Energy Systems Integration

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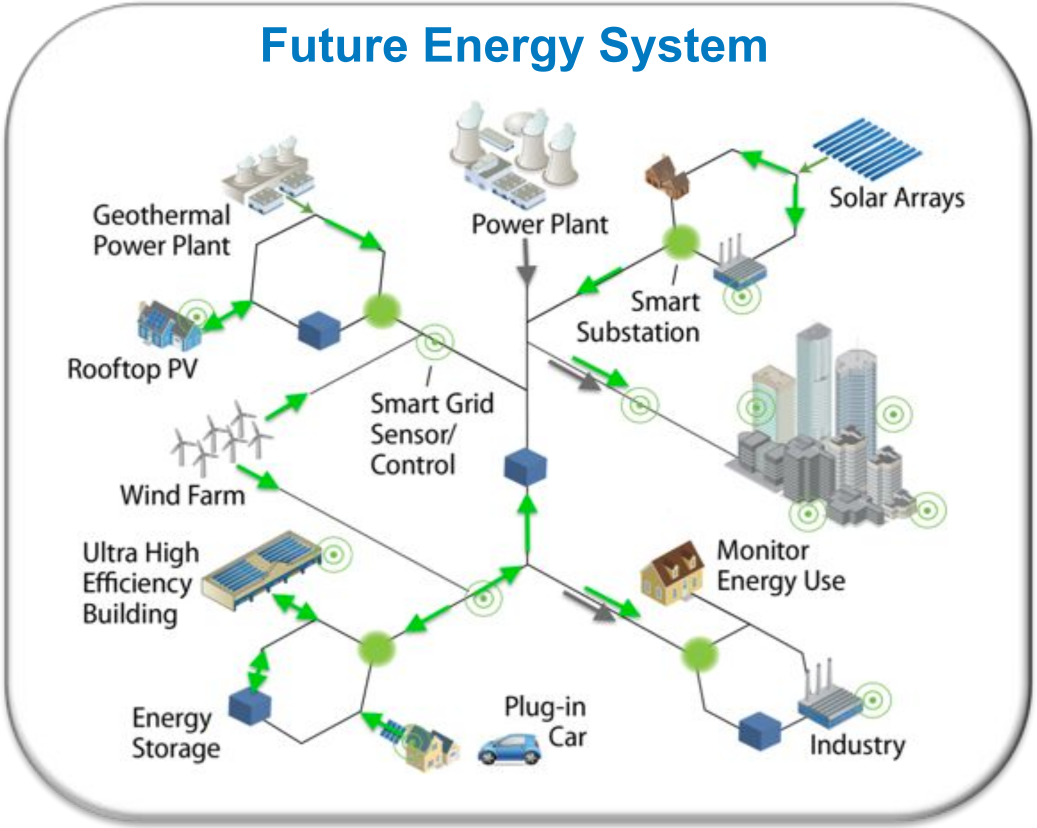
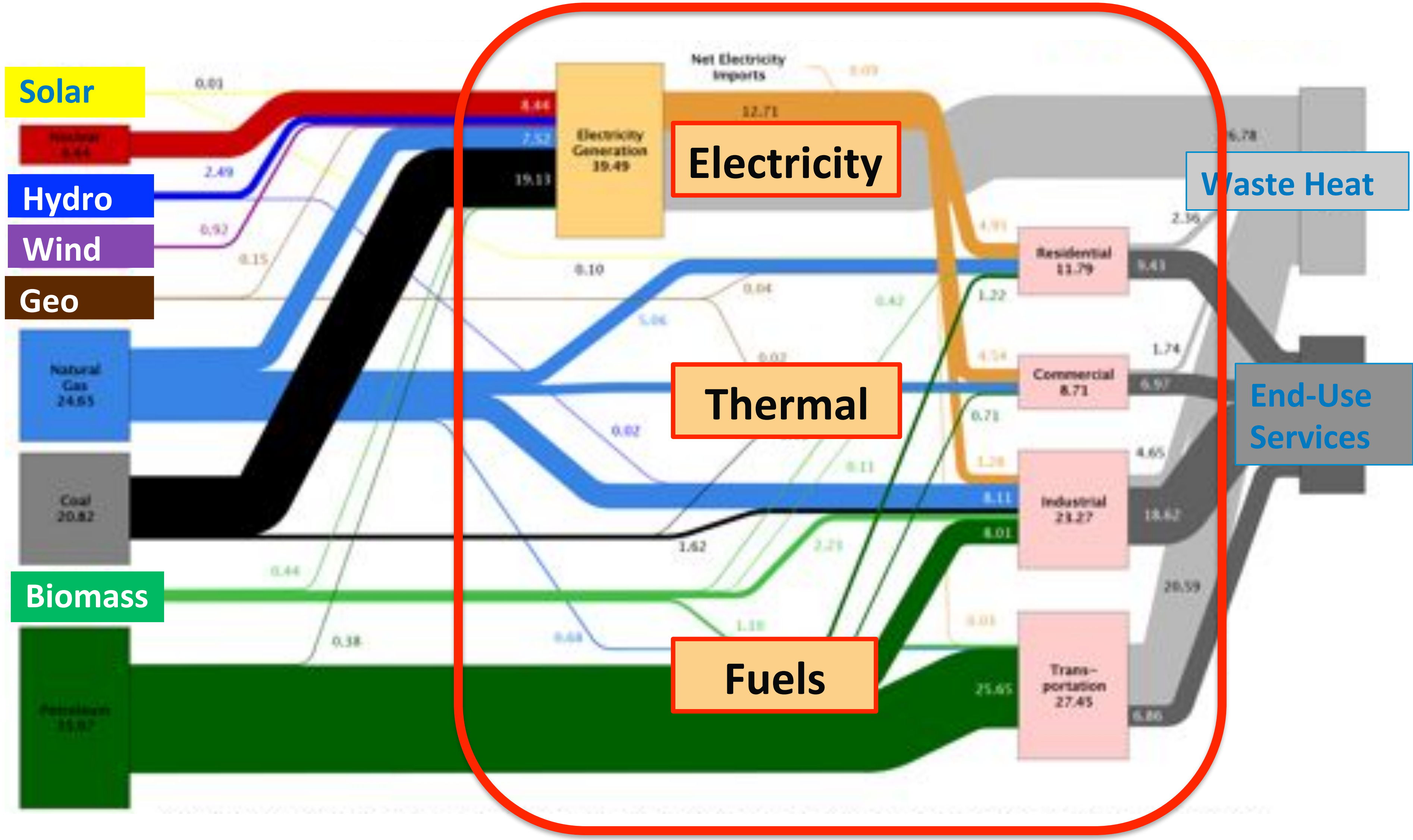
What is an Energy System?

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

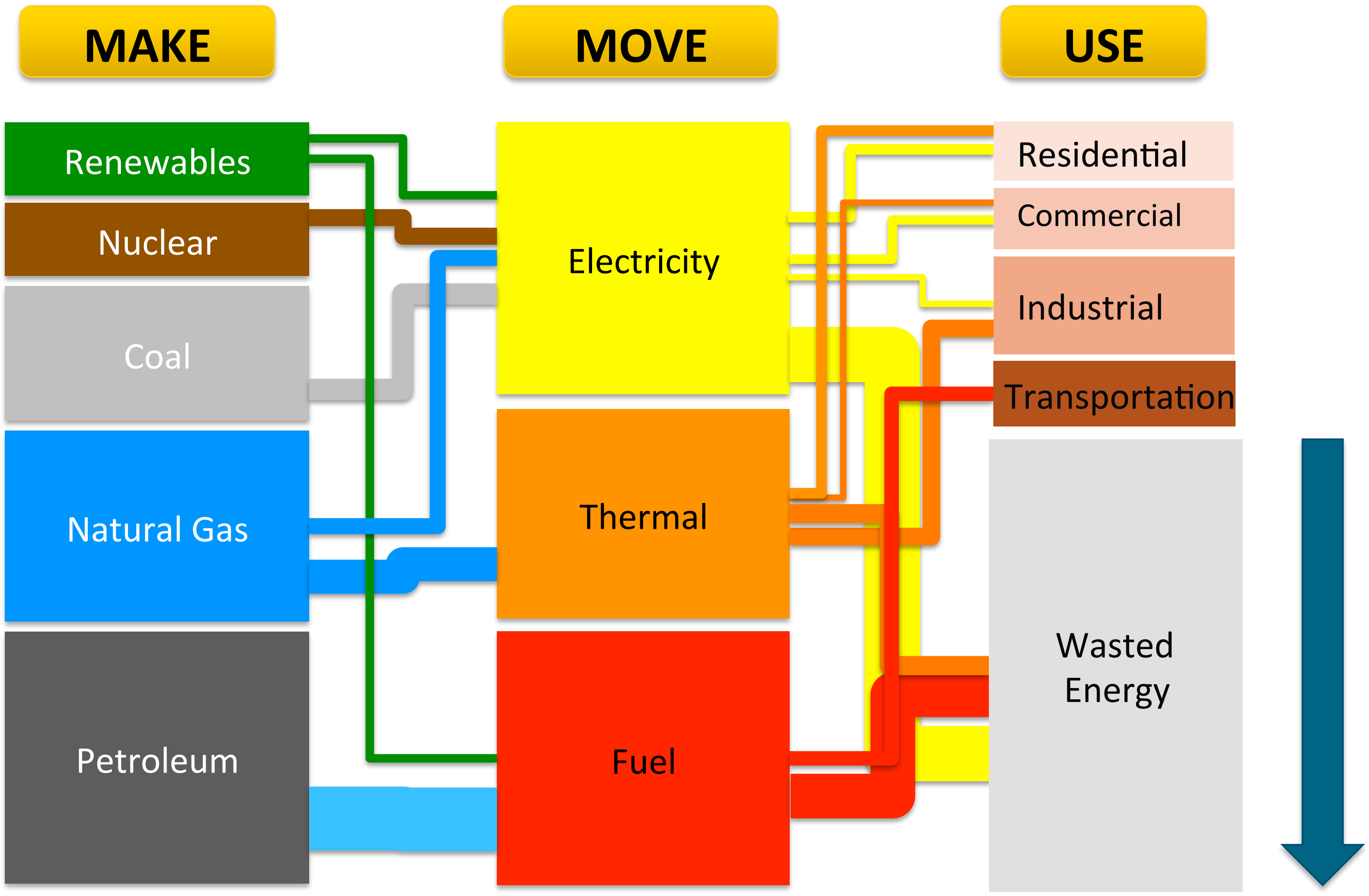
- **Examples:**
  - Buildings
  - Vehicles
  - Distribution feeders
  - Fueling stations
  - Communities
  - T&D grids
  - Pipeline networks



Energy System of the USA



Integration for Optimization



A Profound Transformation is Required

Today's Energy System

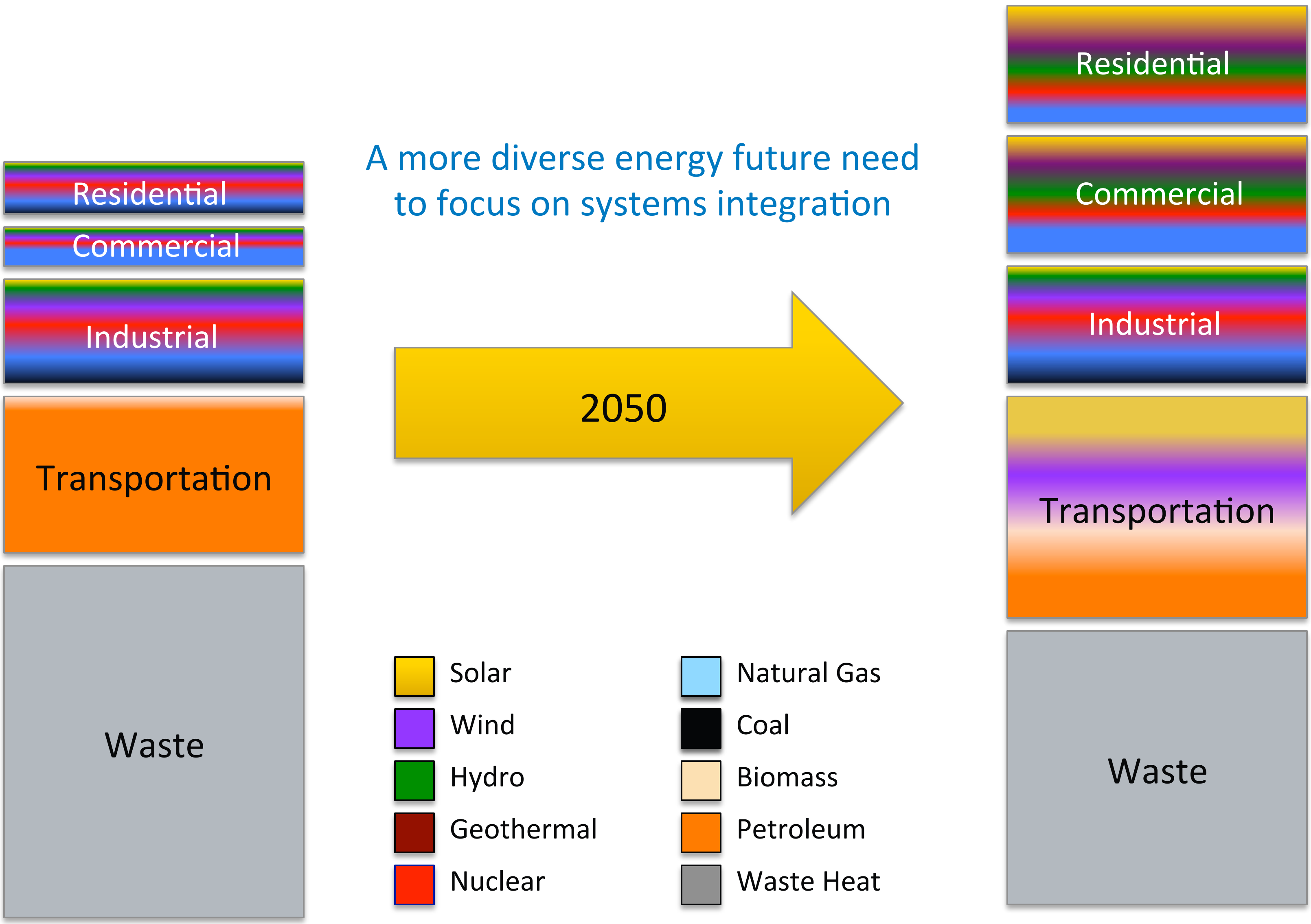
TRANSFORMATION

Sustainable Energy System

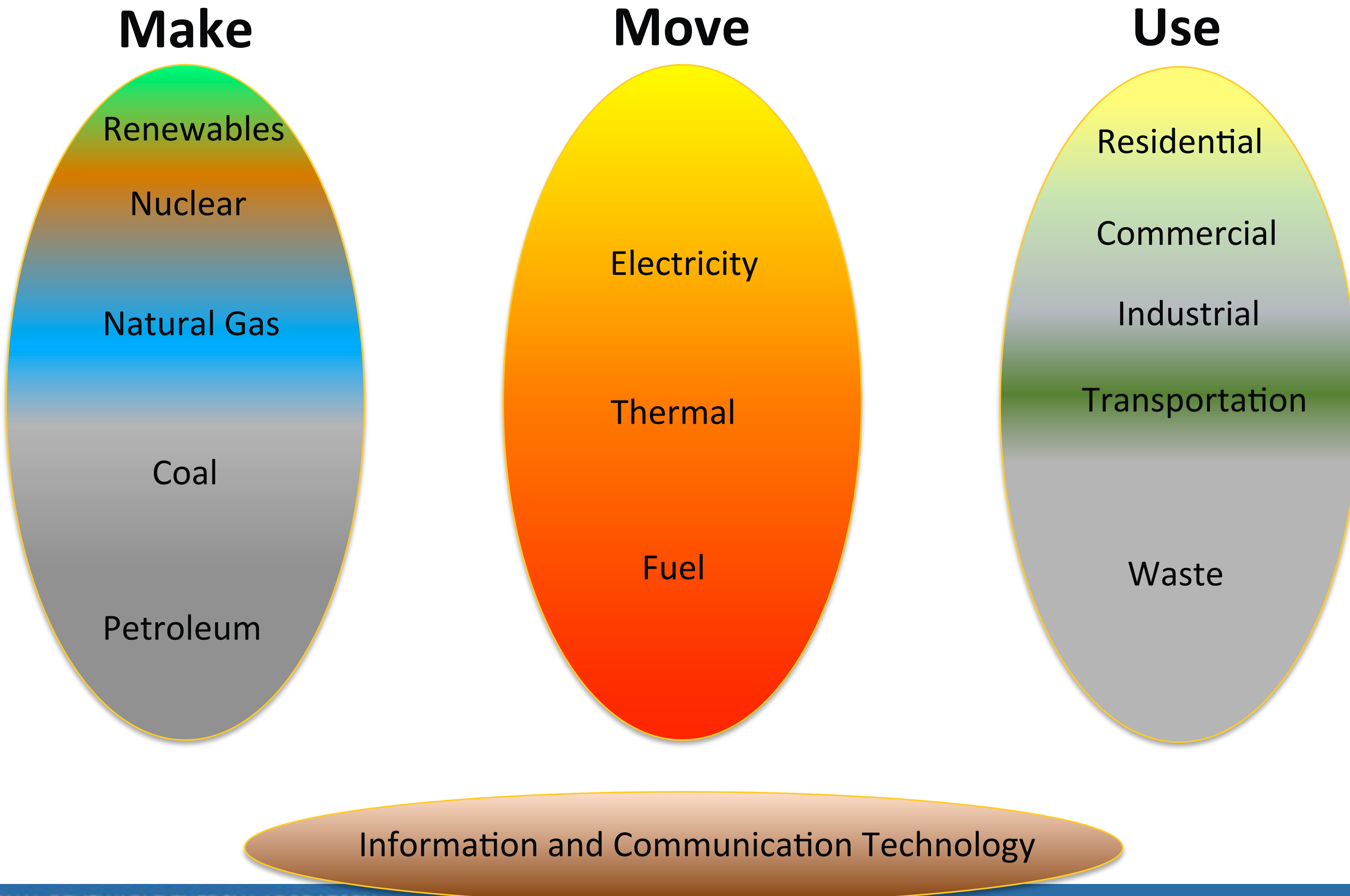
- Dependent on non-domestic sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Significant carbon emissions
- Role of electricity increasing

- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates economic development
- Accessible, affordable and secure

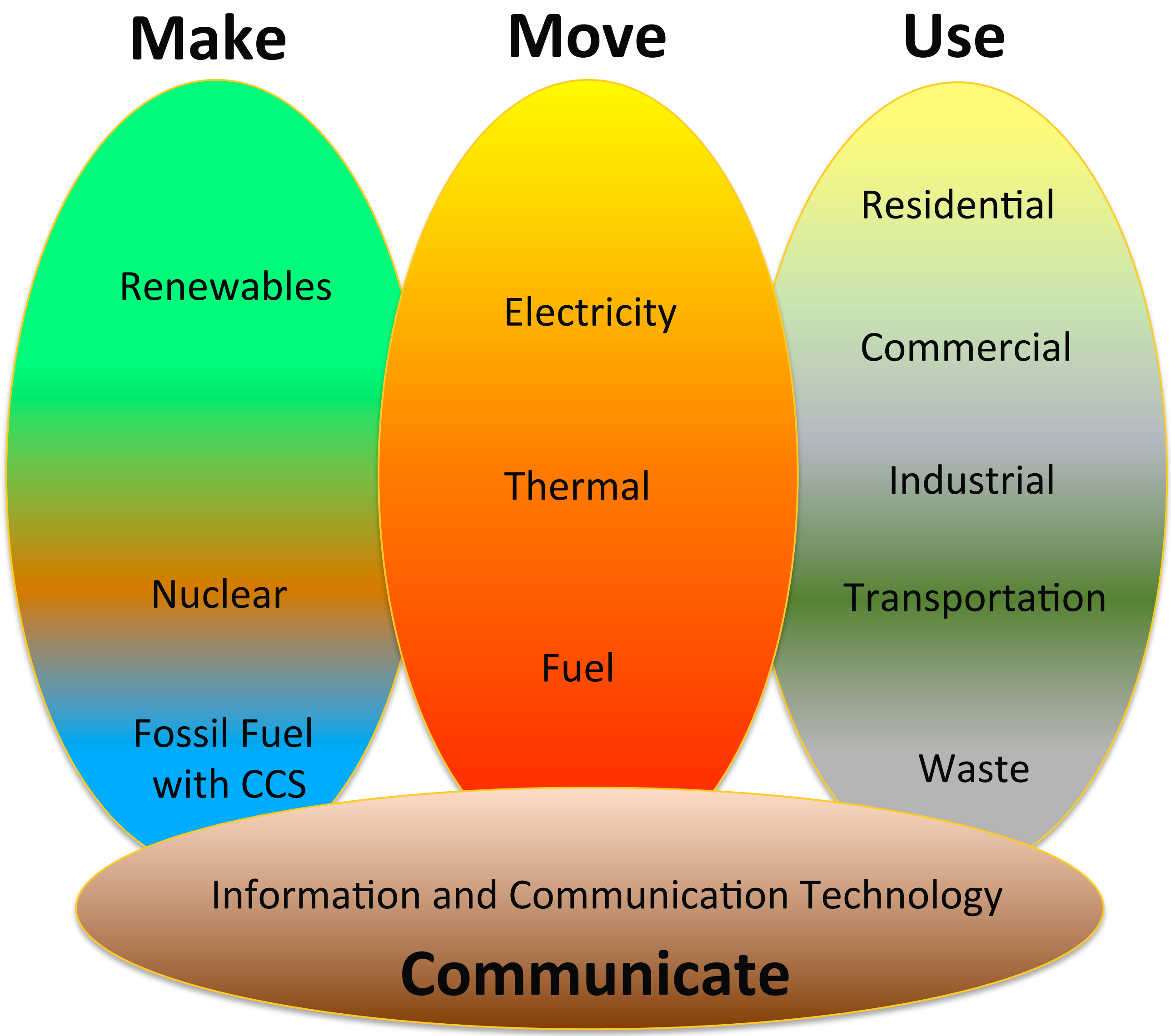
What does that transformation look like?



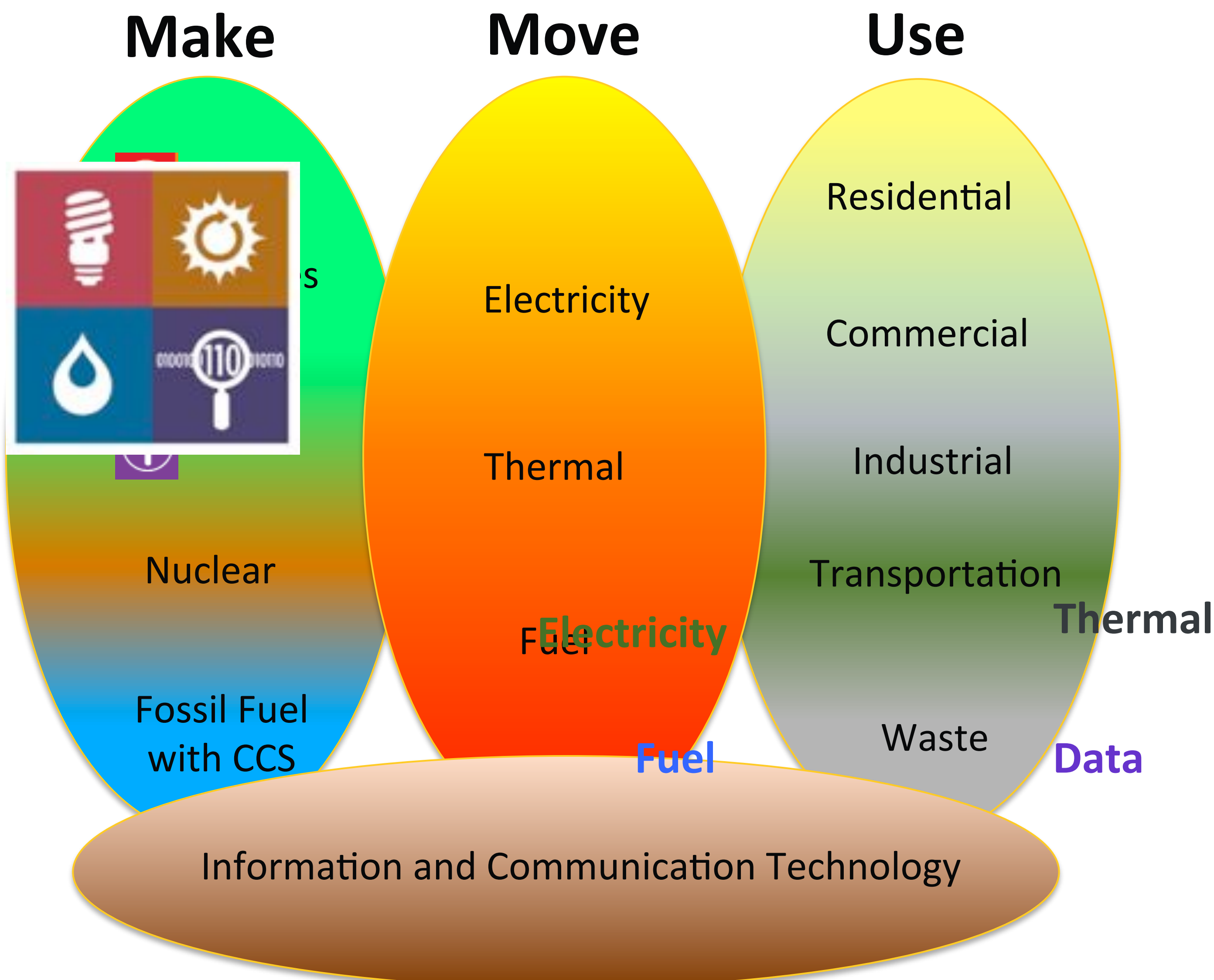
Convergence of Systems



Future Energy Systems

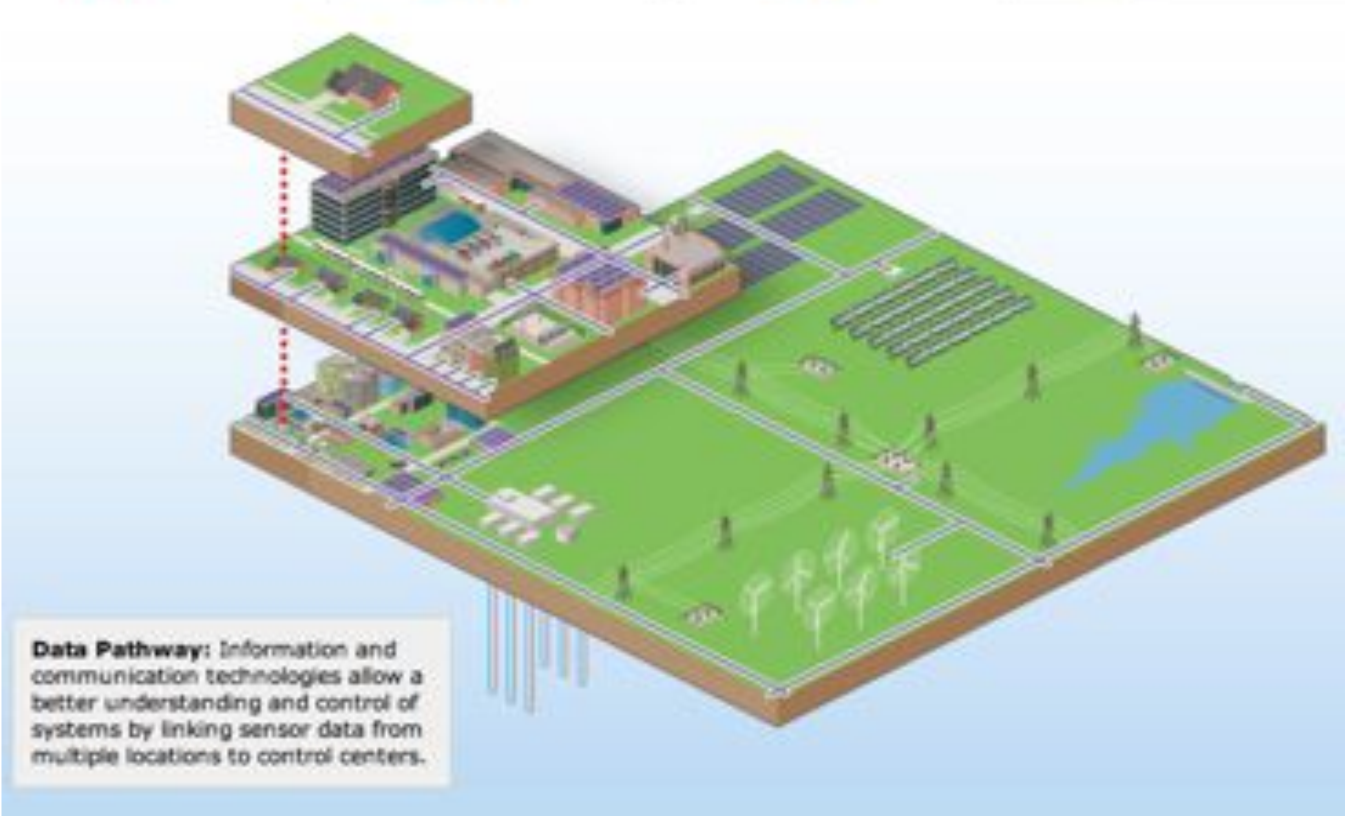


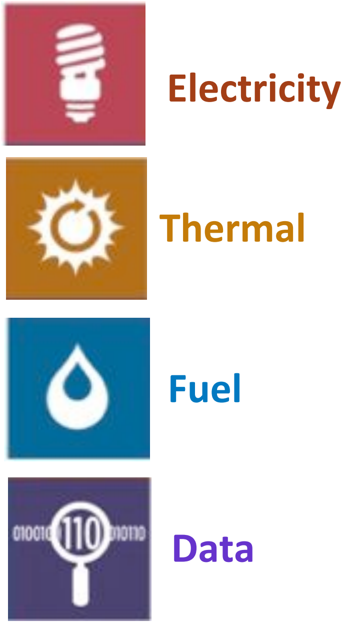
Energy Systems Integration



What is Energy System Integration?

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

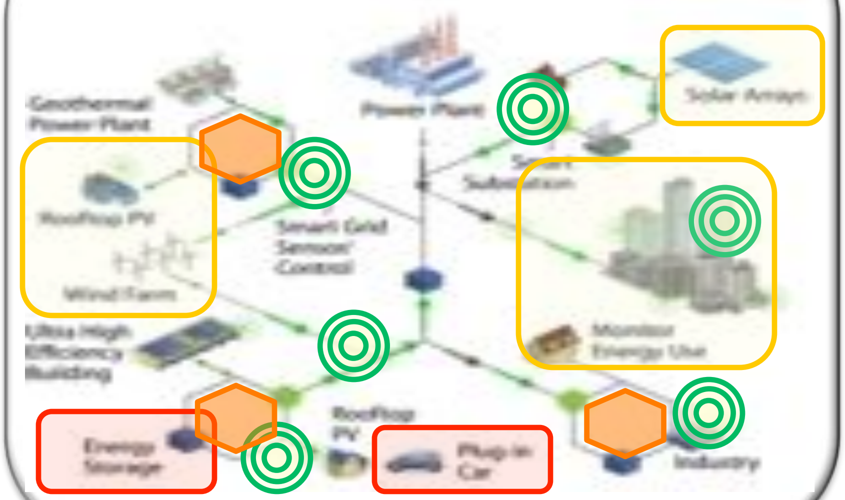




Why Energy Systems Integration?

Current Energy Systems

Future Energy Systems

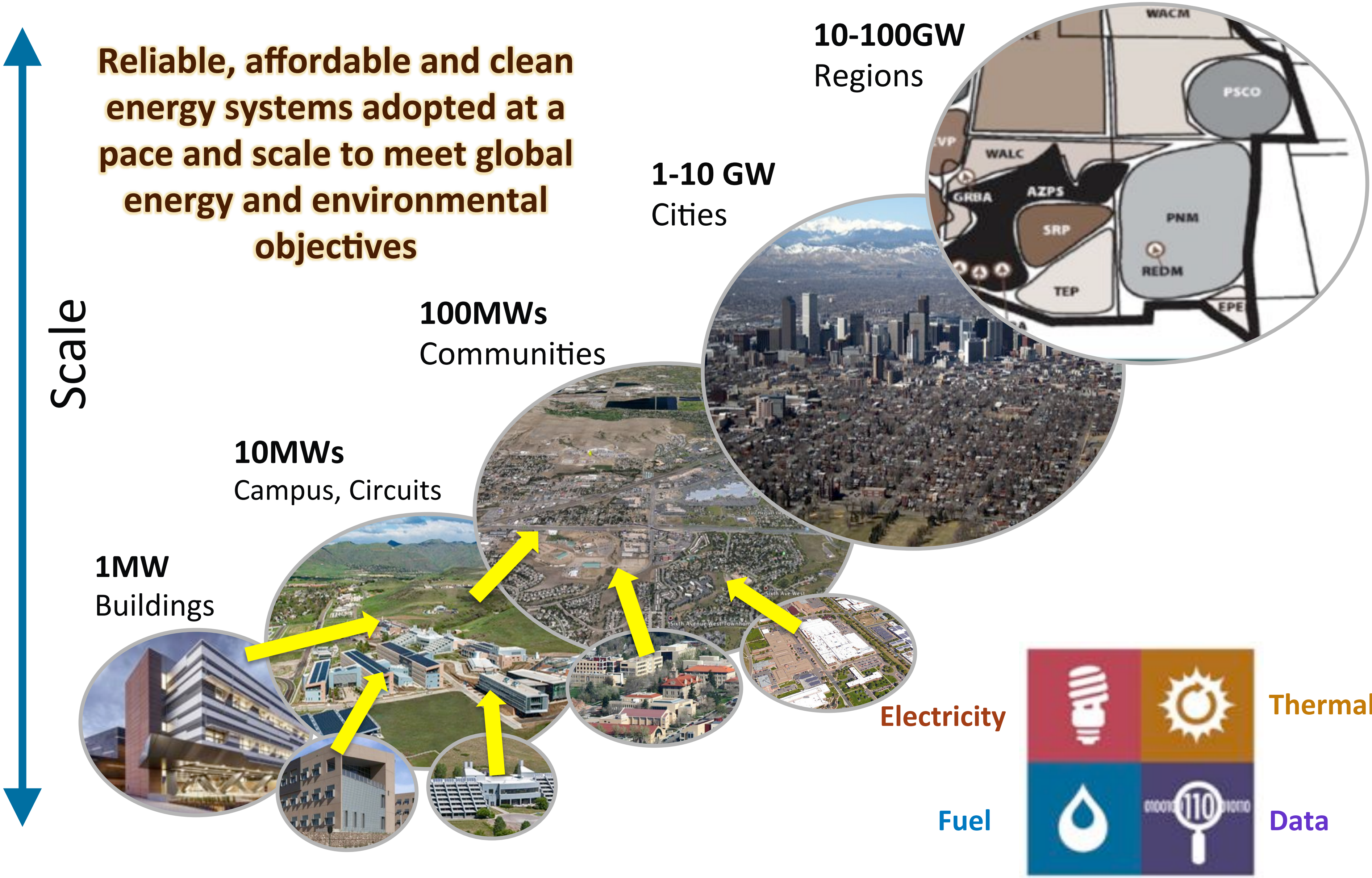


Reducing investment risk and optimizing systems in a rapidly changing energy world

- Increasing penetration of variable RE in grid
- Increasing ultra high energy efficiency buildings and controllable loads
- New data, information, communications and controls
- Changes in transportation fuels (NG, Bio, H2, electricity)
- Integrating energy storage (stationary and mobile) and thermal storage
- Interactions between electricity/thermal/fuels/data pathways
- Increasing system flexibility and intelligence at a variety of scales

ESI at all Scales

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



Energy Systems Integration

Electricity

Thermal

Fuel

Data

+

= **ESI**

Energy Systems Integration optimizes energy systems across multiple pathways and scales

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 energy when compared with individual technologies

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

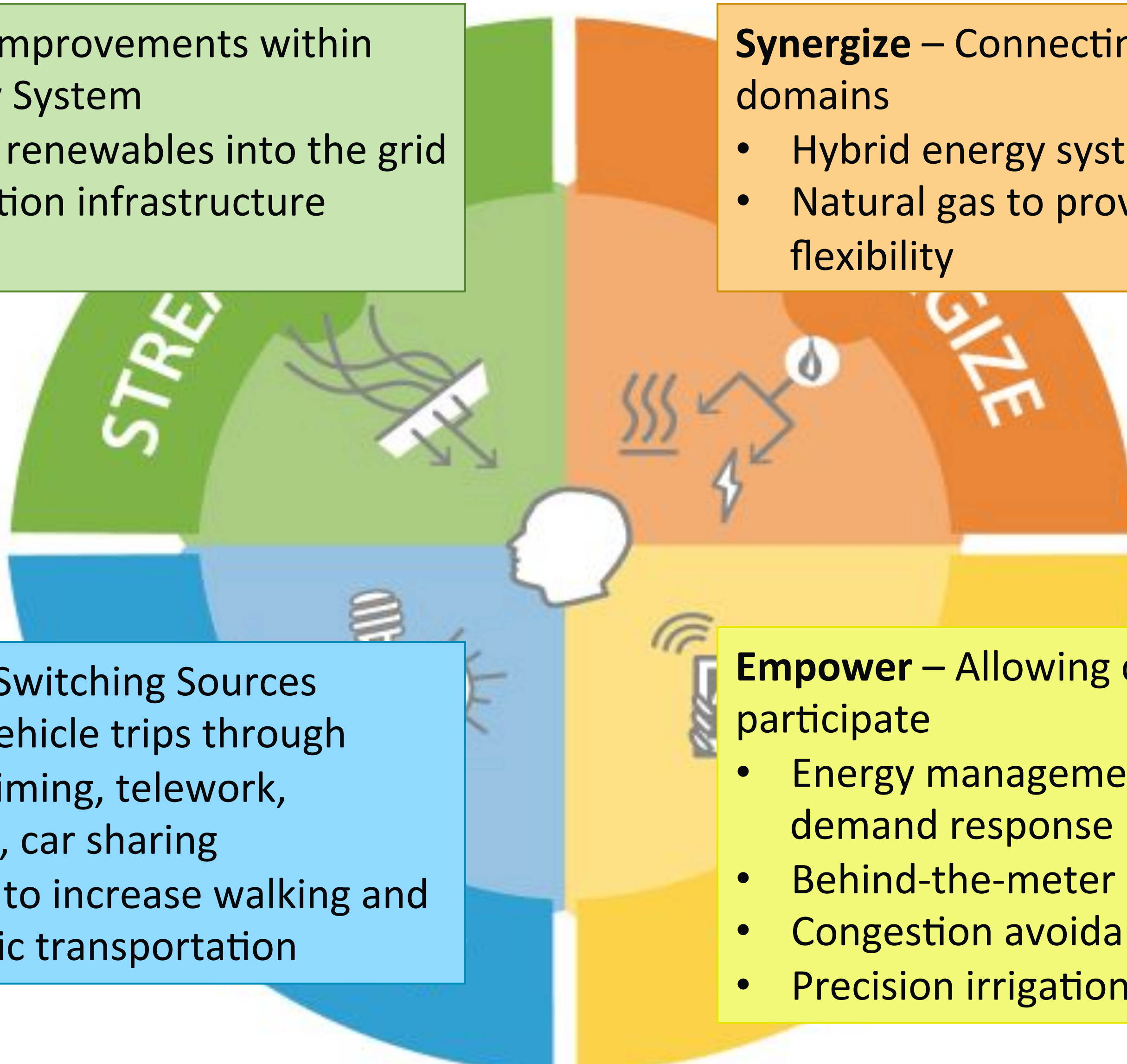
ESI allows optimizing systems to simultaneously meet all or any combination of these, depending on system owner or operator requirements

- **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

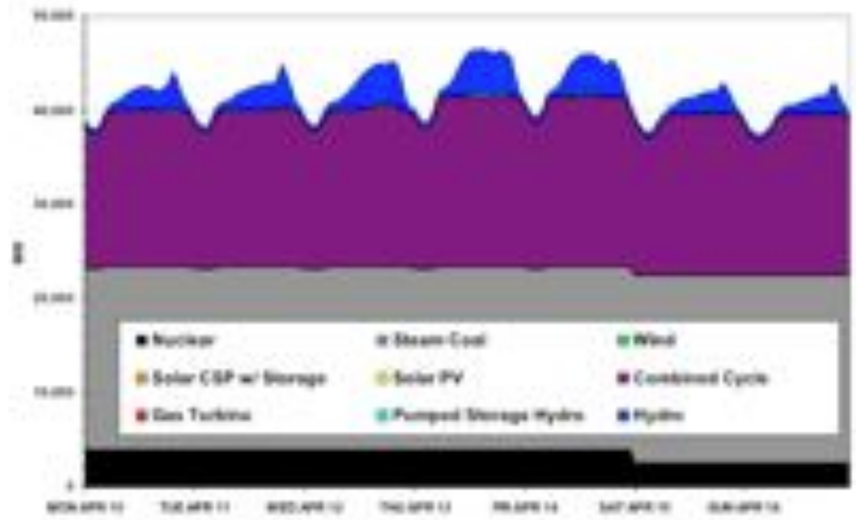
ESI Element #1 - Streamline

Electrical

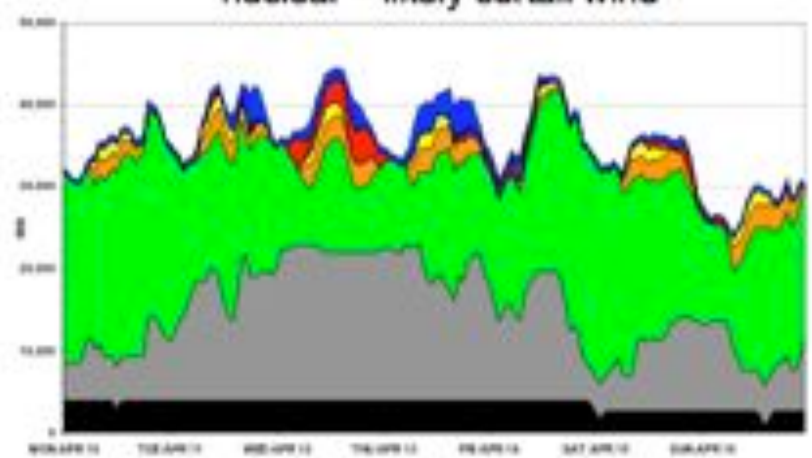
1. Increased grid flexibility
   a. Balancing area coordination (or merging)/ cooperation
   b. Faster ramping and lower minimum power plants
   c. Faster & more flexible market design (i.e., dynamic pricing with enabling technology)
   d. Expanded electric market products
   e. Direct load control (Utility-controlled demand response)
2. Expansion of transmission grid
3. Increased use of large-scale electricity storage
4. Simplified/Faster Distributed Generation Interconnection
5. Microgrids for improved customer reliability and resilience
6. Services from backup generators and UPS systems when not providing backup electricity
7. Flex-fuel and fossil-renewable hybrid energy systems producing only electricity

Transmission Integration

No wind



30% wind – starting to impact nuclear – likely curtail wind



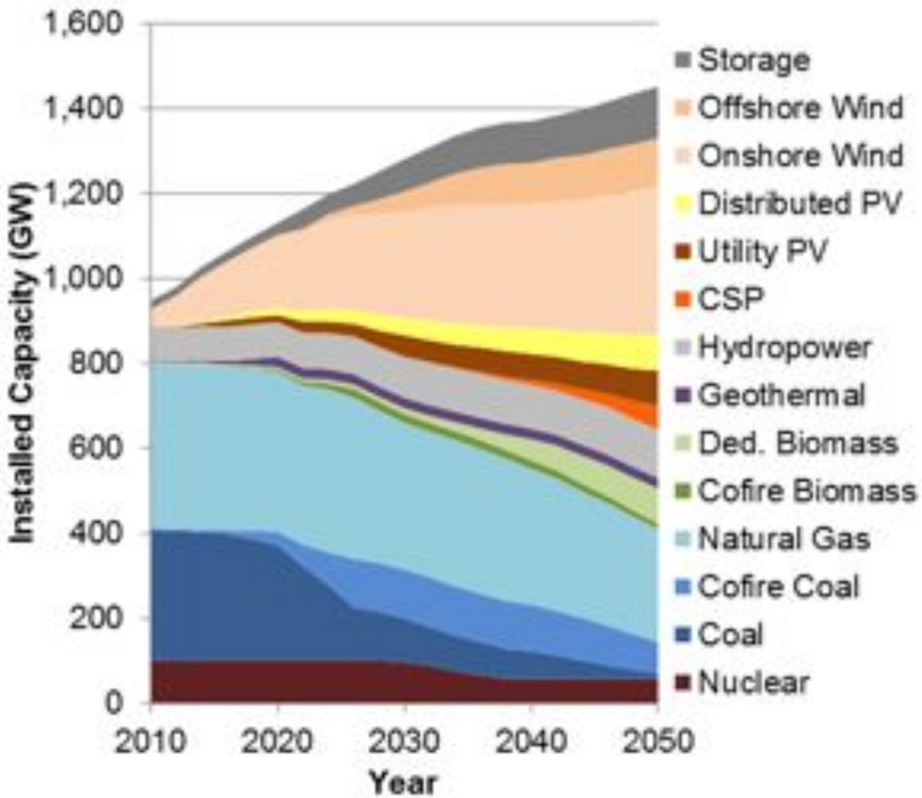
Western Wind and Solar Integration Study

Identified issues with high penetrations of wind and solar in large western part of U.S.

http://www.nrel.gov/electricity/transmission/western_wind.html

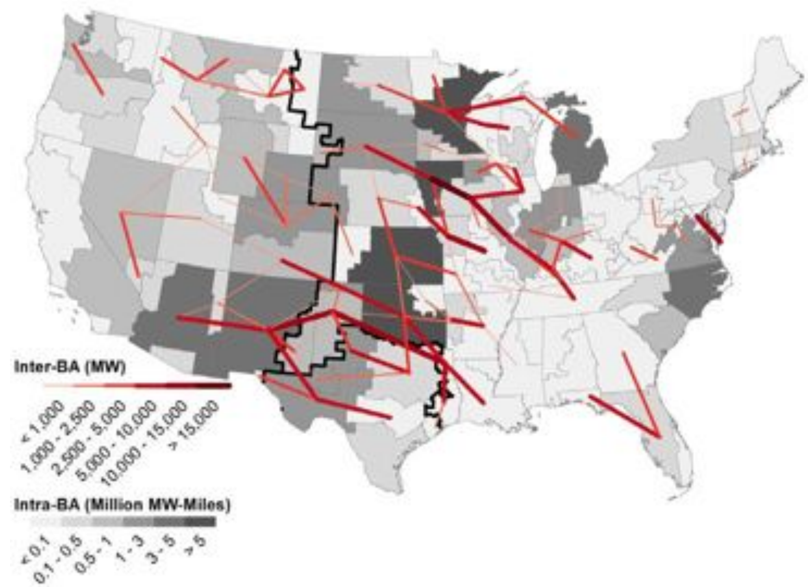
Renewable Electricity Futures Study

80% RE Scenario



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

New Transmission Needs



ESI Element #1 - Streamline

Fuel: Alternative transportation fuel infrastructure

1. Ability to increase penetration of ethanol and other biofuels
2. Pipeline infrastructure for E85

Thermal: District heating and cooling infrastructure

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

Data

1. Utility use of smart grid informatics for operations
2. Improved weather forecasting

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 – Synergy

1. **Integrated Energy Systems**
   1. CHP and trigeneration for building and campus use (possibly with heat pumps)
   2. Cogeneration for industrial uses
2. **Using available electricity that might otherwise be curtailed for other products**
   1. 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**
   1. Solar furnaces
5. **Synthetic natural gas**
6. **Combined transmission opportunities**
   1. Integrated Electric – Hydrogen Transmission – Pipelines
   2. 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 - Synergy

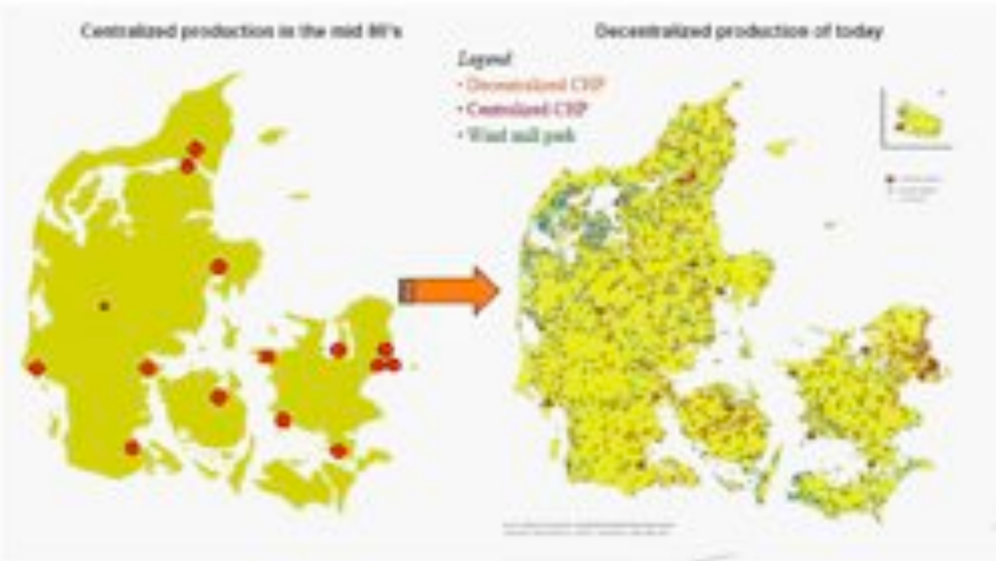
Electrified transportation

1. Plug-in and hydrogen vehicles
2. With and without V2G capabilities
3. On-road inductive charging

Using what is traditionally waste energy

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

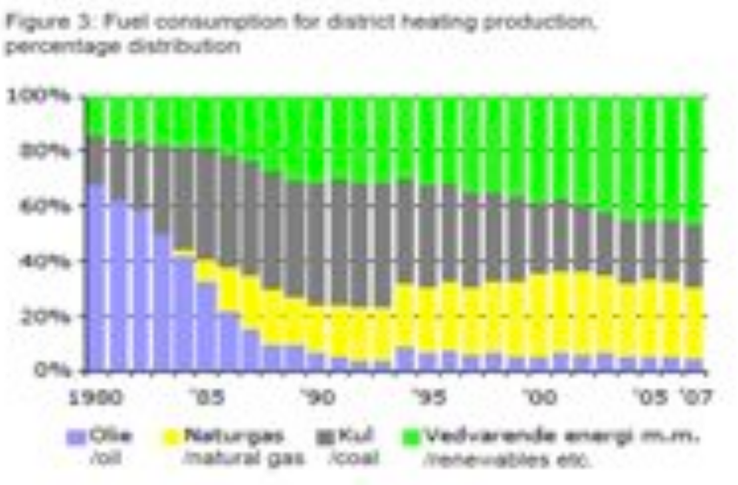
ESI – Integration of CHP and Wind



Denmark

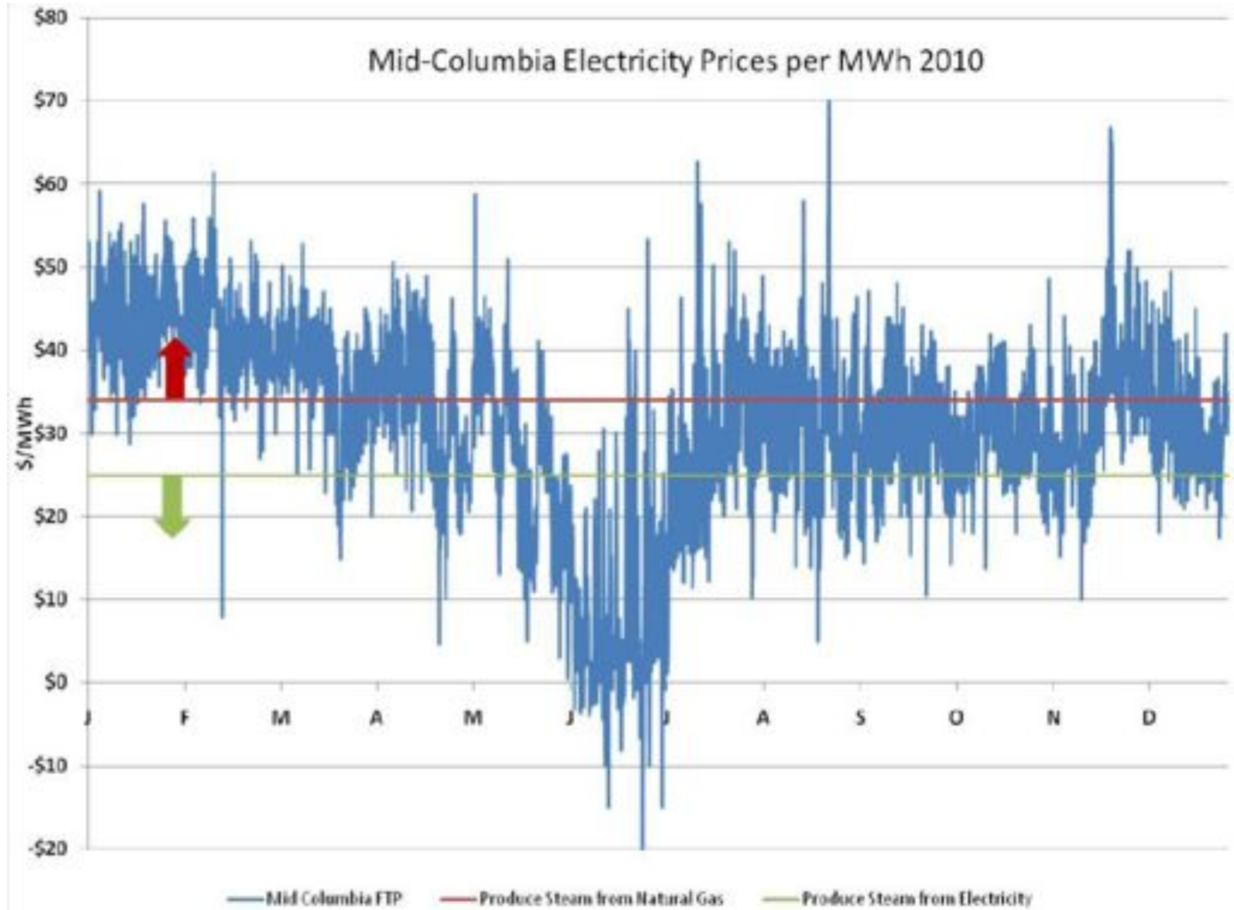
- Small Country (5.5M people) -> about the size of the state of Maryland in USA
- Highly interconnected to neighboring countries which facilitates the import/export of energy

- Integrated combined heat and power has:
  - Dramatically increased efficiency (30 %)
  - Allowed 10 % of electricity from biomass
  - Reduced CO2 emissions by 20 %
  - Increasing the opportunity for natural gas



ESI – Integration of CHP and Wind

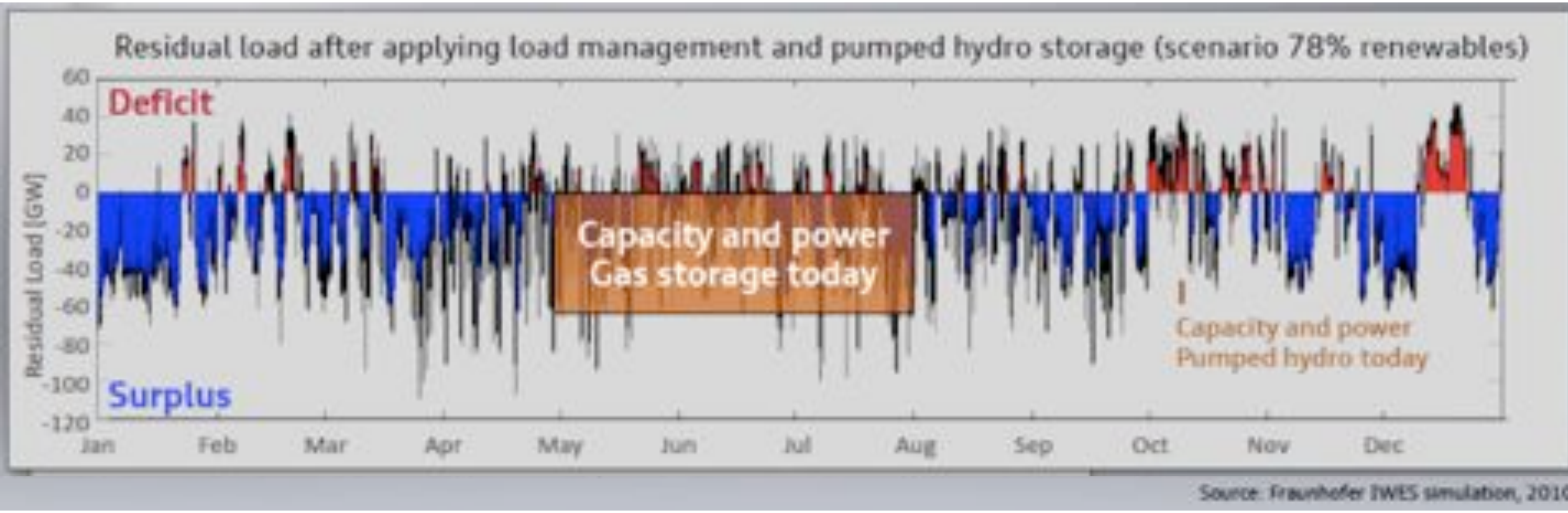
- NG CHP facility can be built with electric steam generators, giving it the ability to use electricity to make heat when surplus electricity is available.
- When there is excess electricity from wind and hydro, the surplus will be used to make steam for delivery to downtown Seattle switching to electric heat within minutes.
- When there is no surplus electricity from wind and hydro, the CHP plant starts and delivers electricity to the system and at the same time makes steam from the waste heat in the combined heat and power cycle.



Virtual electricity storage: Seattle Steam's solution to balancing wind and hydro power
Posted on [December 20, 2013 by districtenergy by Stan Gent]

ESI – Germany – Power to Gas

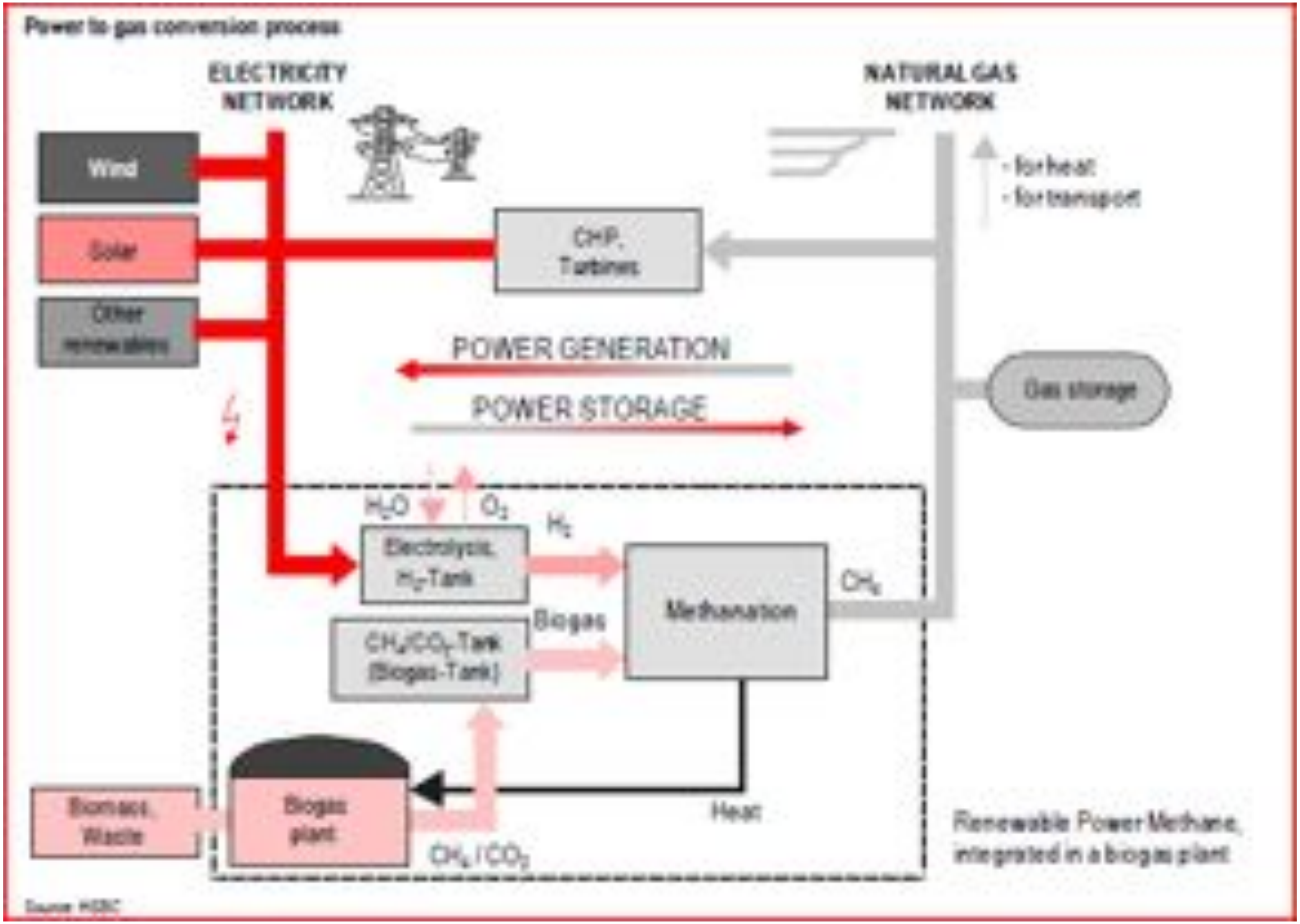
Simulation of German electricity grid with 78% RE, leading to excess power in the German grid



Comparison of different storage technologies in Germany

Gas network has 3,000 times more storage than current pumped hydro

Power to Gas



http://thinkgti.com/case-studies/energy-harvesting/item/56-energy-conversion-power-to-gas

Power to Gas in USA

NREL is partnering with Southern California Gas to evaluate the concept of Power-to-Gas using excess renewable energy

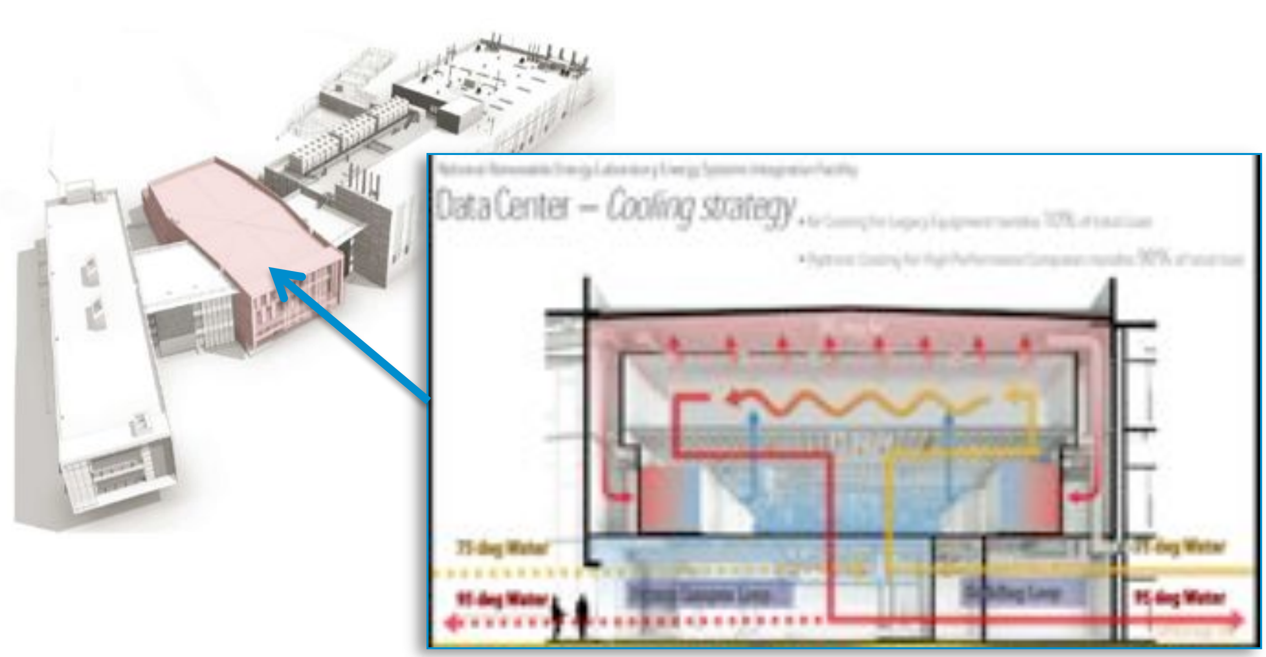
Systems Integration – Integrated variable hydrogen and bio-derived natural gas production for seasonal storage and later power via fuel cells

Three subtasks:

- Develop a power-to-gas storage dynamic simulation model
- Build and operate a small-scale power-to-gas system at ESIF
- Determine value to the grid and to the owner

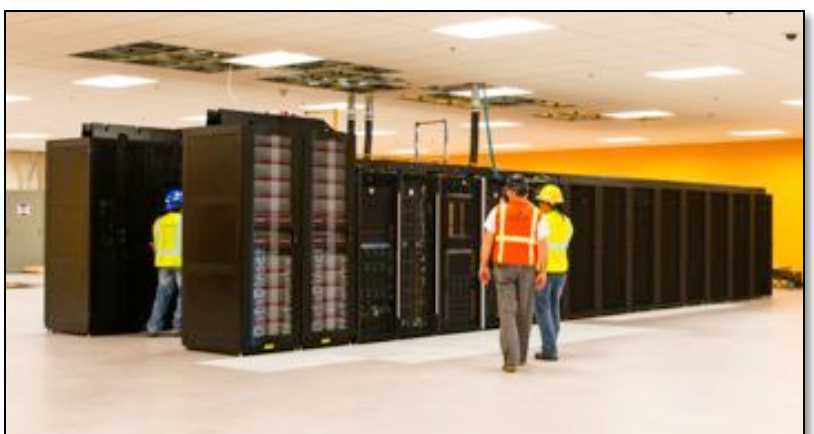
11 TWh storage – shift the entire load of L.A. by 2 months

ESIF - High Performance Computing Data Center



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

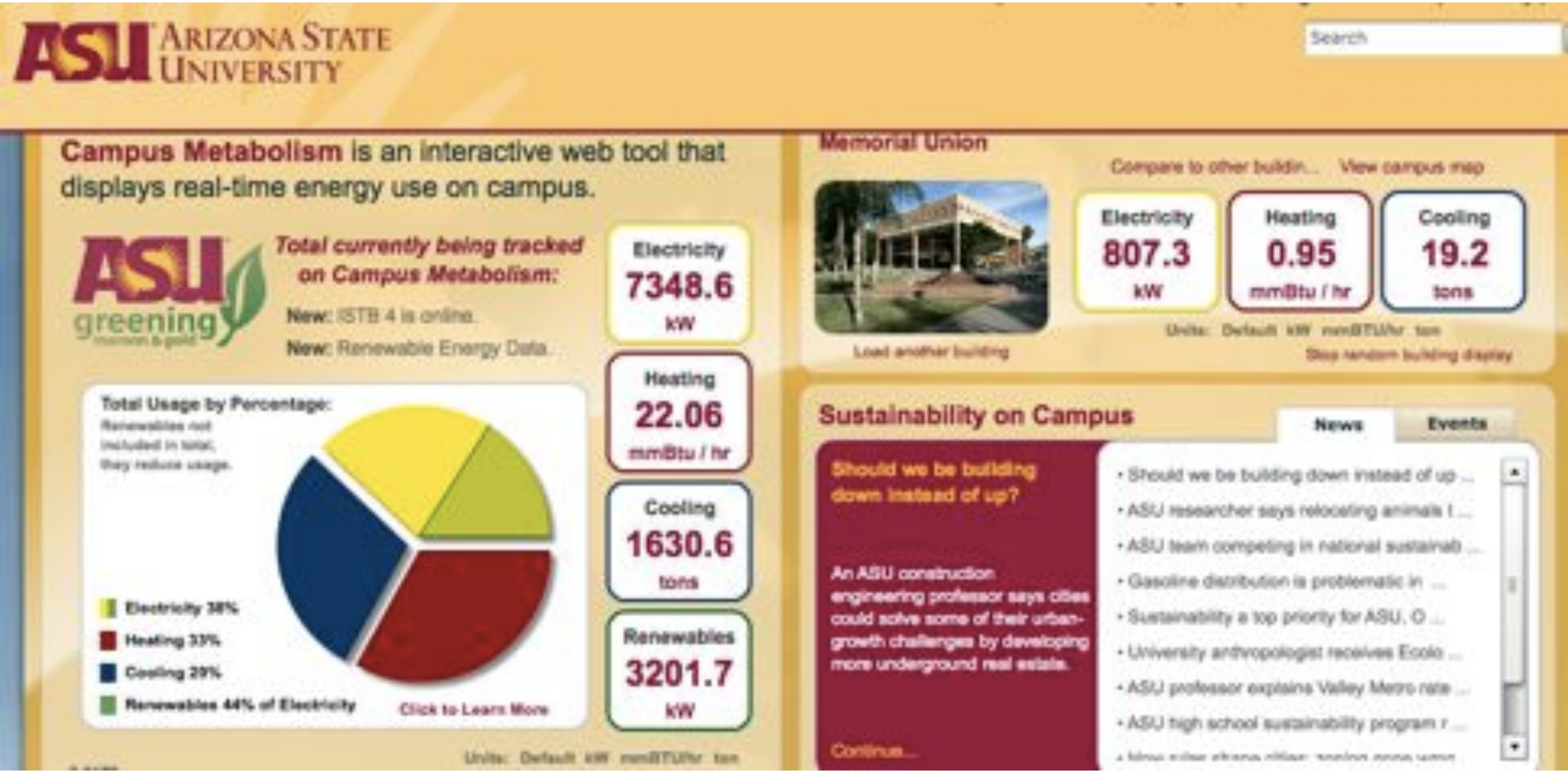
Informed customers as active participants within energy systems

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

Examples

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

ASU – Campus Metabolism



http://cm.asu.edu/#

Customer sited Distributed Energy Storage

Utilities, Commercial Building Owners Win With Distributed Energy Storage - 10/18/2013 - **Doug Staker**, Demand Energy Networks Inc. - Electric light & Power – www.elp.com

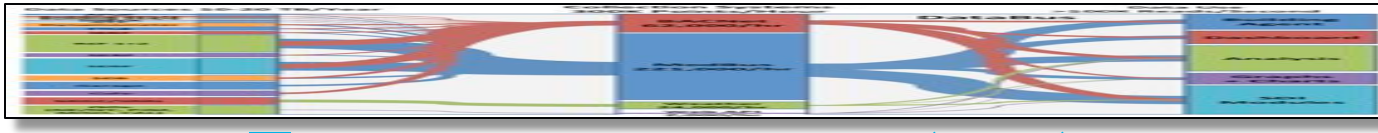
NREL – Campus Energy Project

Data Visualization - Building Dashboard

Data Visualization – End Use Dashboard

NREL Campus Energy - Apps

Energy DataBUS – Data Collection and Analytics



Campus Energy Dashboard

Engaging Occupants with Building Agent

Campus Energy Control and Optimization

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

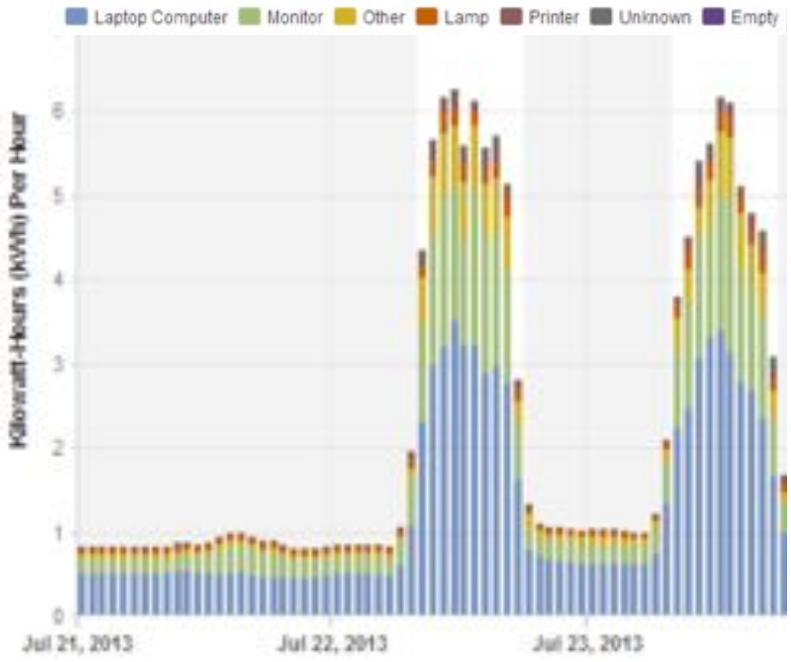
Examples

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

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



Energy Systems Integration Facility (ESIF)

http://www.nrel.gov/esif

NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

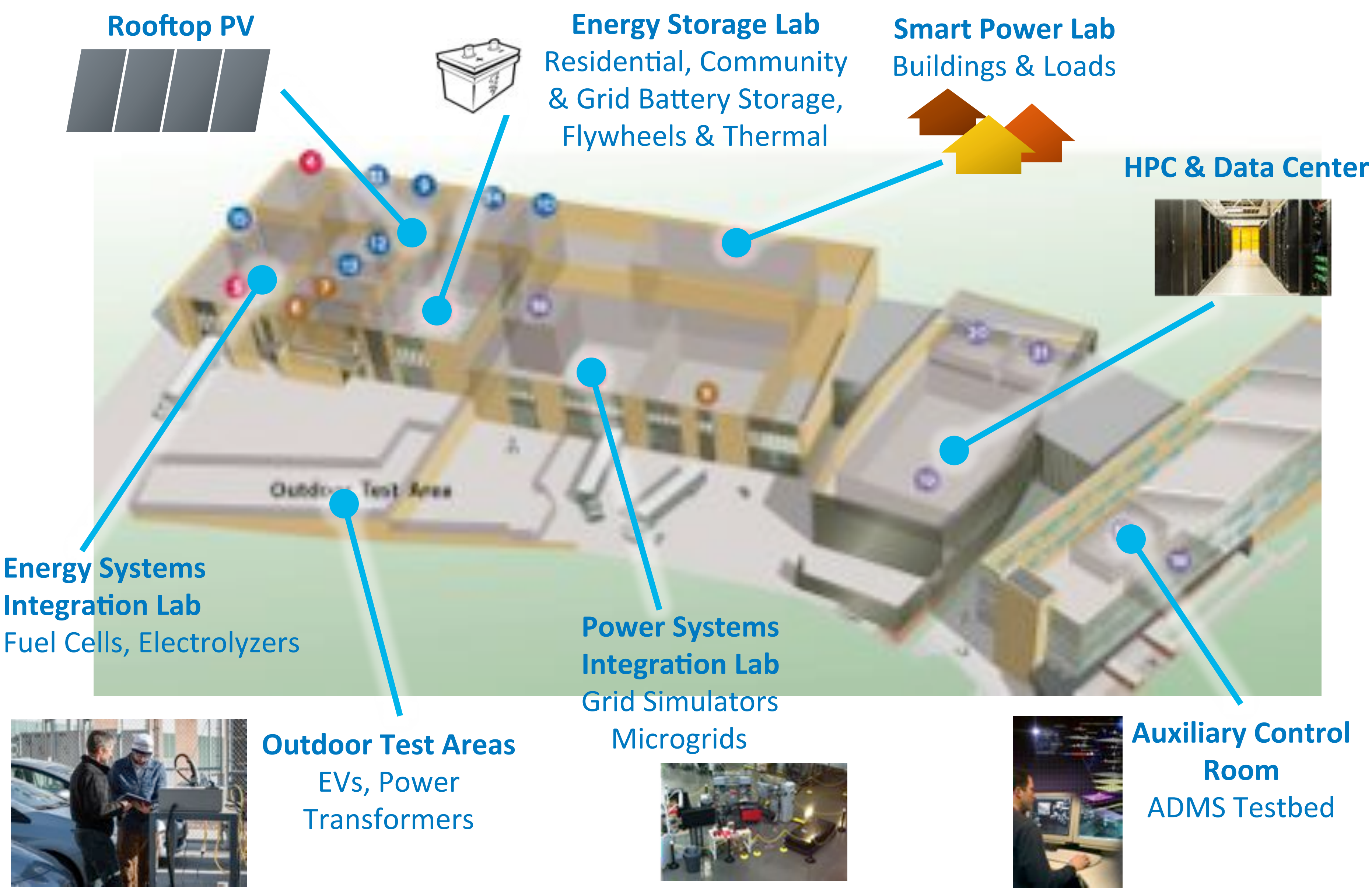
U.S. DEPARTMENT OF ENERGY

Unique Capabilities

- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- MW-scale Power hardware-in-the-loop (PHIL) simulation capability to test grid scenarios with high penetrations of clean energy technologies

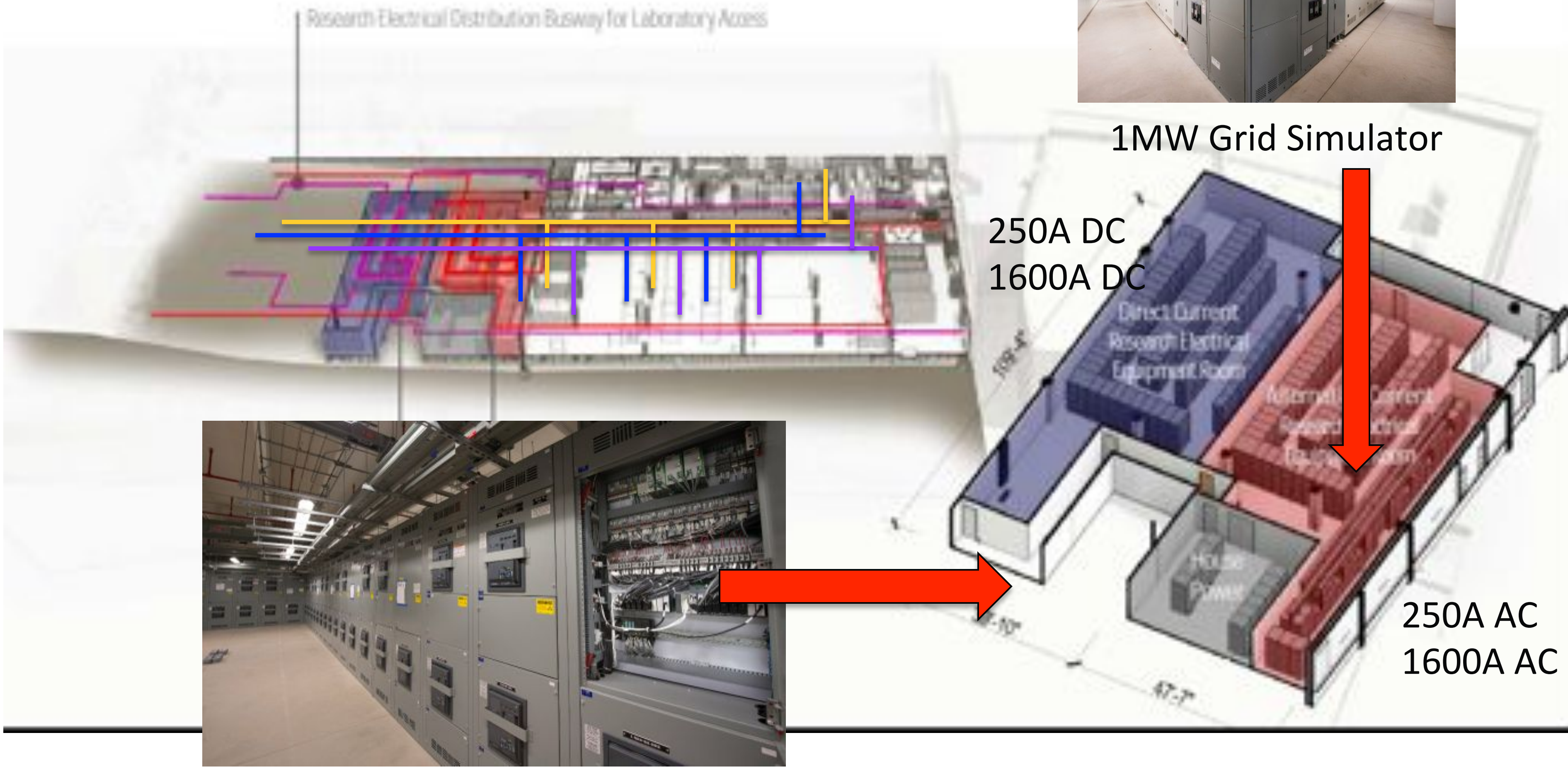
Shortening the time between innovation and practice

ESIF Laboratories

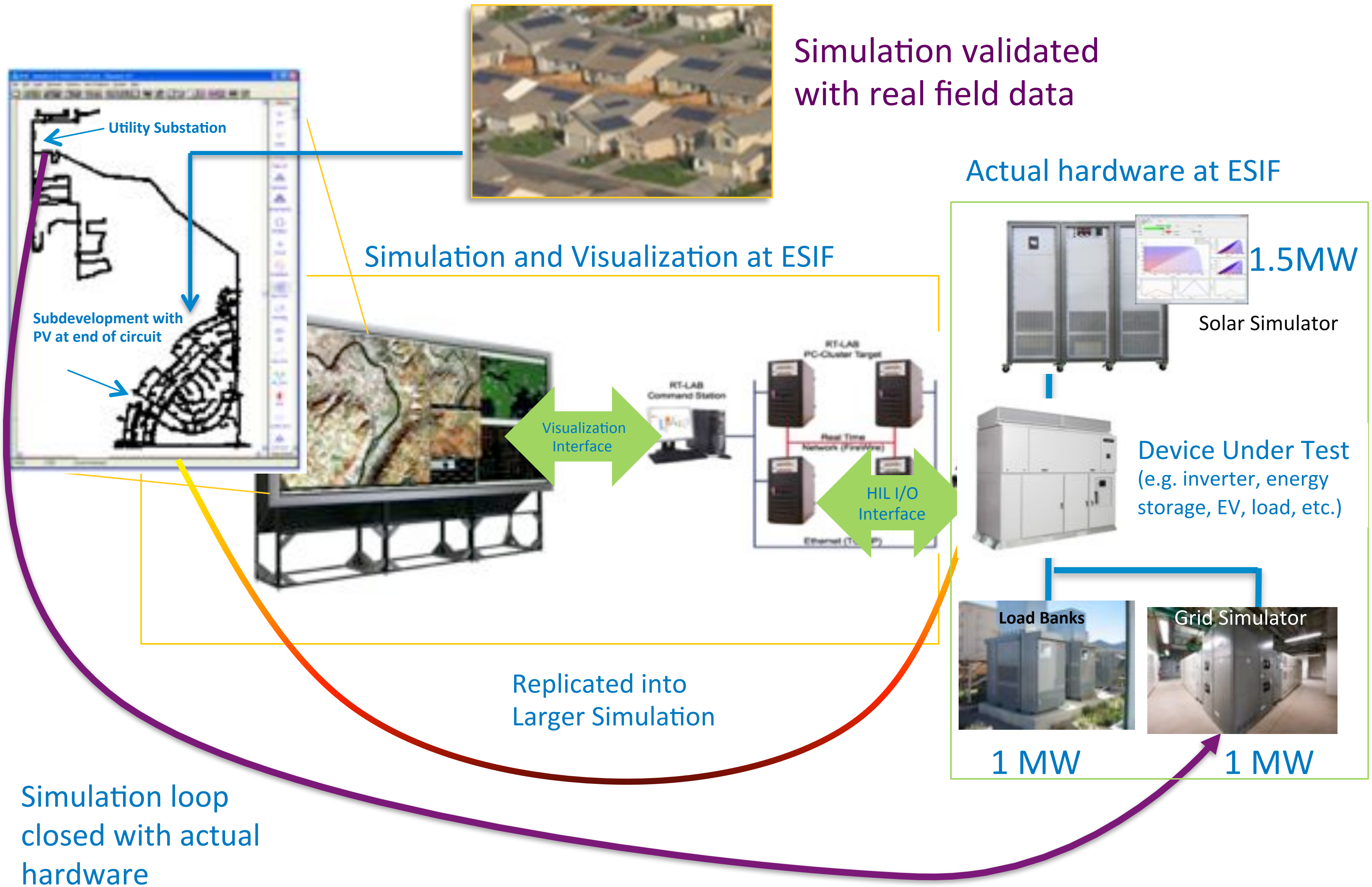


ESIF Research Infrastructure

- Research Electrical Distribution Bus – REDB (AC 3ph, 600V, 1200A and DC +/-500V, 1200A)
- Thermal Distribution Bus
- Fuel Distribution Bus
- Supervisory Control and Data Acquisition (SCADA)



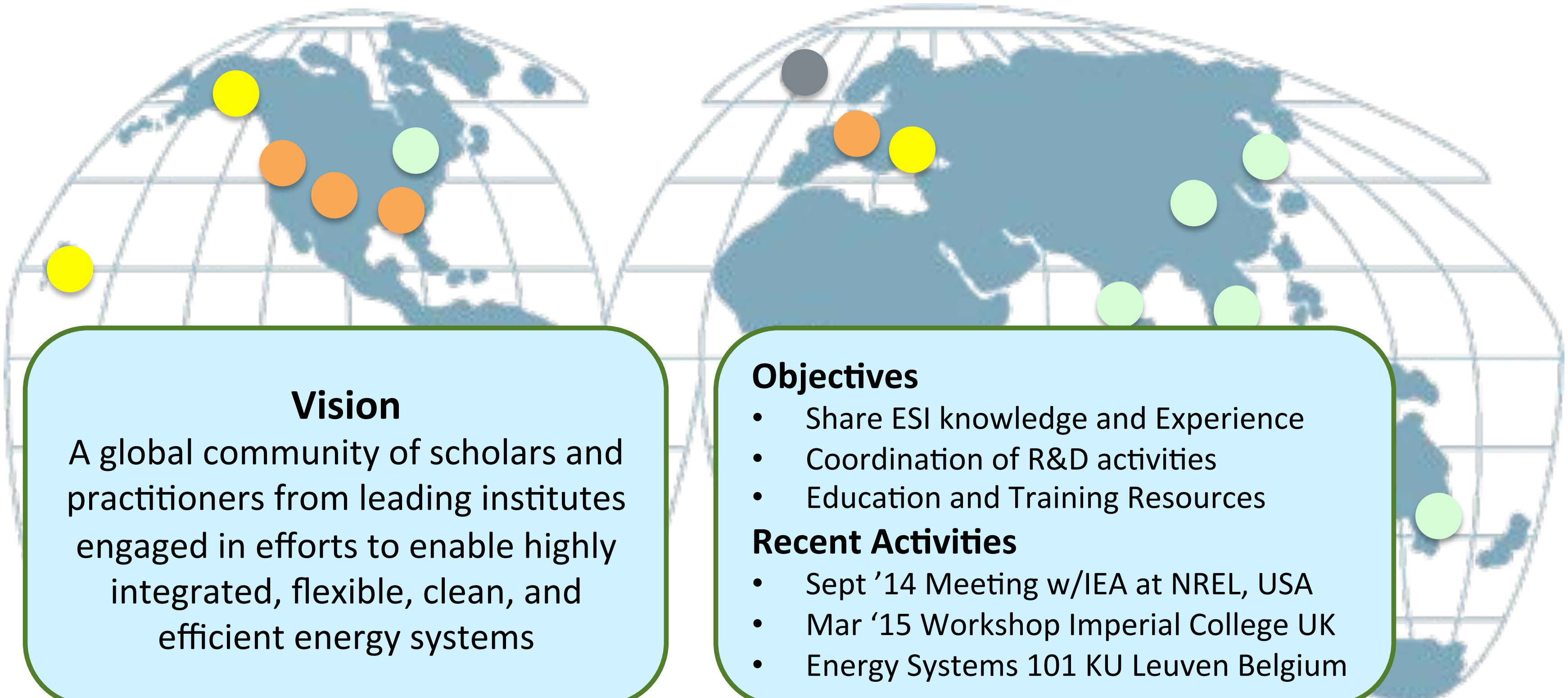
Power Hardware-in-the-Loop: Connecting Experiments to Simulations



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

- Sept '14 Meeting w/IEA at NREL, USA
- Mar '15 Workshop Imperial College UK
- Energy Systems 101 KU Leuven Belgium

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

ESI – IEEE Power & Energy Magazine

Mark O'Malley and Ben Kroposki – Guest Editors (Sept. 2013)

- National-Scale ESI – Jim McCalley, Iowa St.
- EU ESI – John Holms, Oxford
- Danish ESI – Peter Meibom, Danish Energy Association
- China ESI – Chongqing Kang, Tsinghua University
- Hawaii ESI – Dave Corbus, NREL
- Integrating electricity and thermal modeling – Juan Van Roy, KU Leuven

Ben Kroposki, PhD, PE, FIEEE

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National Renewable Energy Laboratory

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
- *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