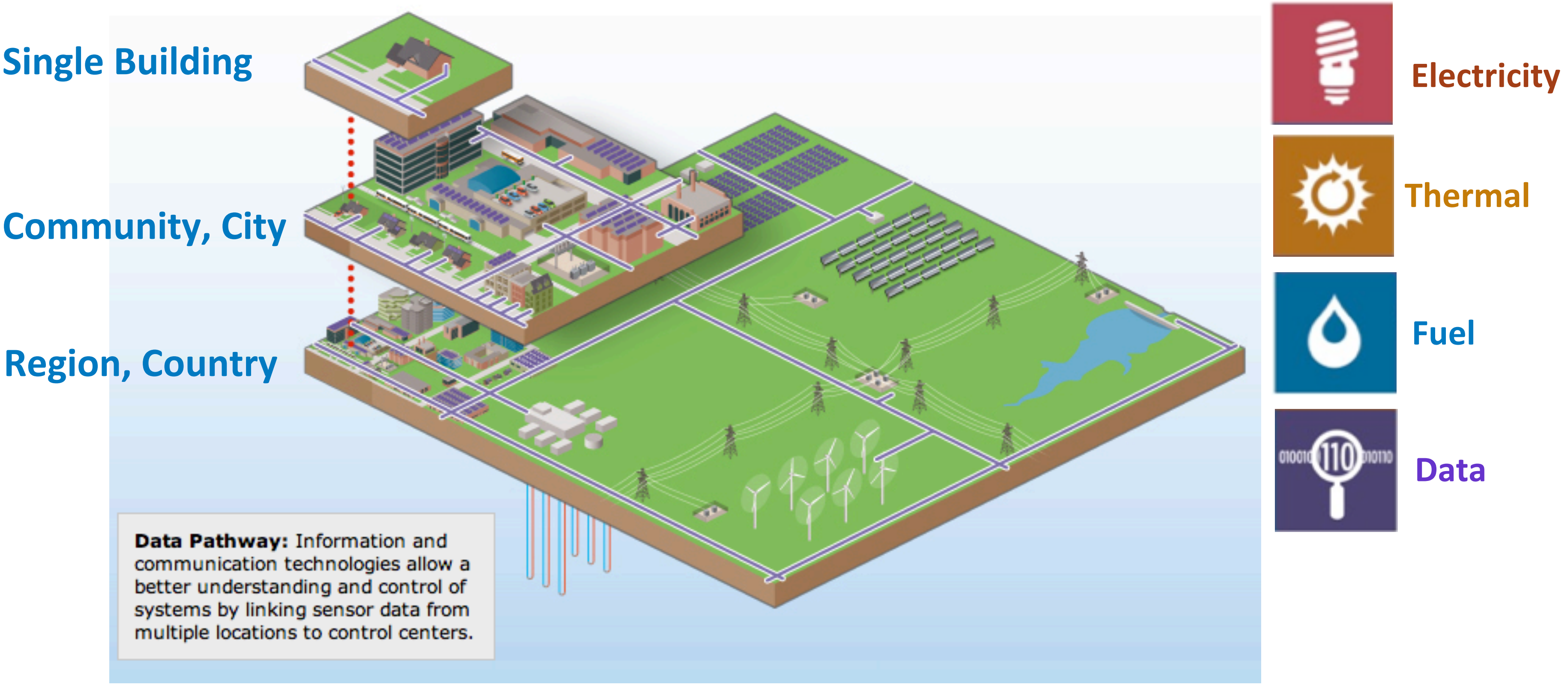


Energy System of the USA



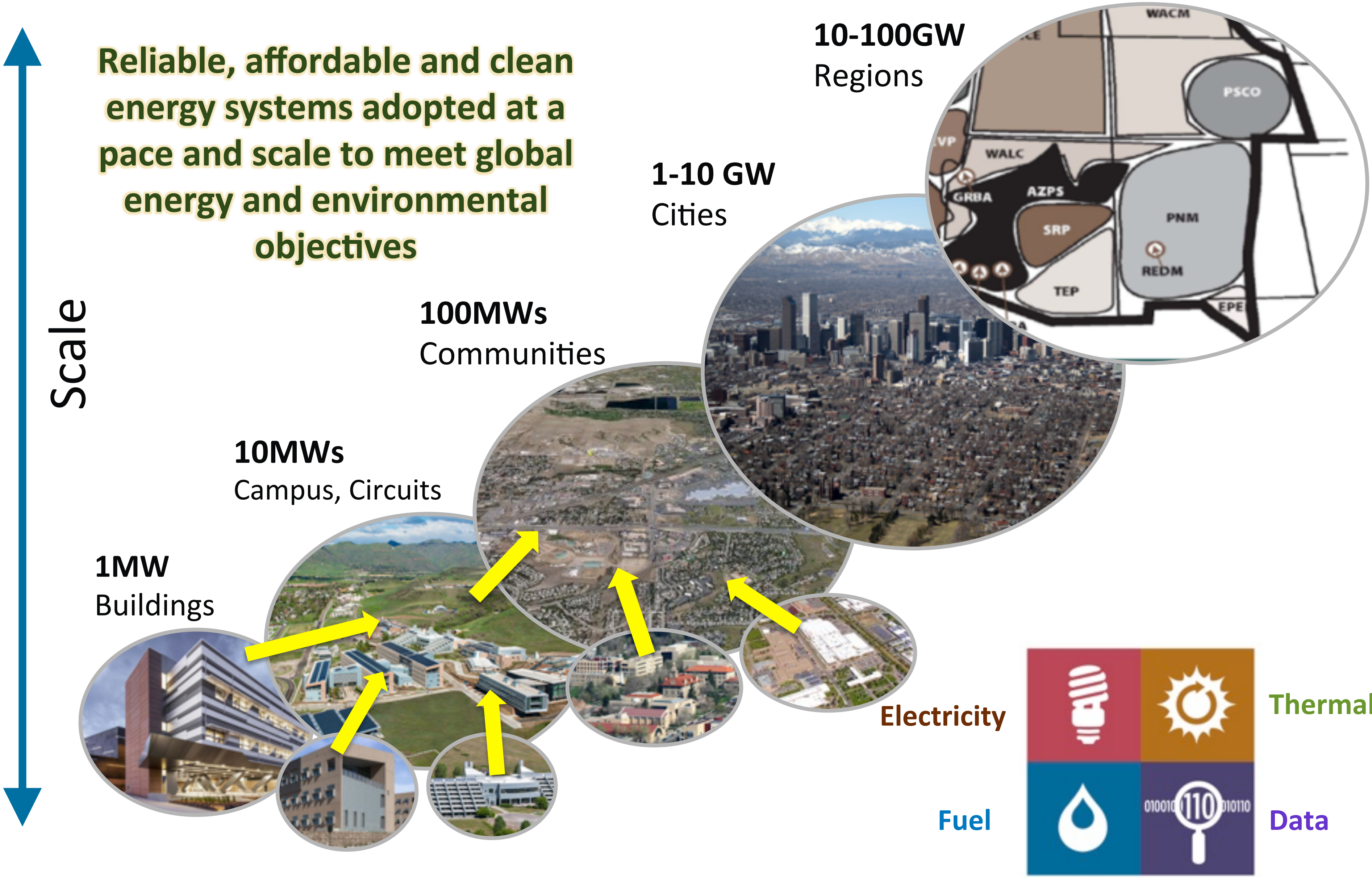
What is Energy System Integration?

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



ESI at all Scales

Reliable, affordable and clean energy systems adopted at a pace and scale to meet global energy and environmental objectives



ESI Value Proposition

- **Improve operational efficiency –** reduce overall system losses by coupling energy systems and making best use of installed generation, storage, and load resources. Incorporating heat, power, and highly efficient devices can increase overall efficiency and conserve en[...] technologies

- **Improve energy security -** Increas[...] intensity, and encourage adoption [...] g for seamless integration of variable re[...] operations of RE and non-RE sour[...]

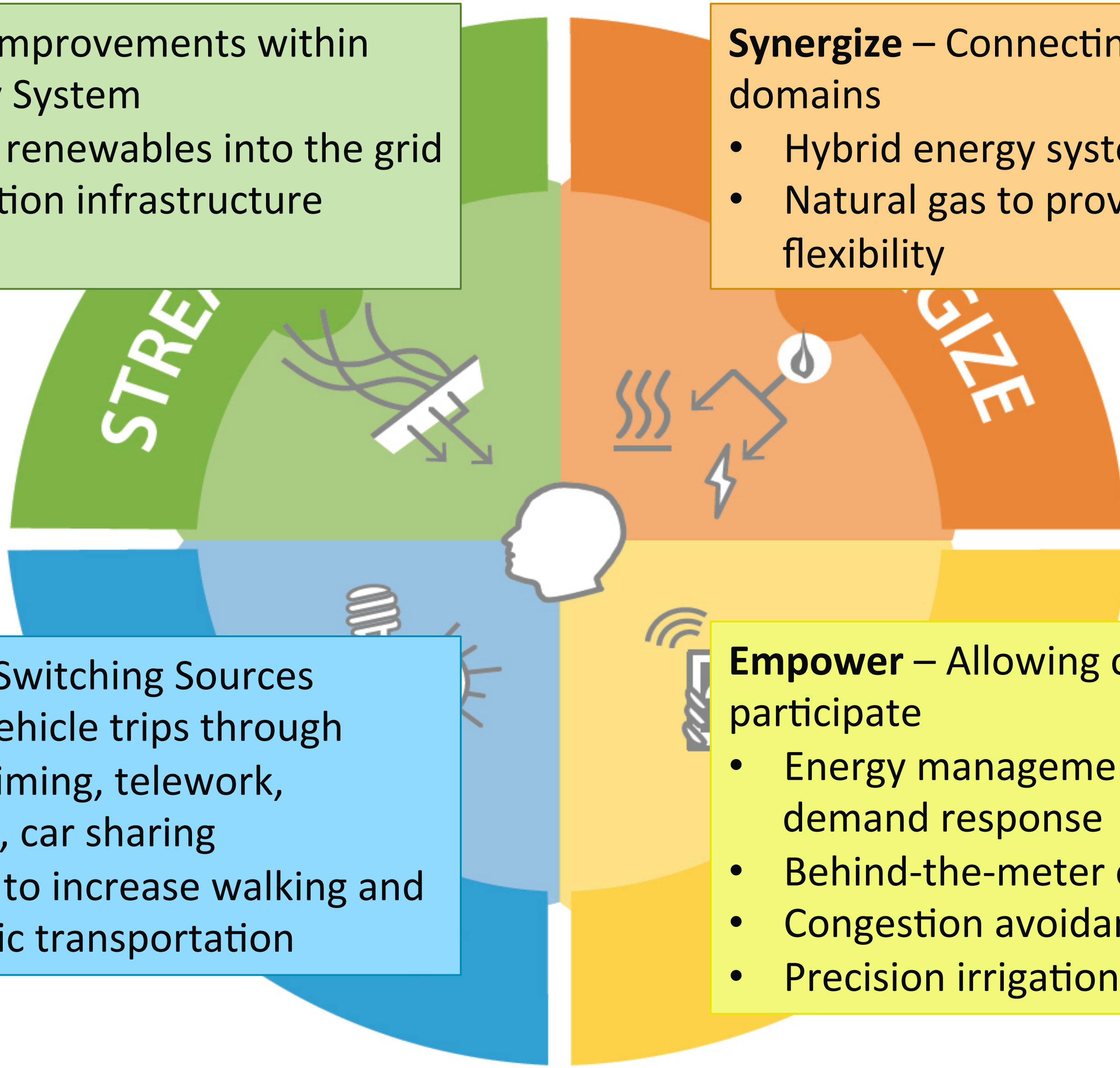
ESI allows optimizing systems to simultaneously meet all or any combination of these, depending on system owner or operator requirements

- **Increase asset utilization -** defer/avoid capital cost investment in energy system infrastructure, reduce spinning reserves, increase system flexibility

- **Enhance energy supply quality and reliability –** increase diversity of supply, monitor and reconfigure energy system operations as needed

- **Enable increased customer load efficiency, customer empowerment and satisfaction –** allow for all customers to participate and choose how to minimize their energy bills and provide positive environmental impacts.

ESI Opportunity Areas



Streamline – Improvements within Todays Energy System
- Integrating renewables into the grid
- Transportation infrastructure

Synergize – Connecting energy domains
- Hybrid energy systems
- Natural gas to provide grid flexibility

Mode-Shift - Switching Sources
- Reducing vehicle trips through commute timing, telework, ridesharing, car sharing
- City design to increase walking and use of public transportation

Empower – Allowing consumers to participate
- Energy management such as demand response
- Behind-the-meter energy storage
- Congestion avoidance and pricing
- Precision irrigation

ESI Element #1 - Streamline

Improvements to Existing Energy Infrastructures - Restructure, reorganize, and modernize current energy system

Electrical

- Increased grid flexibility
- Expansion of transmission grid
- Increased use of large-scale electricity storage
- Simplified/Faster Distributed Generation Interconnection
- Flex-fuel and fossil-renewable hybrid energy systems producing only electricity

Fuel: Alternative transportation fuel infrastructure

- Ability to increase penetration of ethanol and other biofuels
- Pipeline infrastructure for E85

Thermal: District heating and cooling infrastructure

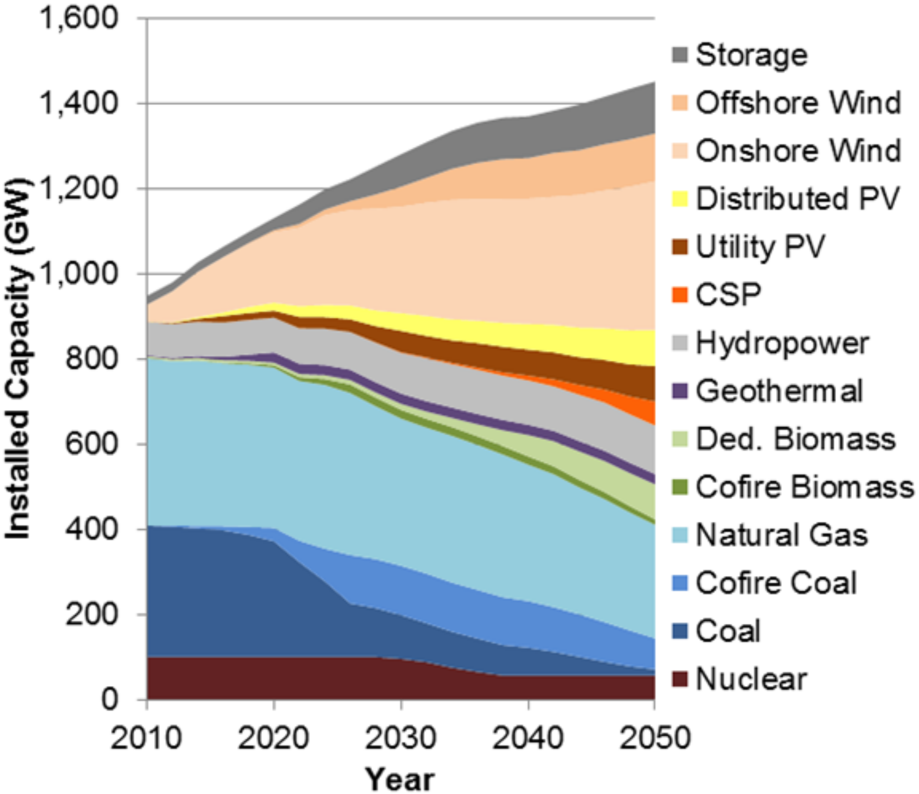
- More heat networks (reducing capital cost and/or adding ground-source heat pumps)
- Increased thermal storage for thermal uses

Data and Information

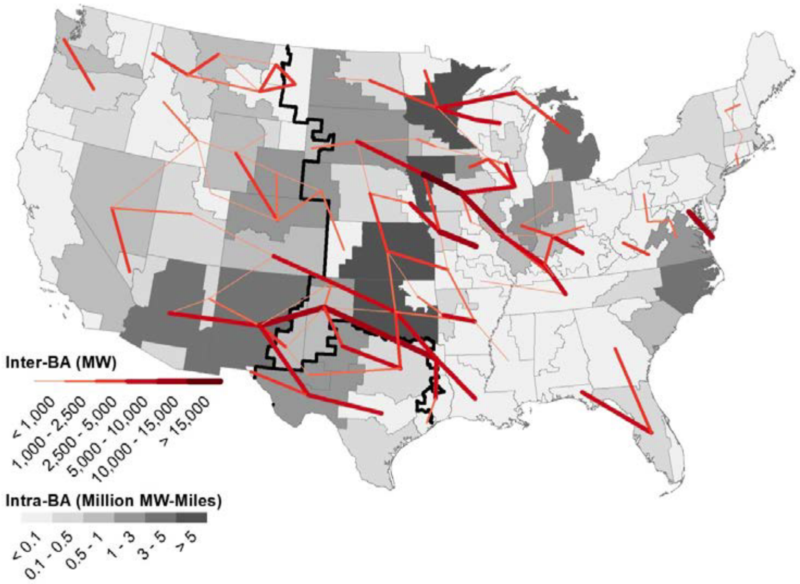
- Utility use of smart grid informatics for operations
- Improved weather forecasting

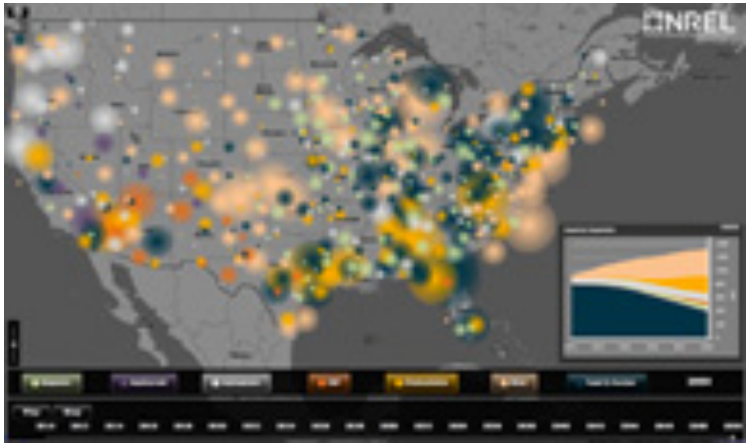
Streamline: Renewable Electricity Futures Study

80% RE Scenario



New Transmission Needs





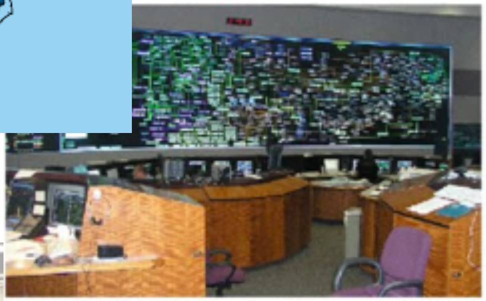
- Make existing system better: add transmission
- Merge balancing areas
- Increase generation fleet flexibility

http://www.nrel.gov/analysis/re_futures/

Early Efforts with Energy Informatics Show Large Potential

Connecting Big Data to Operations - PJM is demonstrating the ability to use information technology to **double the capability of their existing network** of long-distance line to move energy through data-centric command center, generating $2 billion a year in savings.

"Big Data Unleashes the Electric Equivalent of a Free Keystone Pipeline", http://www.forbes.com/sites/markpmills/2012/03/19/information-technology-unleashes-the-electric-equivalent-of-a-free-keystone-pipeline/



Other utility examples:

- Systems operators could act upon metrics that are early predictors of changes in network quality or reliability.
- Distribution system operators could deliver reliable power at the lowest cost using output forecasts for DER.

ESI Element #2 – Synergize

Taking advantage of underutilized interfaces and adding new interfaces

Meeting consumer needs more effectively by linking energy systems that are not often (or never) linked in today's energy system

ESI Element #2 – Synergize

1. **Integrated Energy Systems**
   - CHP and trigeneration for building and campus use (possibly with heat pumps)
   - Cogeneration for industrial uses
2. **Using available electricity that might otherwise be curtailed for other products**
   - Production of other energy or energy-intensive products like methane and hydrogen in large facilities
3. **Thermal storage for electrical demand response**
4. **Reducing industrial energy use through direct use of renewables**
   - Solar furnaces
5. **Synthetic natural gas**
6. **Combined transmission opportunities**
   - Integrated Electric – Hydrogen Transmission – Pipelines
   - Combined Transportation - Transmission Corridors (ROW integration)
7. **Hybrid energy systems (e.g. polygeneration conversion facilities (with or without flex-fuel capabilities) with dynamic response to pricing)**

ESI Element #2 - Synergize

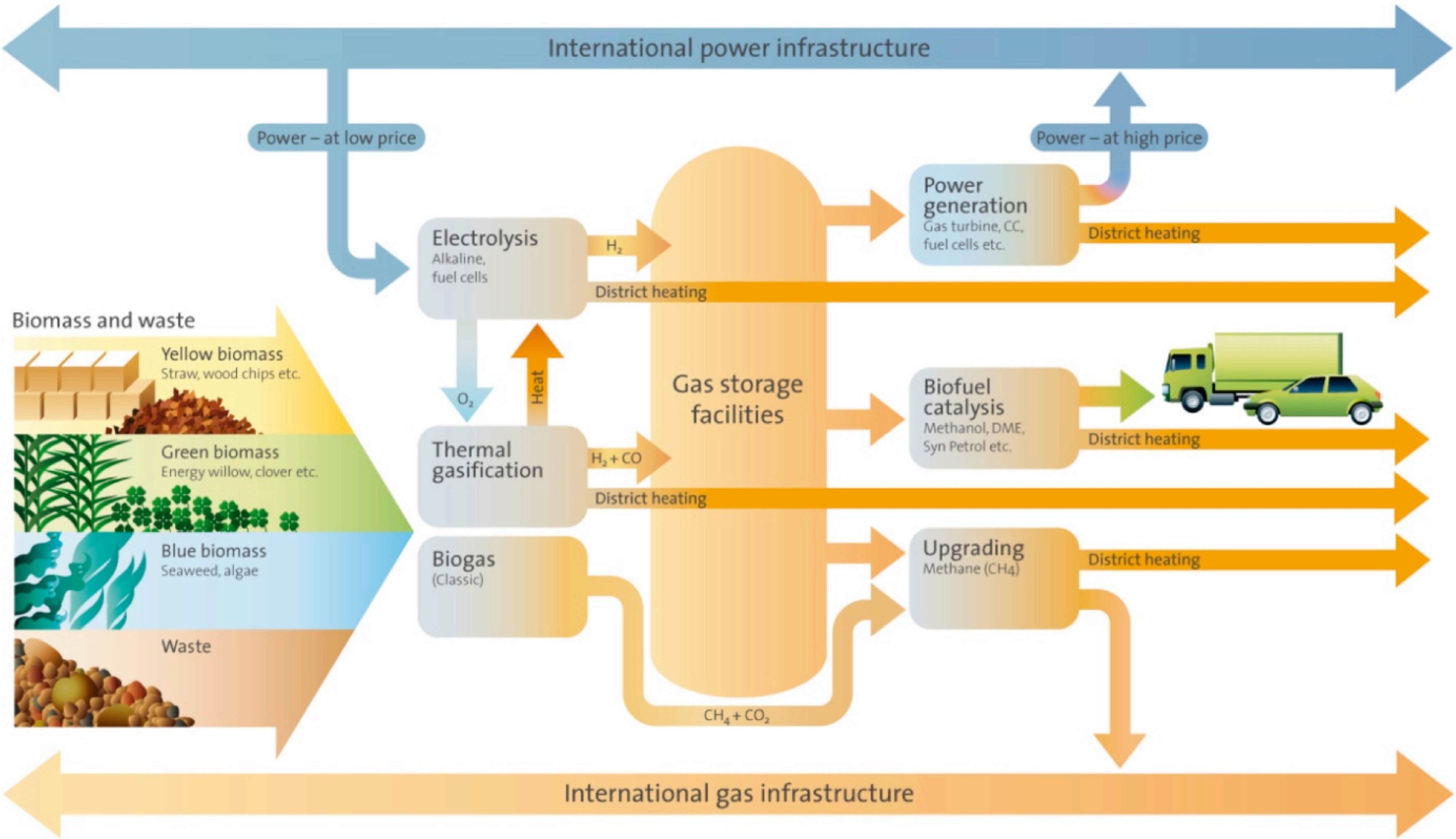
Electrified transportation

- Plug-in and hydrogen vehicles
- With and without V2G capabilities
- On-road inductive charging

Using what is traditionally waste energy

- Utilizing work from high-temperature heat
- Utilizing waste heat (e.g., waste energy from a power plant for heating industrial processes and commercial and residential buildings)
- Bottom cycles to increase overall plant efficiency (binary, organic, or Kalina)
- Utilizing warm water in heat pumps
- Utilize the thermoelectric effect to convert waste heat to power
- Aquiculture and agriculture in colder climates/seasons or with CO_2 for algae production

Synergize: Electricity and Natural Gas



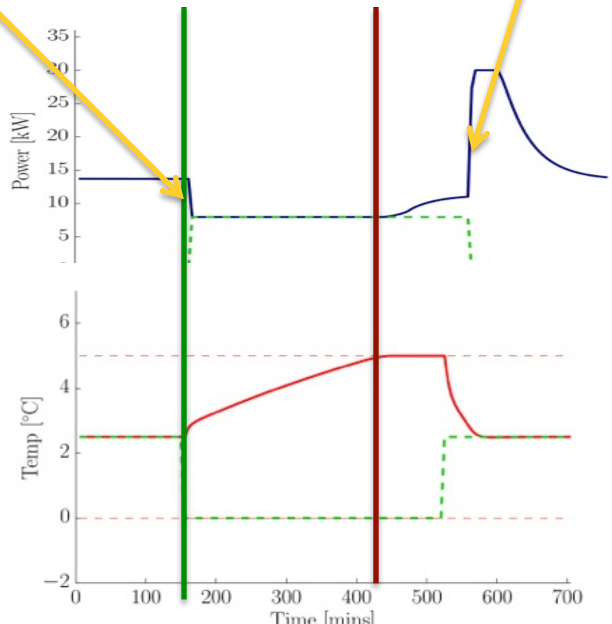
Energy Comes Together in Denmark, P. Meibom, K. Hilger, H. Madsen, D. Vinther, IEEE Power and Energy Magazine, 2013

Synergize: Virtual Storage using Thermal Demand Response

Thermal mass in refrigeration display cases facilitates the adjustment of power consumption while maintaining acceptable temperatures for food.

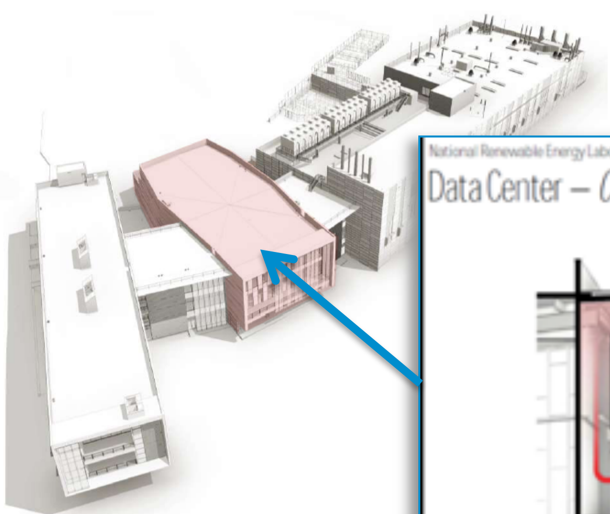
6kW of DR

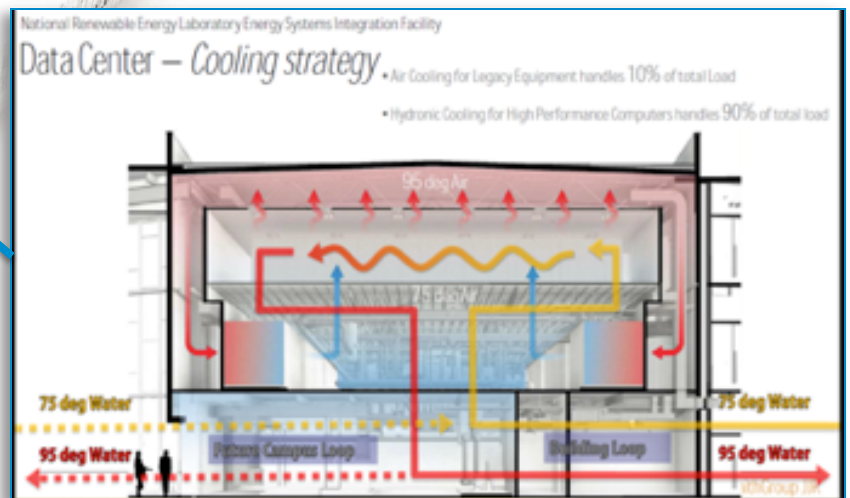
Recovery period



On the Inclusion of Energy Shifting Demand Response in Production cost Models: Methodology and a Case Study, N. O' connell, e. Hale, I. Doebber, and J. Jorgenson, NREL/TP-6A20-64465, July 2015

Synergize: Using Waste Heat from Data Centers





NREL HPC – DC Showcase Facility

- Use evaporative rather mechanical cooling.
- Waste heat captured and used to heat labs & offices.
- World's most energy efficient HPC - data center, PUE 1.06!

PUE = Power Usage Effectiveness

ESI Element #3 - Empower

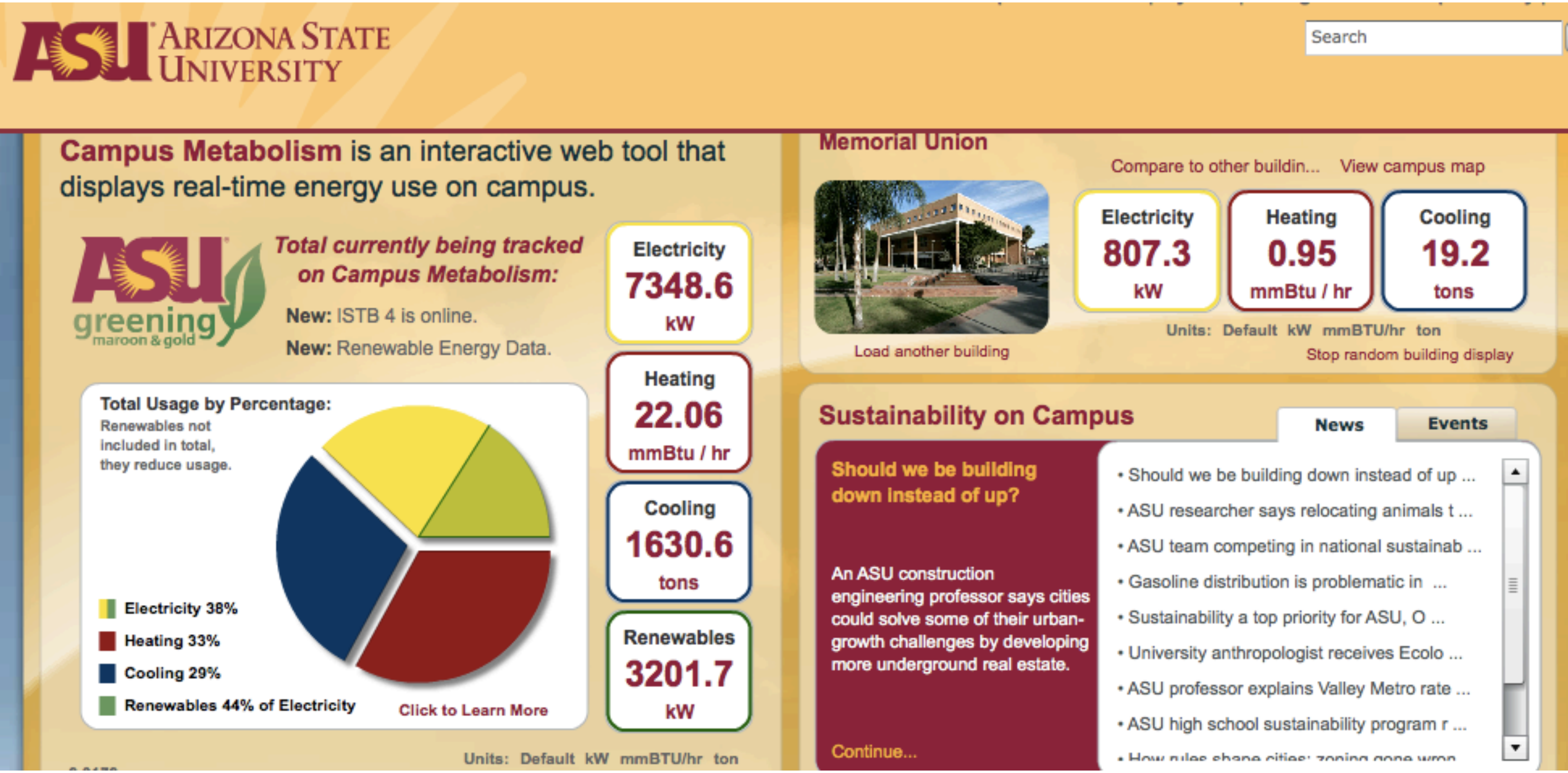
Informed customers as active participants within energy systems

Generating and providing information so the customer uses energy more effectively. Enables customer decisions regarding issues involving energy use.

Examples

- Education resulting in changed behavior
- Customer-driven electrical demand response
- Customer-side distributed energy storage
- Traffic rerouting/changing travel times due to congestion
- Precision irrigation
- Scheduling manufacturing around energy prices

Empower: ASU – Campus Metabolism



http://cm.asu.edu/#

ESI Element #4 – Mode-Shift

Switching the means used to provide energy-requiring end-use services

Focusing on energy services and finding different modes that provide end-users with the necessary services while using less energy

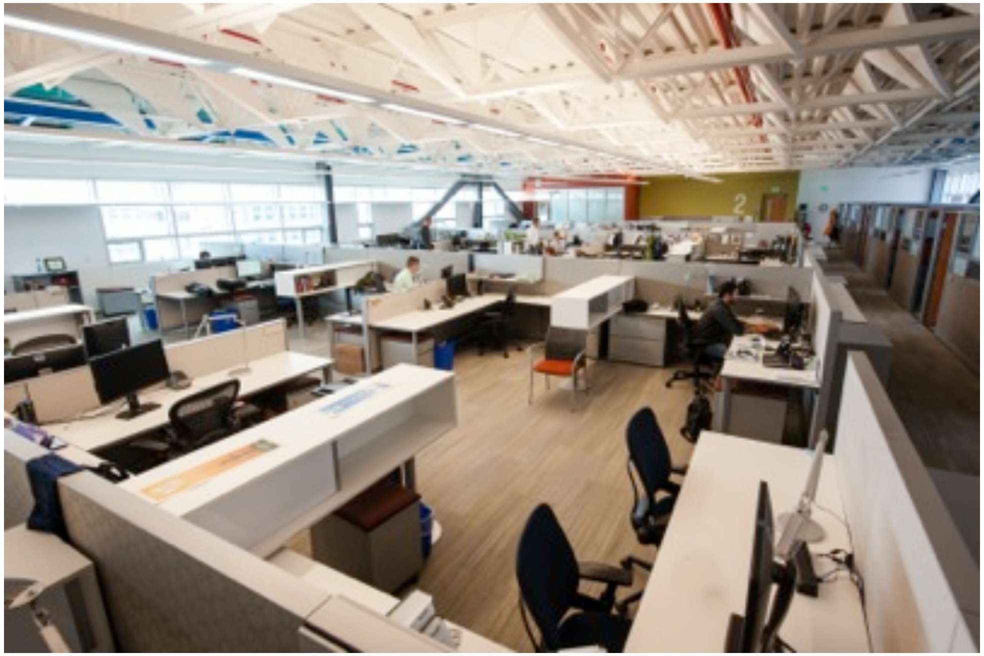
Examples

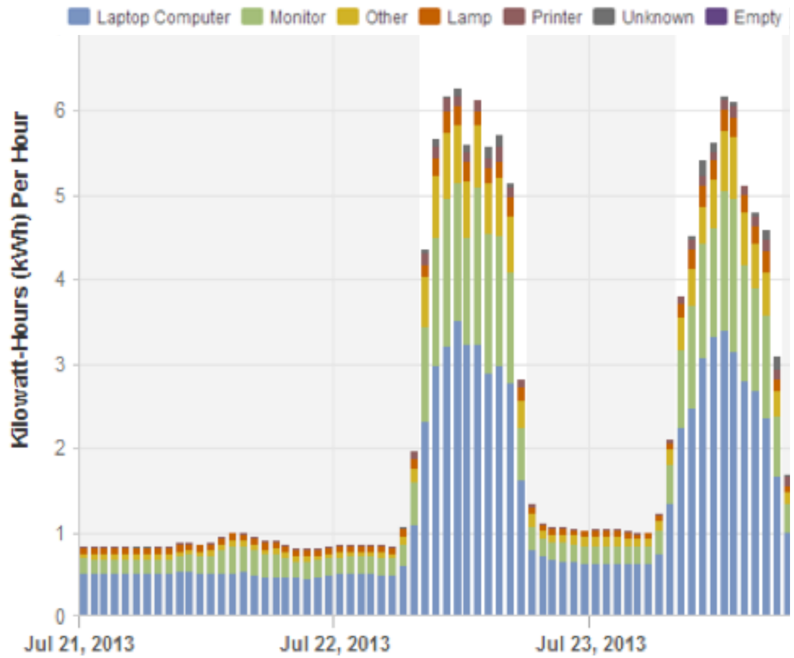
- High-speed electric rail for medium long-distance transport
- Private to public transportation (i.e., cars to buses)
- Urban planning for alternative transportation
- Telework
- Using renewables to provide reaction heat (e.g., solar furnace)
- Daylighting

Mode-Shift: Smart Office Areas - Daylighting

- Integrated Energy Efficiency into Design and Operations
- High use of daylight
- Natural use of ventilation through operable windows
- Uses about 25% national average for energy in office space
- Installed Enmetric plug load control system
- Collecting circuit level load information in office area

Enmetric Plug Load Controller





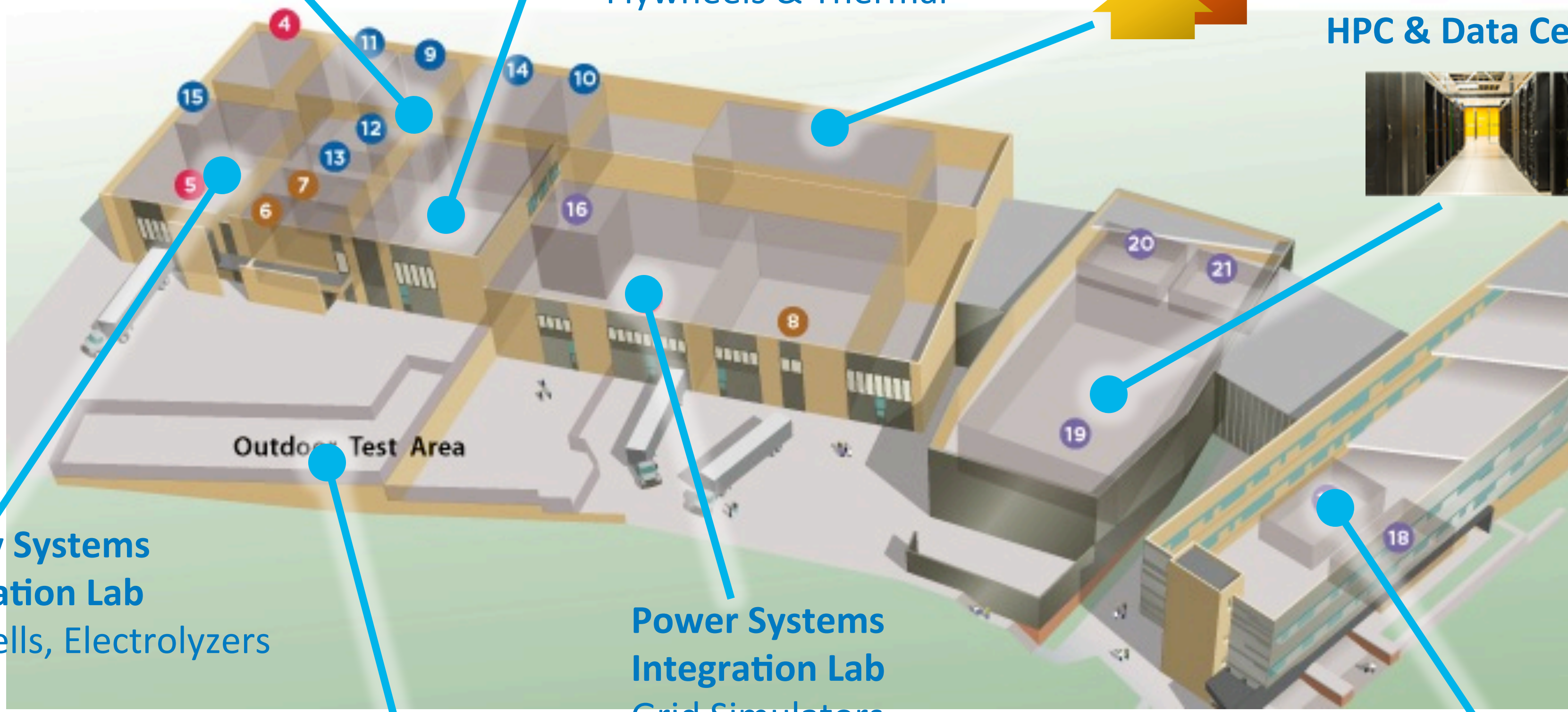
NREL Energy Systems Integration Facility (ESIF)

Rooftop PV

Energy Storage Lab
Residential, Community & Grid Battery Storage, Flywheels & Thermal

Smart Power Lab
Buildings & Loads

HPC & Data Center



Energy Systems Integration Lab
Fuel Cells, Electrolyzers

Power Systems Integration Lab
Grid Simulators
Microgrids

Outdoor Test Areas
EVs, Power Transformers

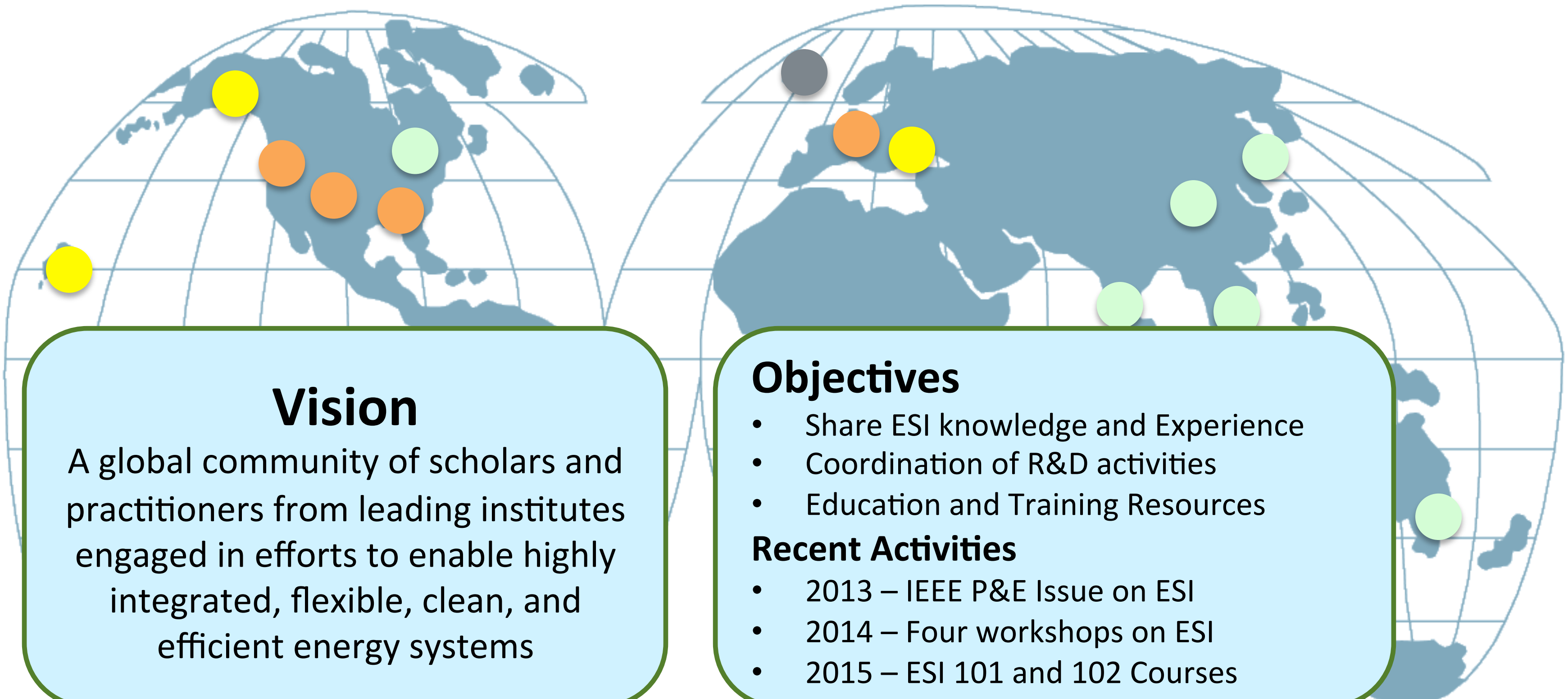
http://www.nrel.gov/esif

Auxiliary Control Room
ADMS Testbed

Foster a Global Community

www.iiesi.org

iiESI International Institute™ for Energy Systems Integration



Vision

A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems

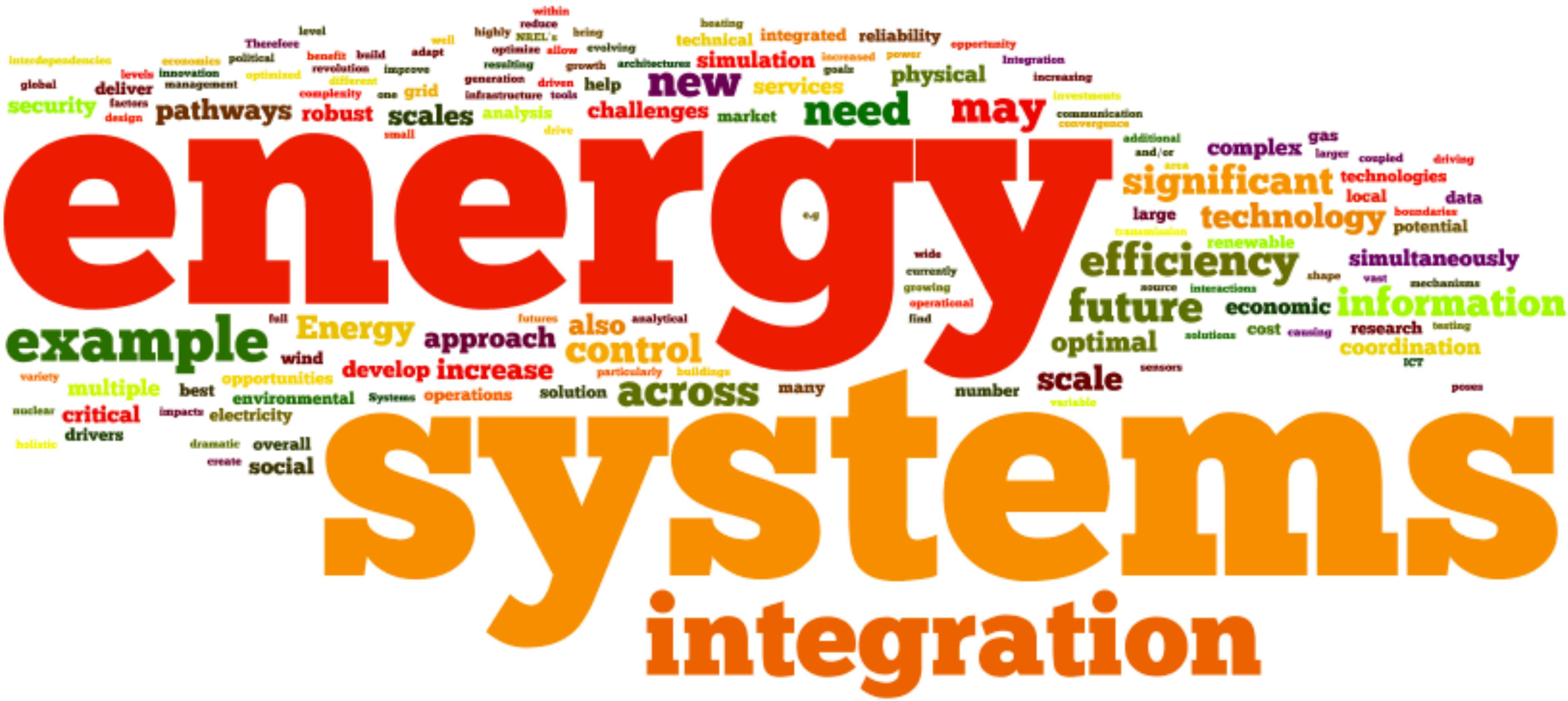
Objectives

- Share ESI knowledge and Experience
- Coordination of R&D activities
- Education and Training Resources

Recent Activities

- 2013 – IEEE P&E Issue on ESI
- 2014 – Four workshops on ESI
- 2015 – ESI 101 and 102 Courses

NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · EPRI ELECTRIC POWER RESEARCH INSTITUTE · UCD DUBLIN · DTU · KU LEUVEN



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For Further Reading

- *"Energy Systems Integration - A Convergence of Ideas"*, B. Kroposki, B. Garrett, S. Macmillan, B. Rice, C. Komomua, M. O'Malley, D. Zimmerle, NREL/TP-6A00-55649, July 2012, http://www.nrel.gov/esi/pdfs/55649.pdf
- *"Energy Comes Together – The Integration of All Systems"*, M. O'Malley and B. Kroposki, *IEEE Power & Energy Magazine*, Sept/Oct 2013, pp. 18-23, Digital Object Identifier 10.1109/MPE.2013.2266594
- *"Energy Systems Integration: An Evolving Energy Paradigm"*, M. Ruth and B. Kroposki, *The Electricity Journal*, 2014
- *"Energy Comes Together in Denmark"*, P. Meibom, K. Hilger, H. Madsen, D. Vinther, IEEE Power and Energy Magazine, Sept/Oct 2013
- *On the Inclusion of Energy Shifting Demand Response in Production cost Models: Methodology and a Case Study*, N. O' connell, e. Hale, I. Doebber, and J. Jorgenson, NREL/TP-6A20-64465, July 2015 http://www.nrel.gov/docs/fy15osti/64465.pdf
- *Renewable Electricity Futures Study (Entire Report) National Renewable Energy Laboratory. (2012). Renewable Electricity Futures Study. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures/*
- *"Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*", M. Melaina, O. Antonia, and M. Penev, NREL/TP-5600-51995, March 2013, http://www.nrel.gov/docs/fy13osti/51995.pdf