Value of
Energy Systems Integration

Ben Kroposki & Mark Ruth

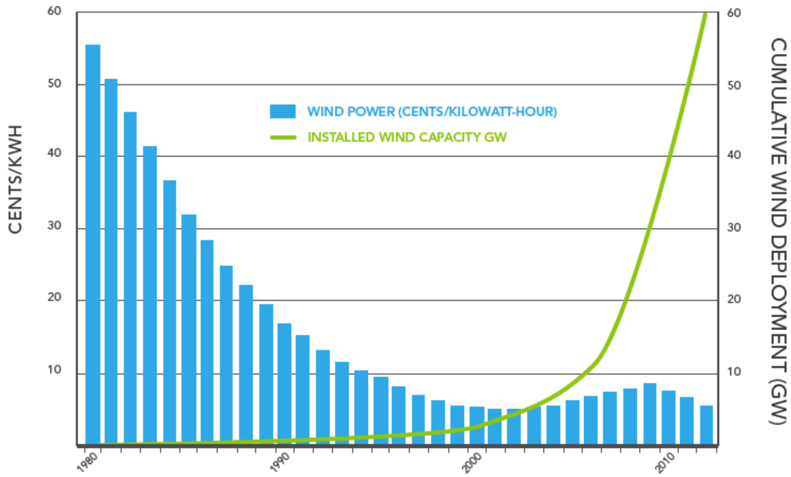
July 2014

Outline

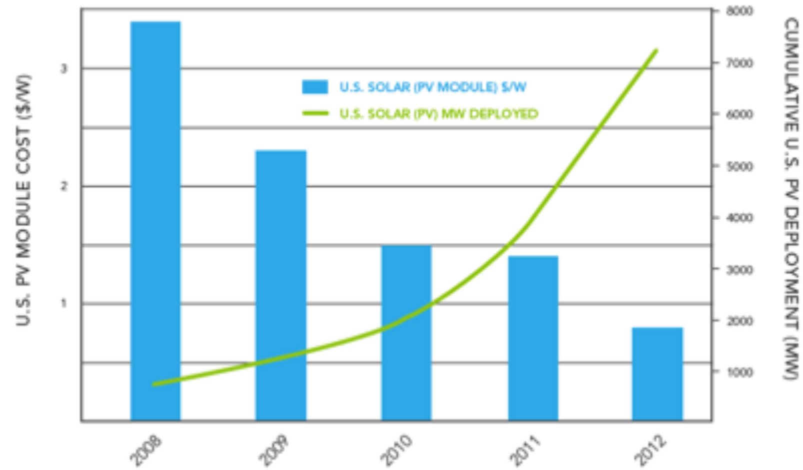
- **Drivers towards ESI**
- **General benefits**
- **Specific opportunity categories**
  - Improving system performance
  - Increasing flexibility at end-use
  - Cross-system integration

Driver – Advances in Energy Technologies

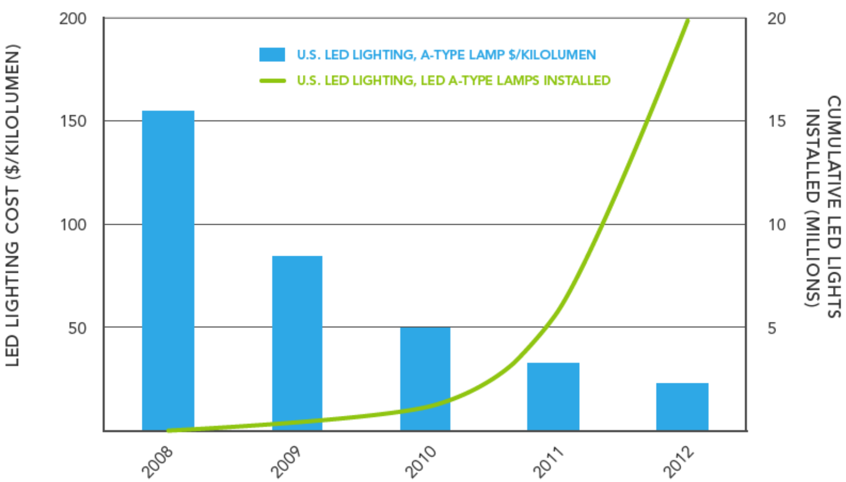
Deployment and Cost for U.S. Land-Based Wind
1980-2012



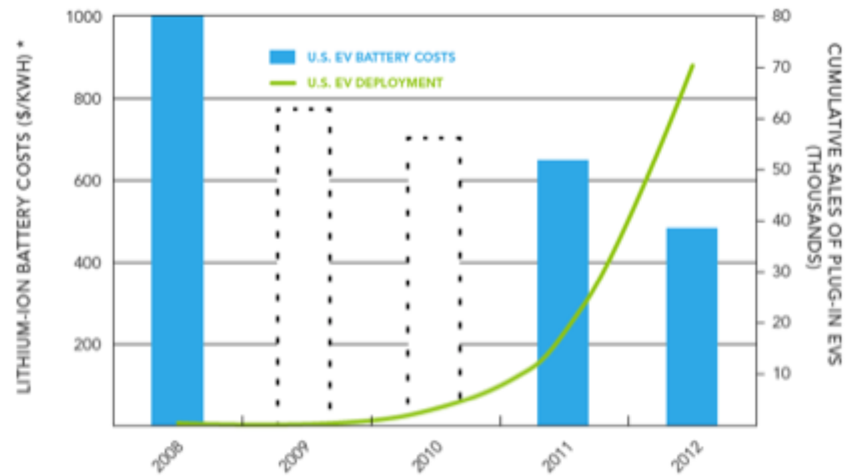
U.S. Deployment and Cost for Solar PV Modules
2008-2012



Deployment and Cost for A-Type LED Lights
2008-2012

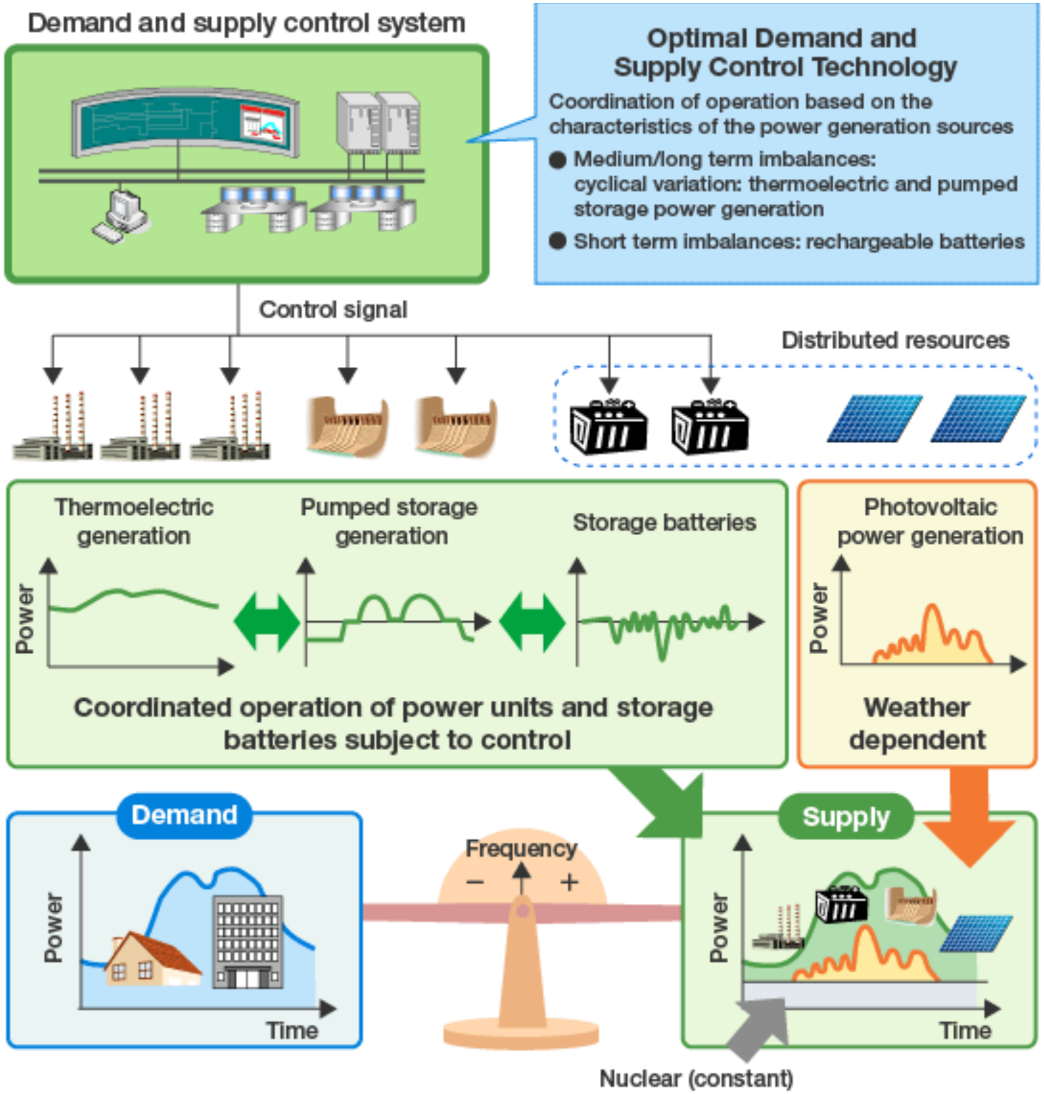


Deployment and Cost for Electric Vehicles and Batteries*
2008-2012

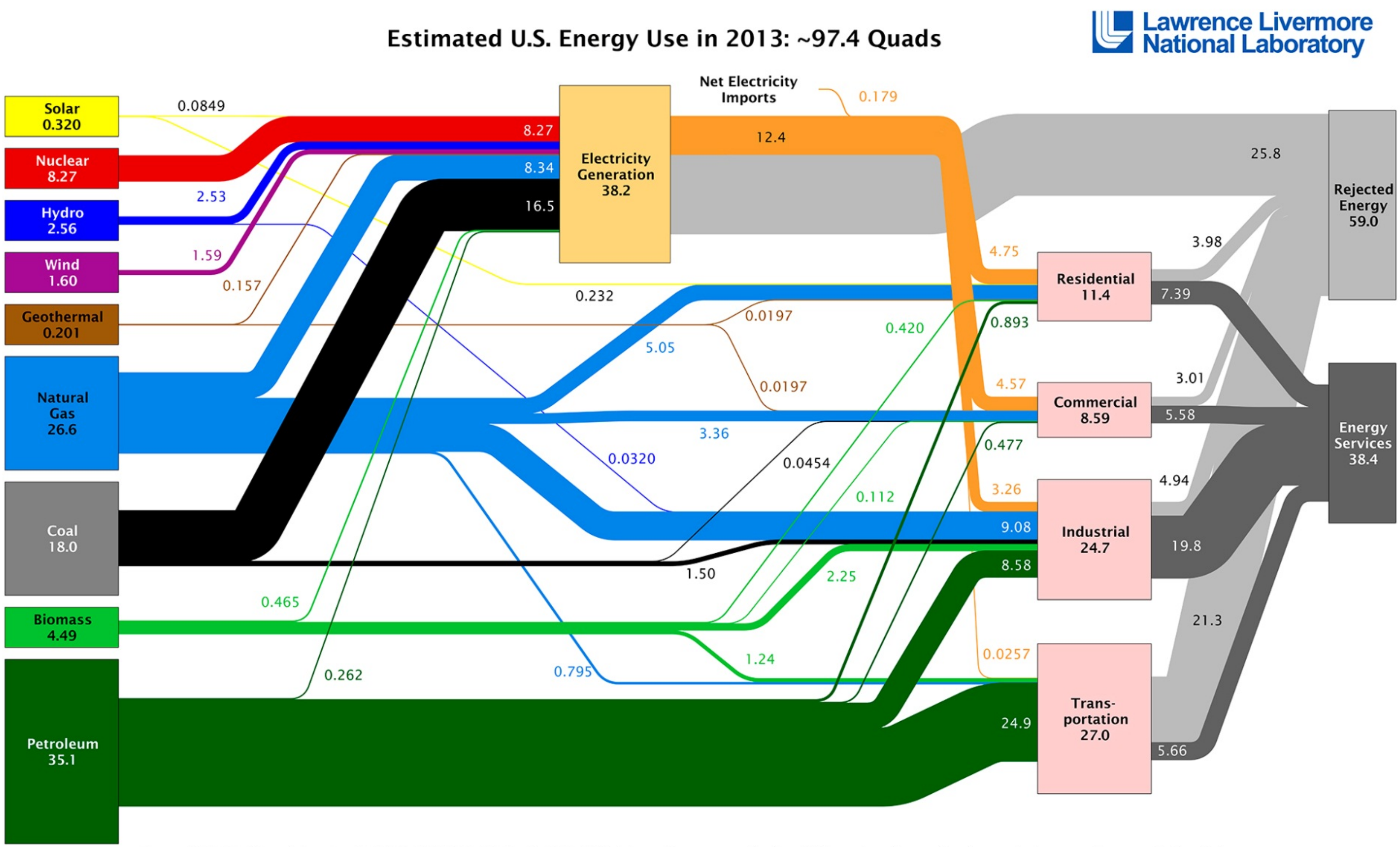


… Can They Create Grid Integration Issues

- High wind and solar means lesser but ***more variable*** use of other assets
- Issues with voltage regulation, protection and coordination can limit PV
- High efficiency, demand response, and new loads are changing demand and making it ***more variable***
- Existing T&D grid increasingly strained by two-way power flow



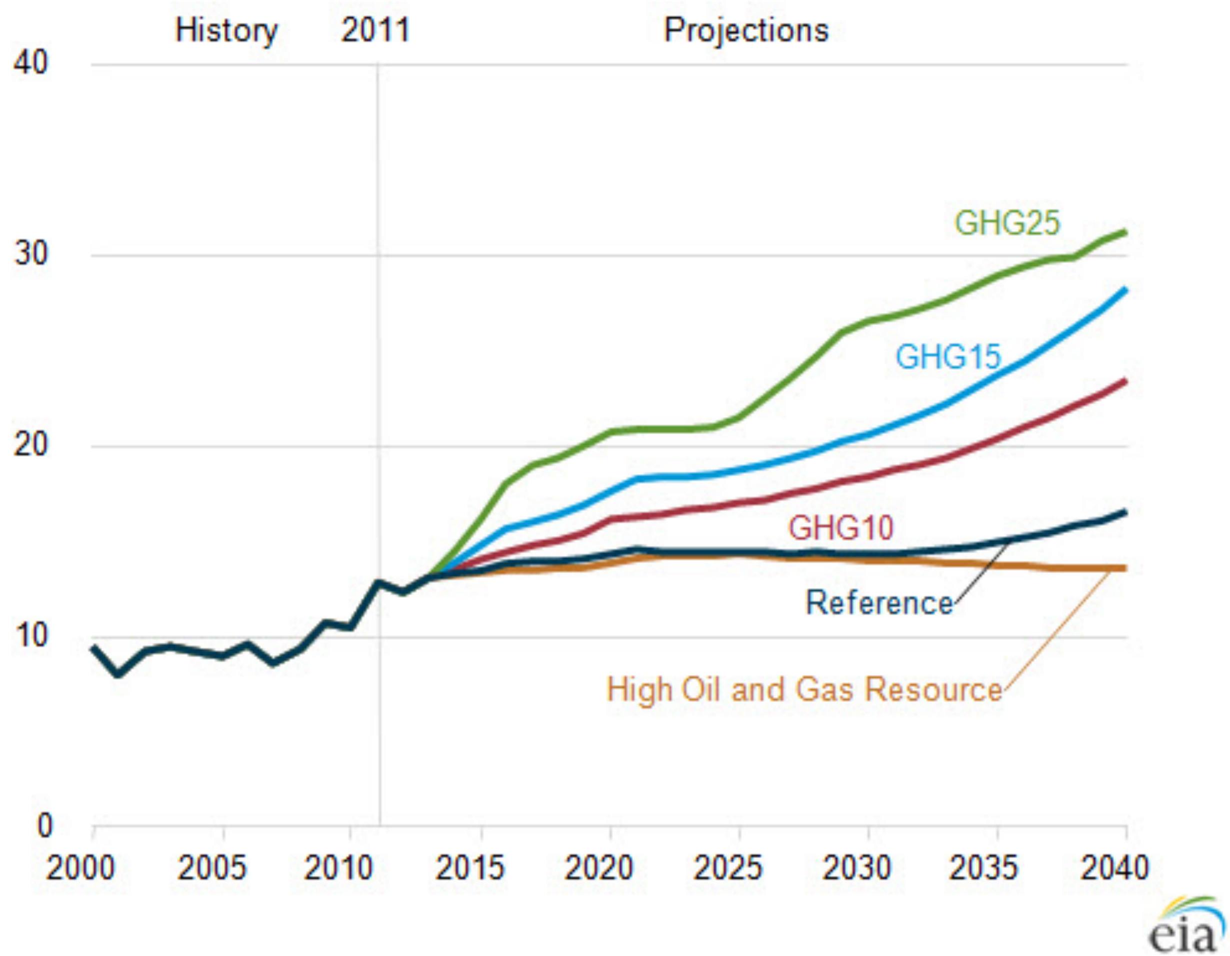
Driver – Sankey Diagram



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Driver - But Challenges Remain…

Figure 8. Renewable energy share of U.S. electricity generation in five cases, 2000-2040 (percent)



- Flat Electricity Demand
- Low Natural Gas Prices
- Wind, Solar Integration Costs
- Regulatory Barriers
- Consumer Value Proposition
- Business Models

General Benefits of ESI

Economic

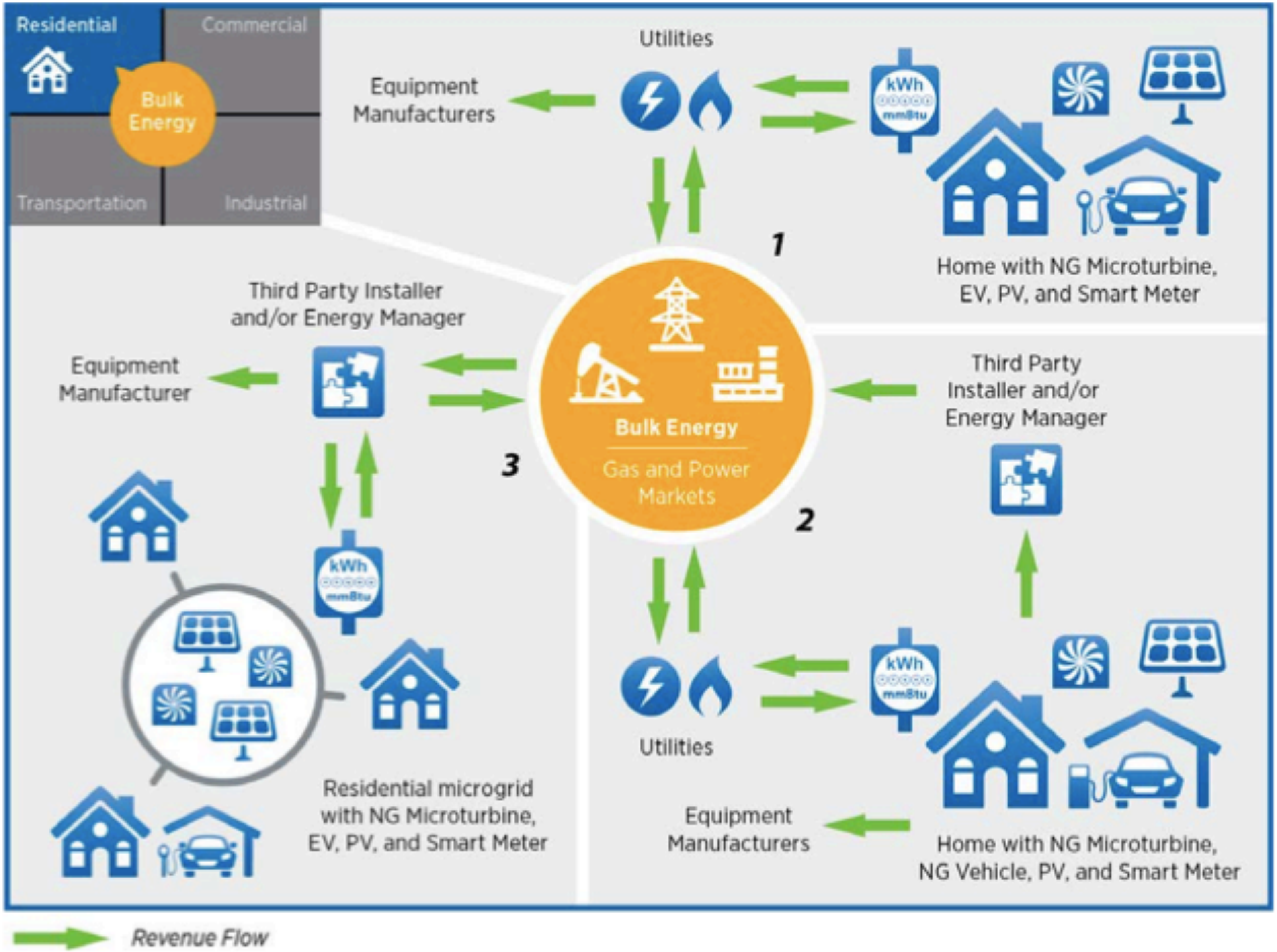
- Cut overall energy use through optimization
- Reduce price volatility through supply diversity
- Increase asset utilization and avoid excess new build
- Capture system losses for valuable reuse
- Enhance system flexibility and resilience to disruption

Environmental

- Enable high penetration of renewable energy
- Reduce air, land and water pollution
- Meet future greenhouse gas reduction goals
- Manage water demands from the energy sector
- Move towards long-term resource sustainability

No single technology or approach can do it alone!

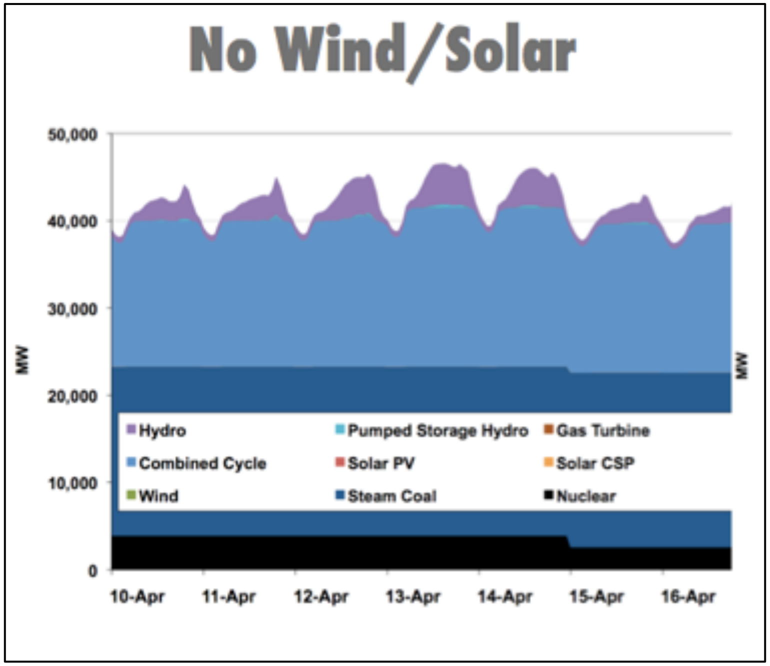
General Benefits – Potential New Business Models

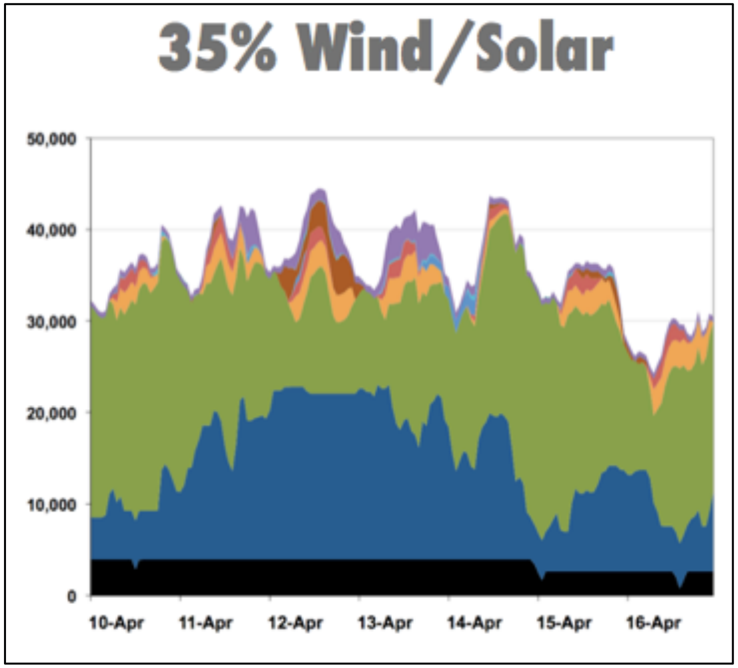


ESI Opportunities

- Integration of new technologies (e.g. variable renewables, electric vehicles, controllable loads) in systems of all scales place demands on the overall system that it was not originally designed to address

Bulk Power System Level





Performance - Interconnections

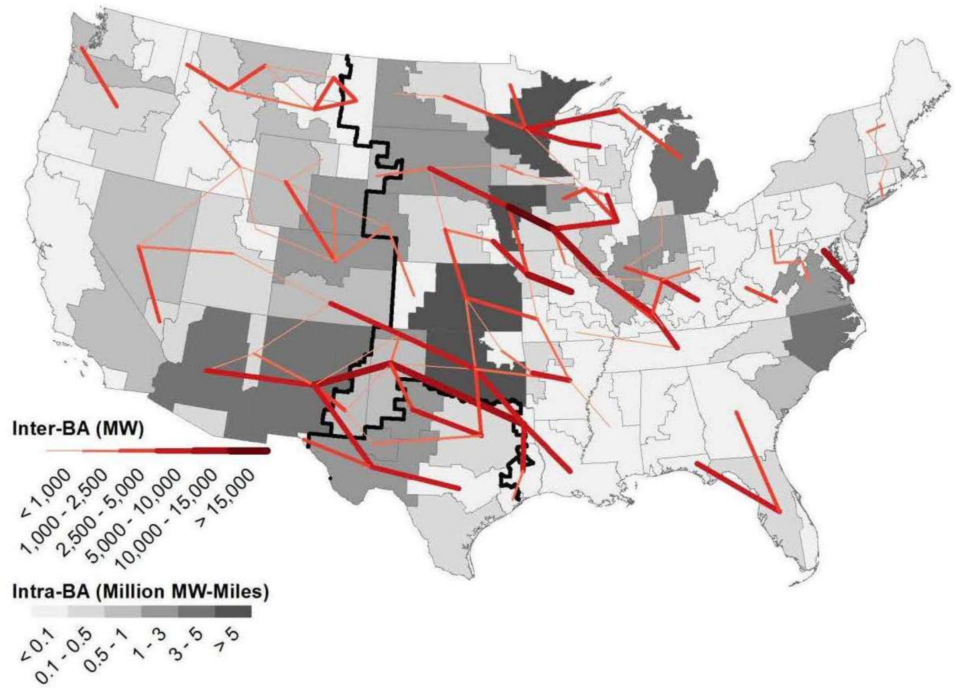


Figure ES-9. New transmission capacity additions and conceptual location in the 80% RE-ITI scenario

Source: Mai, T.; Sandor, D.; Wiser, R.; Schneider, T (2012). Renewable Electricity Futures Study: Executive Summary. NREL/TP-6A20-52409-ES. Golden, CO: National Renewable Energy Laboratory.

- **Connecting balancing areas helps manage ramps in net load with high renewables**
- **REF estimated requirement: 200 million MW-mile transmission and 80 GW of AC-DC-AC interties to achieve 80% renewable electricity generation**

Performance – Smart Grid

- **Energy use and GHG emissions reductions**

Table S.1. Potential Reductions in Electricity and CO_2 Emissions in 2030 Attributable to Smart Grid Technologies

Mechanism	Reductions in Electricity Sector Energy and CO_2 Emissions[(a)] Direct (%)	Indirect (%)
Conservation Effect of Consumer Information and Feedback Systems	3	-
Joint Marketing of Energy Efficiency and Demand Response Programs	-	0
Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings	3	-
Measurement & Verification (M&V) for Energy Efficiency Programs	1	0.5
Shifting Load to More Efficient Generation	<0.1	-
Support Additional Electric Vehicles and Plug-In Hybrid Electric Vehicles	3	-
Conservation Voltage Reduction and Advanced Voltage Control	2	-
Support Penetration of Renewable Wind and Solar Generation (25% renewable portfolio standard [RPS])	<0.1	5
Total Reduction	**12**	**6**

(a) Assumes 100% penetration of the smart grid technologies.

Source: "The Smart Grid: An Estimation of the Energy and CO2 Benefits", R. Pratt, et al. 2010, PNNL-19112 http://energyenvironment.pnnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf.

Performance – Smart Grid

- ## Economic benefits

Exhibit 1

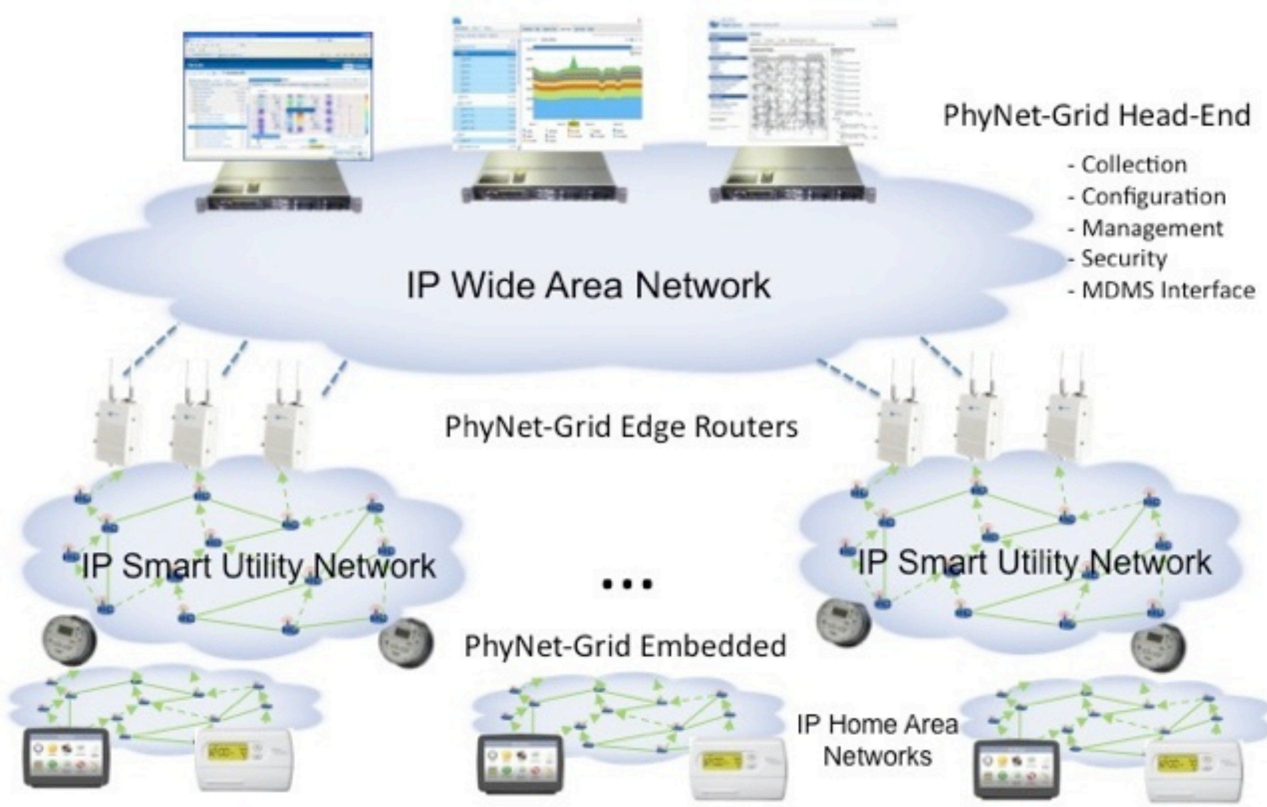
The $130 billion question

The U.S. smart grid value at stake is over $130 billion annually.

Source: "Booth, A.; Greene, M.; Tai, H. "U.S. smart grid value at stake: The $130 billion question" McKinsey on Smart Grid Summer 2010. http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid

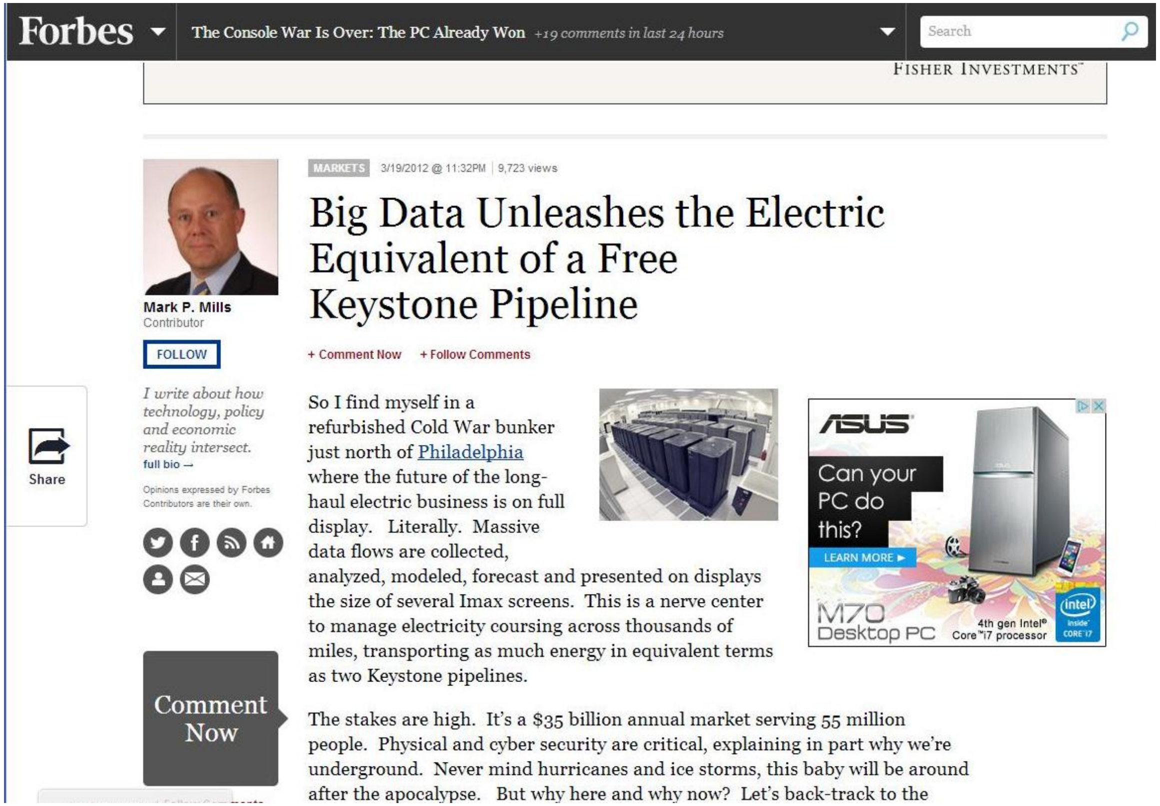
ESI Opportunities

- Data and information about energy system operations is increasing at a rapid rate across disparate systems – opportunity to use this data to make better energy decisions



Performance – Dispatch Optimization

PJM estimates a $200MM investment in analytics for dispatch optimization will result in $500MM annual savings



Forbes The Console War Is Over: The PC Already Won +19 comments in last 24 hours

Search

MARKETS 3/19/2012 @ 11:32PM | 9,723 views

Big Data Unleashes the Electric Equivalent of a Free Keystone Pipeline

Mark P. Mills
Contributor

FOLLOW

I write about how technology, policy and economic reality intersect.
full bio →

Opinions expressed by Forbes Contributors are their own.

+ Comment Now + Follow Comments

Share

So I find myself in a refurbished Cold War bunker just north of Philadelphia where the future of the long-haul electric business is on full display. Literally. Massive data flows are collected, analyzed, modeled, forecast and presented on displays the size of several Imax screens. This is a nerve center to manage electricity coursing across thousands of miles, transporting as much energy in equivalent terms as two Keystone pipelines.

Comment Now

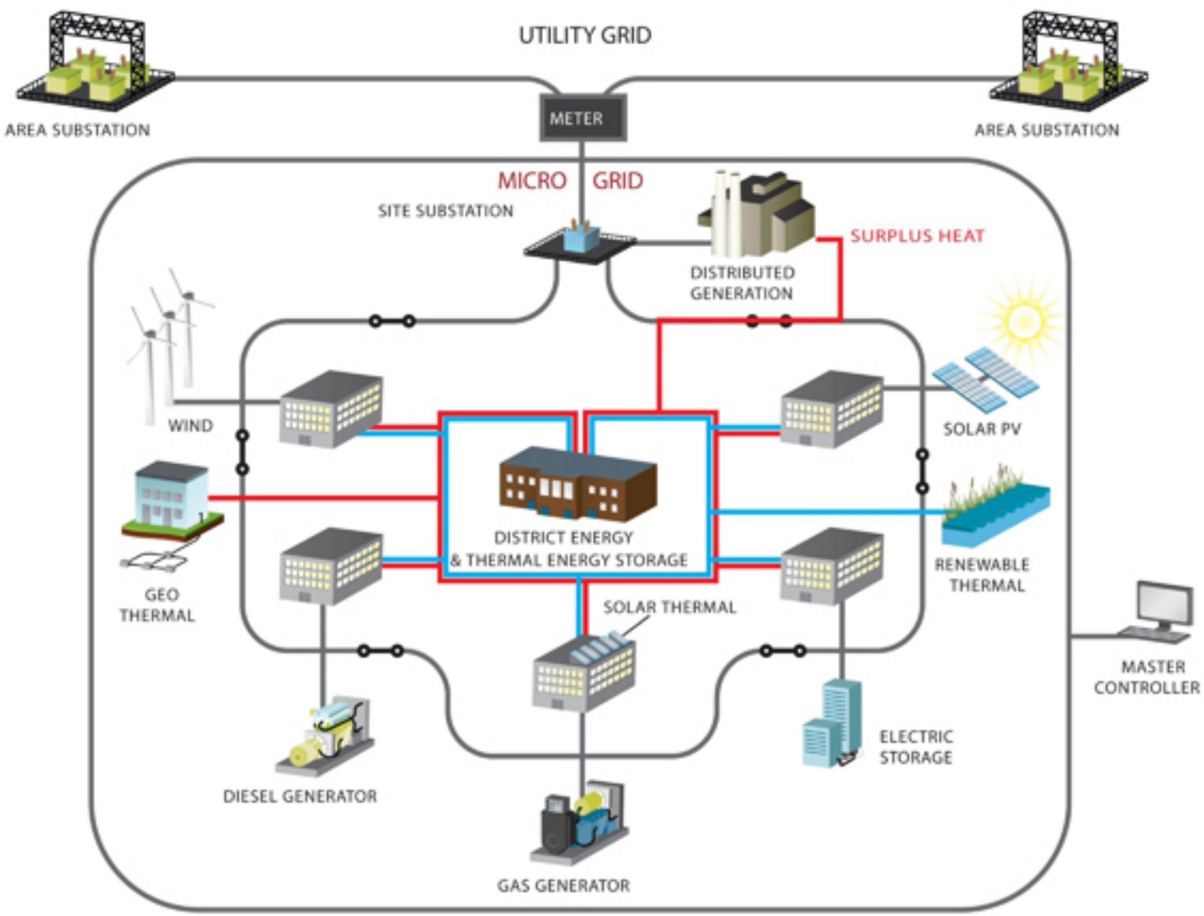
The stakes are high. It's a $35 billion annual market serving 55 million people. Physical and cyber security are critical, explaining in part why we're underground. Never mind hurricanes and ice storms, this baby will be around after the apocalypse. But why here and why now? Let's back-track to the

Source: 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/2/

Performance – Improving Resilience

Large power outages cost the nation $18-$33 billion annually and were as high as $75billion in 2012 (Hurricane Ike).

Microgrids can be resilient and reduce losses.



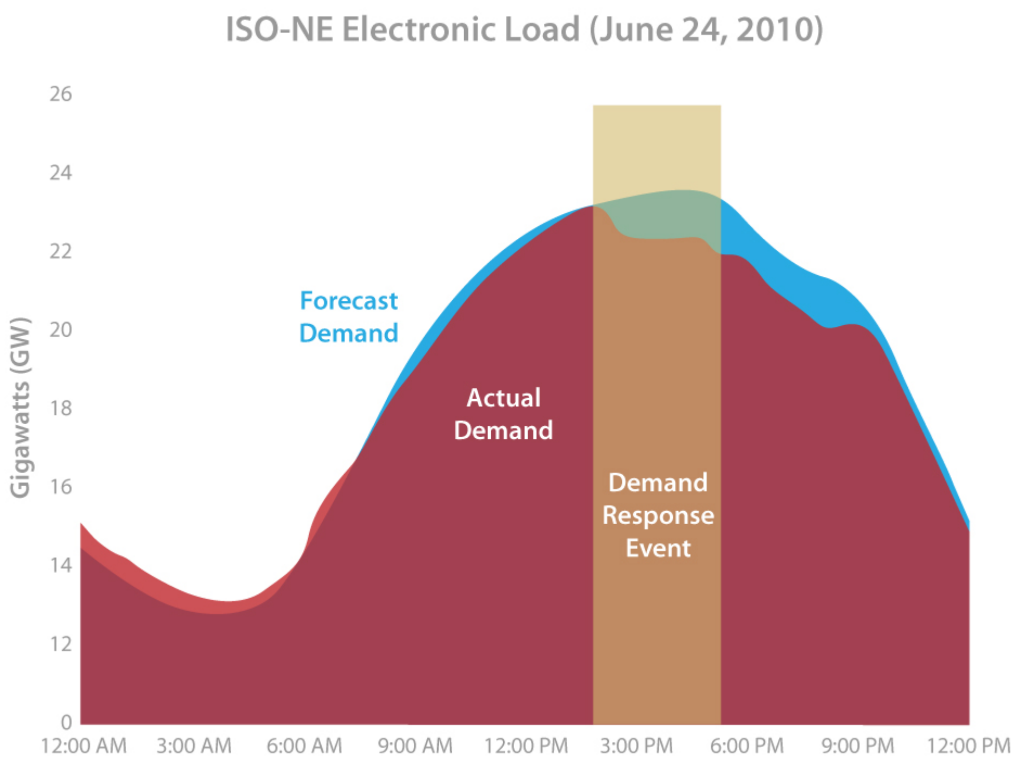
Credit: Preliminary Microgrid Study Findings, Tom Bourgeois, Pace Energy and Climate Center

Source: Economic Benefits of Increasing Electric Grid Resilience to Weather Outages, http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf

Flexibility – Demand Response

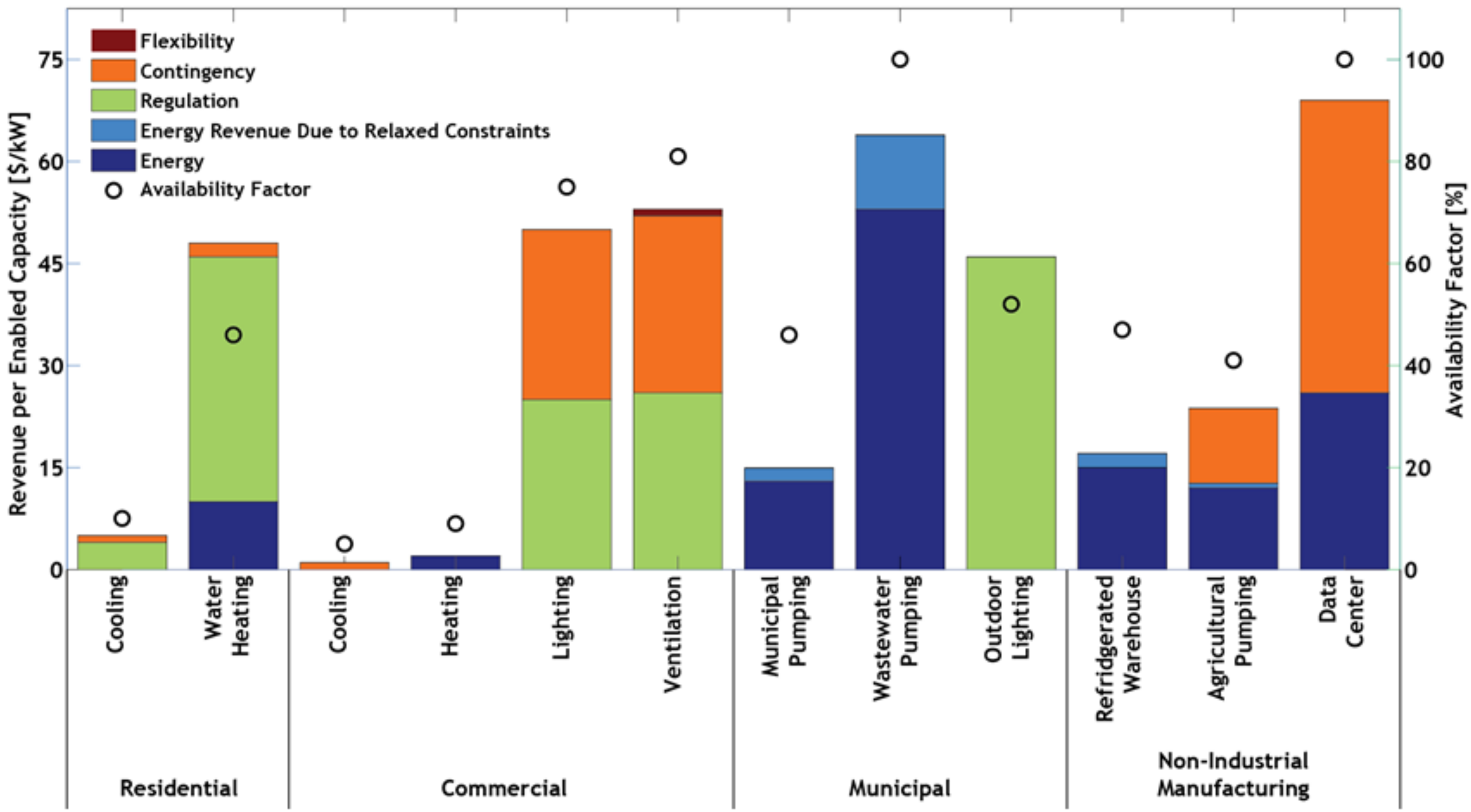
DR can reduce both capacity and energy requirements

- **A McKinsey study estimates the value of 10% DR to be $17 billion / yr and 4% reduction in electricity generation.**
- **Another study estimated 1.5%-6% reduction in generation in Europe.**



Sources: McKinsey & Company. (2010). *McKinsey on Smart Grid*. Available at: http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid
Capgemini. (2010). '*Demand Response : a decisive breakthrough for Europe How Europe could save Gigawatts , Billions of Euros*'. Available at: http://www.vaasaett.com/wp-content/uploads/2010/01/0805_Demand-Response_PoV_Final.pdf

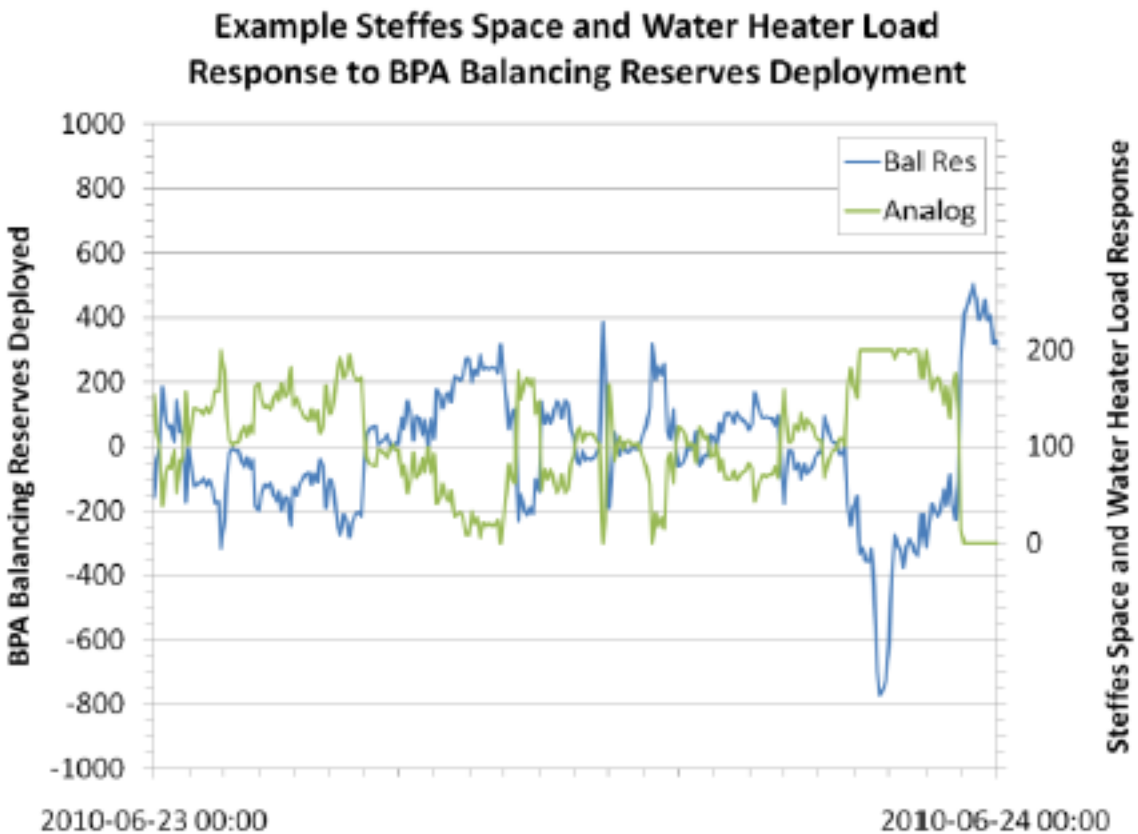
Flexibility – Non-Capacity Value of DR



Source: Hummon, M.; Palchak, D.; Denholm, P.; Jorgenson, J.; Olsen, D. J.; Kiliccote, S.; Matson, N.; Sohn, M.; Rose, C.; Dudley, J.; Goli, S.; Ma, O. (2013). Grid Integration of Aggregated Demand Response, Part 2: Modeling Demand Response in a Production Cost Model. 72 pp.; NREL Report No. TP-6A20-58492.

ESI Opportunities

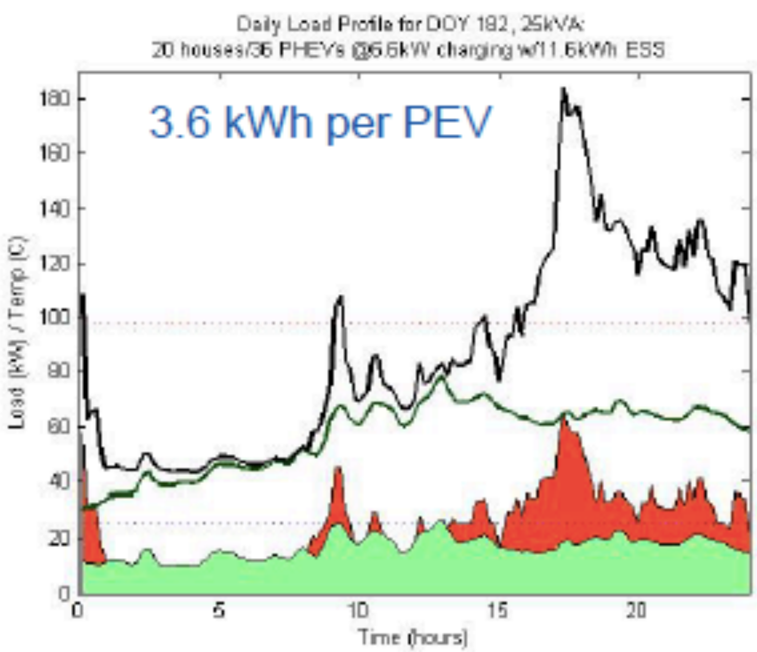
Responsive loads respond to RE variability

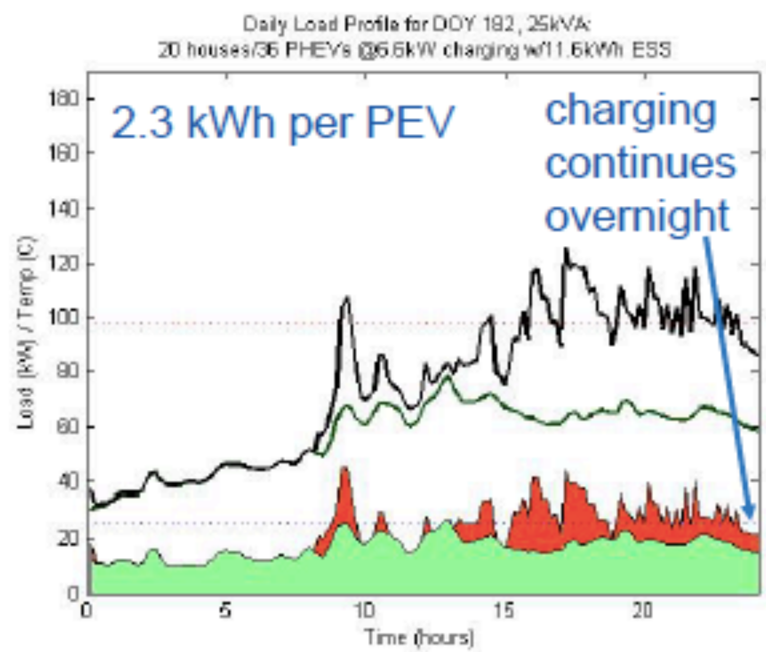


ESI Opportunities

Smart Charging can reduce system impacts for EVs

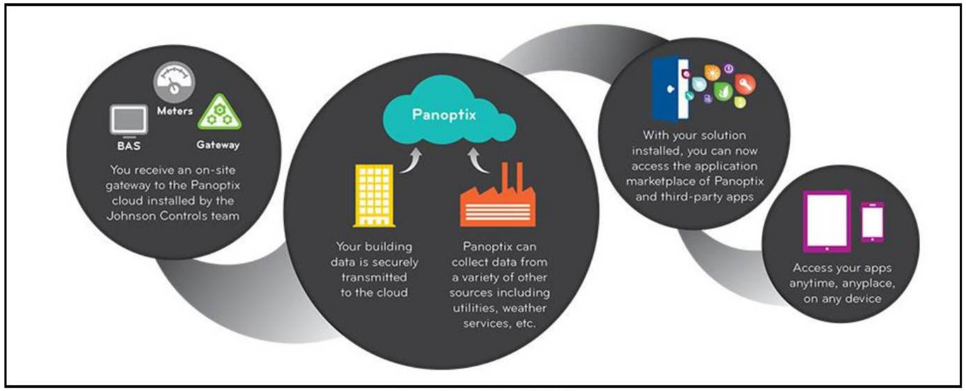
- Simple 1-way communication tells vehicles to delay charging when transformer temperature rises above 98°C threshold
- Temperature input could be measurement- or model-based
- Smart Grid extends capacity of 25kVA transformer





Flexibility – Intelligent Controls in Buildings

Figure 5. Panoptix System by Johnson Controls



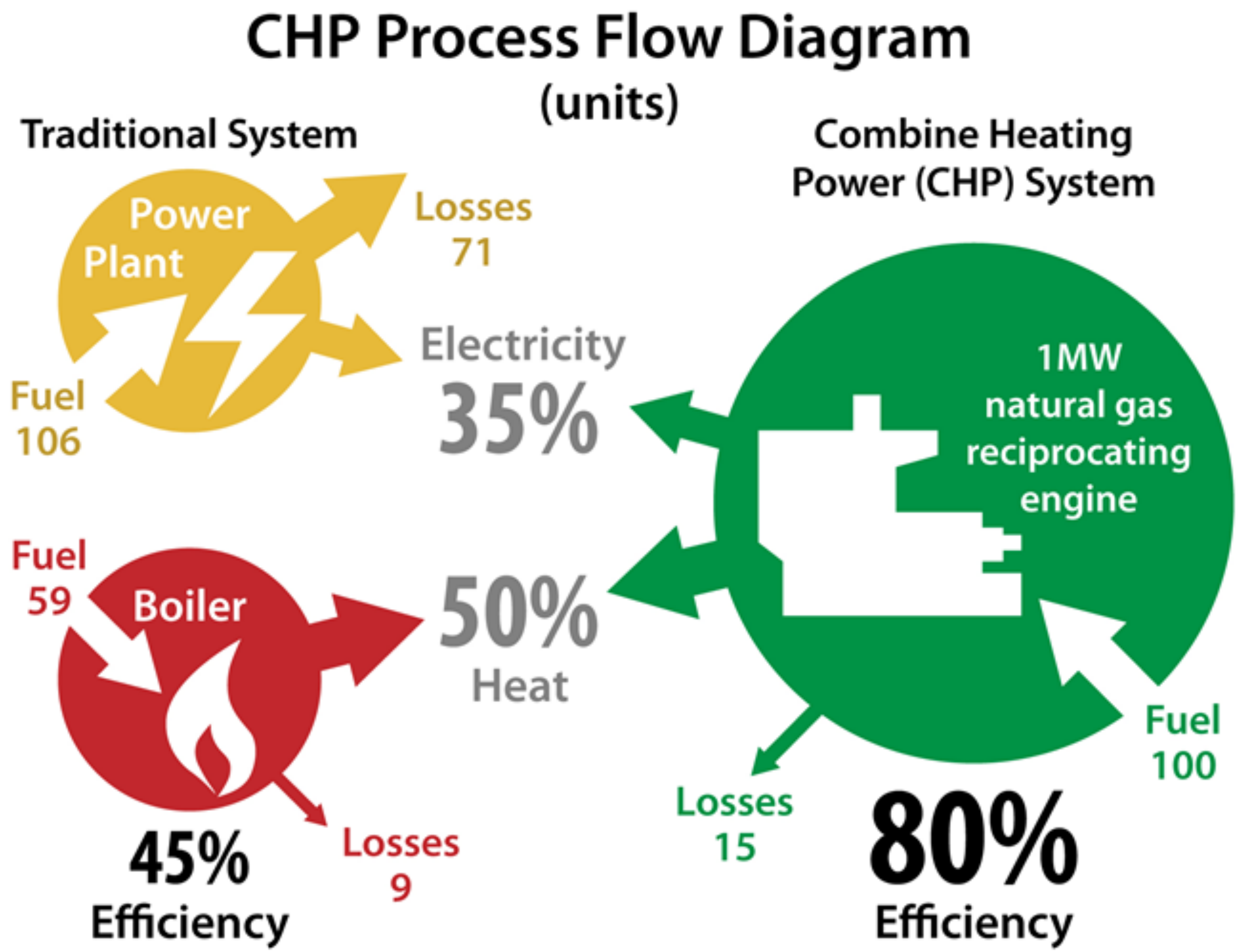
Source: Panoptix website3

Table 4: Intelligent Energy Measures for Commercial Sector

Energy Measure	Range of Savings from Literature Search	Estimate Use in Economic Analysis
Smart Building Components	5–20%	10%
Smart Lighting	Up to 75%	35%
Smart HVAC Components	15%	10–15%
Advanced BMS	10–30%	10–20%
Smart Grid	10%	10%
User Interfaces	10—20%	10%
Office Equipment and Cloud Computing	2--50%	50%
Refrigeration Energy Management	30%	30%
Smart Fume Hoods	10—30%	15%
Miscellaneous Measures	20—50%	2%

Source: Rogers, E.A.; Elliott, R.N.; Kwatra, S.; Trombley, D.; Nadadur, V. "Intelligent Efficiency: Opportunities, Barriers, and Solutions" American Council for an Energy-Efficient Economy Report Number E13J (October 2013).

Cross-system: Combined Heat & Power



Cross-system - CHP with District Heating in Denmark

- 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

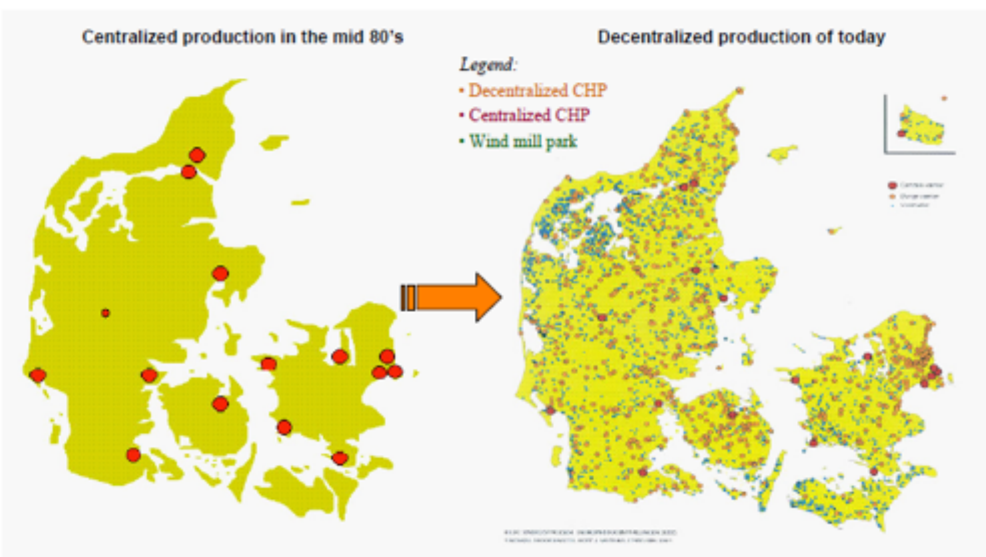
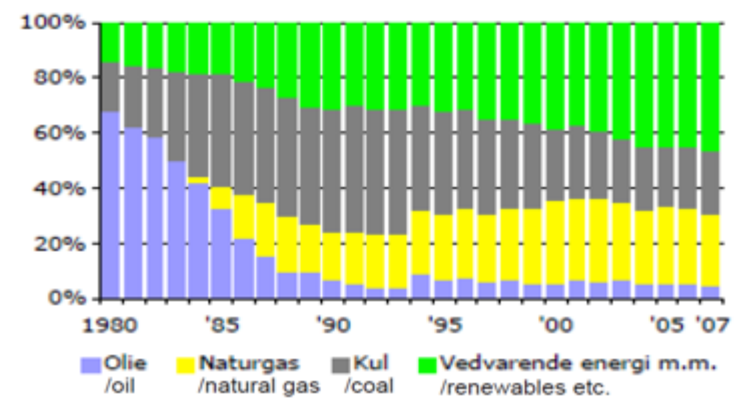
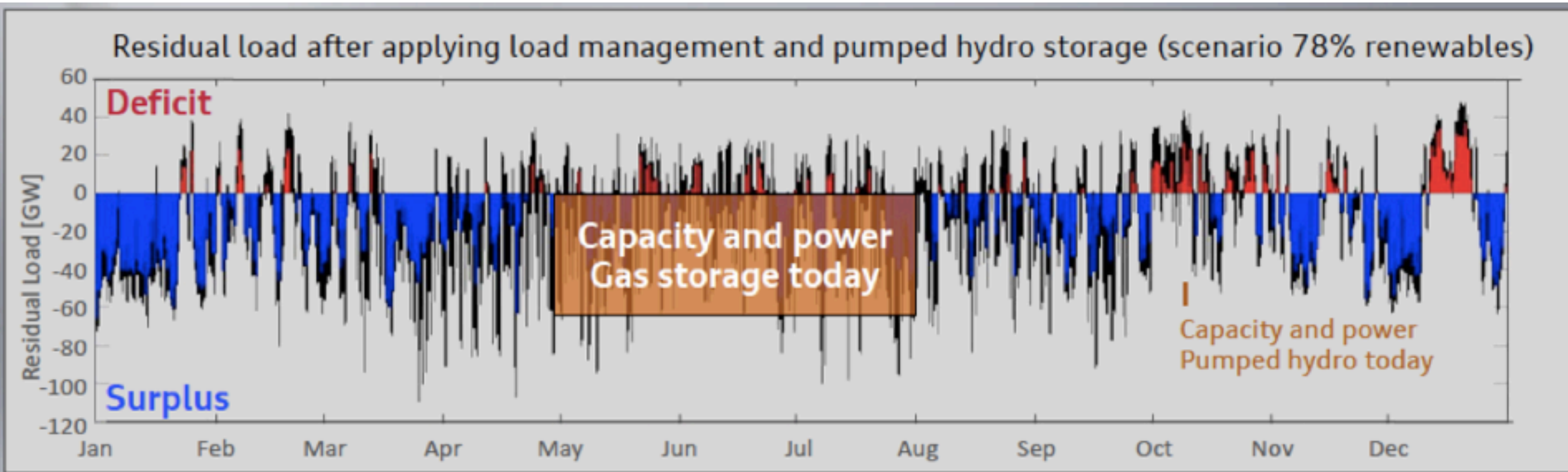


Figure 3: Fuel consumption for district heating production, percentage distribution



Cross-system – Power to Gas - Germany

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



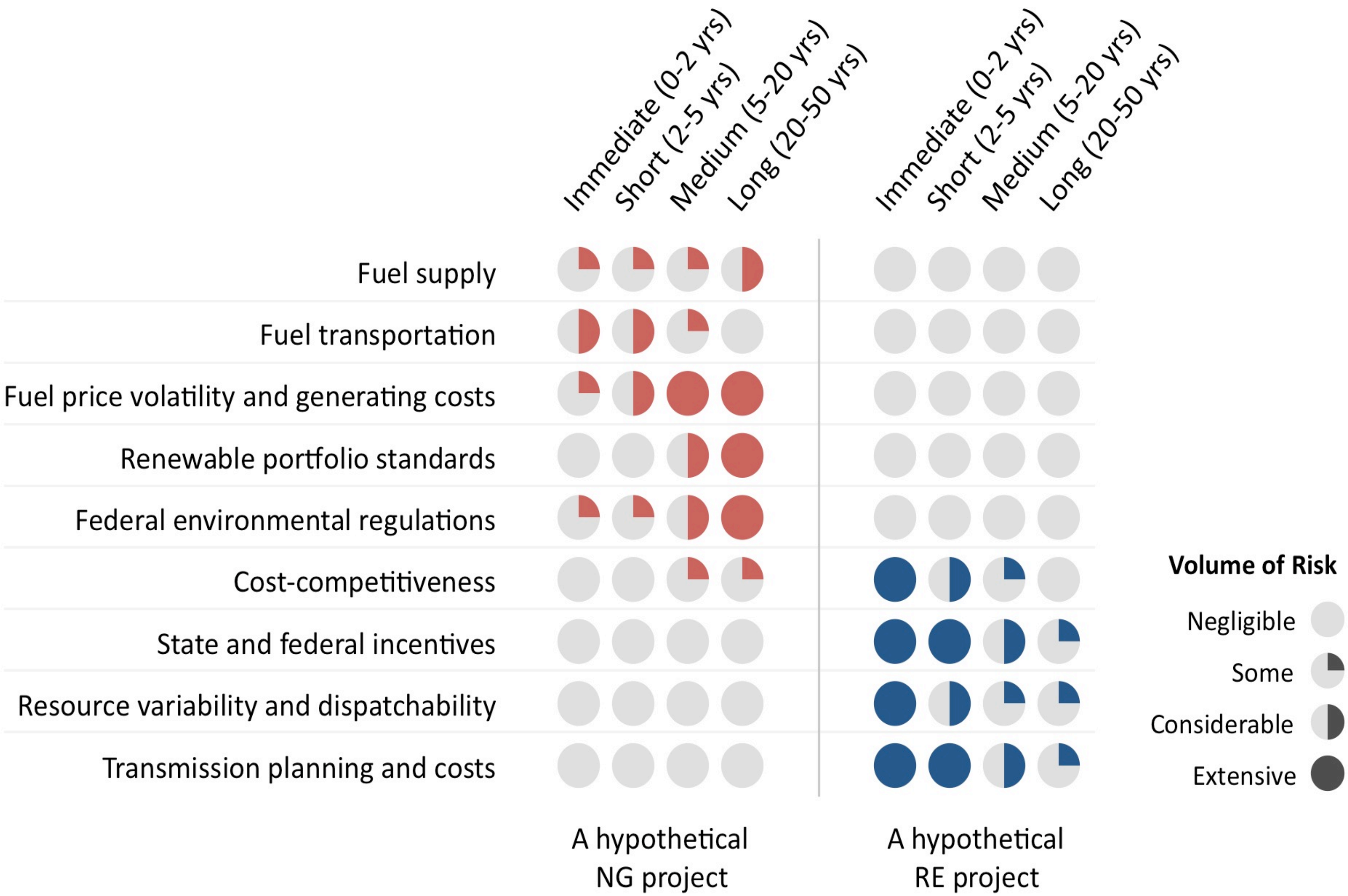
Source: Fraunhofer IWES simulation, 2010

	Pumped storage, batteries: **app. 0.04 TWh_{el}**	
	Capable of supplying Germany for:	**< 1 hour**
	Electromobility: **max. 45 million cars @ 10 kWh_{el} → 0.45 TWh_{el}**	
	Capable of supplying Germany for:	**6 hours**
	Gas network: **220 TWh_{th} ~ app. 130 TWh_{el}**	
	Capable of supplying Germany for:	**2 months**

Comparison of different storage technologies in Germany

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

Cross-system - Natural Gas & Renewables: Opportunities for Synergies



Lee, Zinaman, Logan, Arent, Bazlian, Newmark: Electricity Journal Dec 2012

Cross-system - PV + Battery

FIGURE 1: OFF-GRID VS. UTILITY PRICE PROJECTIONS
COMMERCIAL - BASE CASE
[Y-AXIS 2012$/kWh]

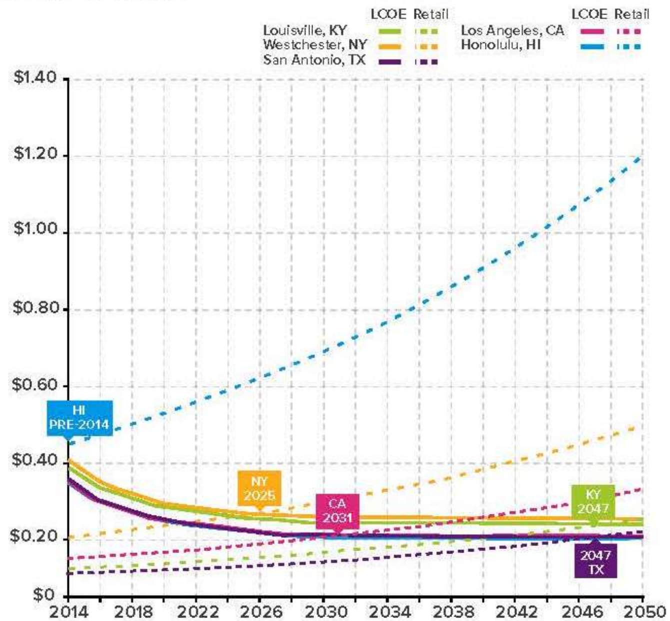
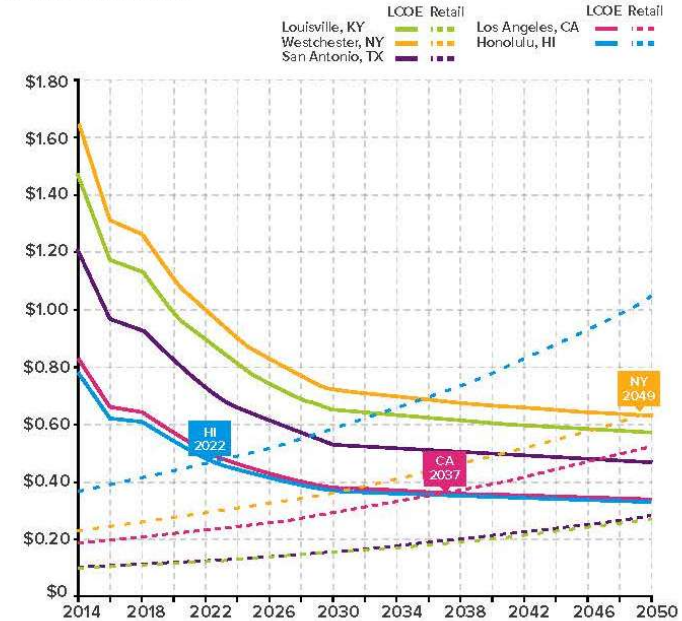


FIGURE 2: OFF-GRID VS. UTILITY PRICE PROJECTIONS
RESIDENTIAL - BASE CASE
[Y-AXIS 2012$/kWh]



ROCKY MOUNTAIN INSTITUTE

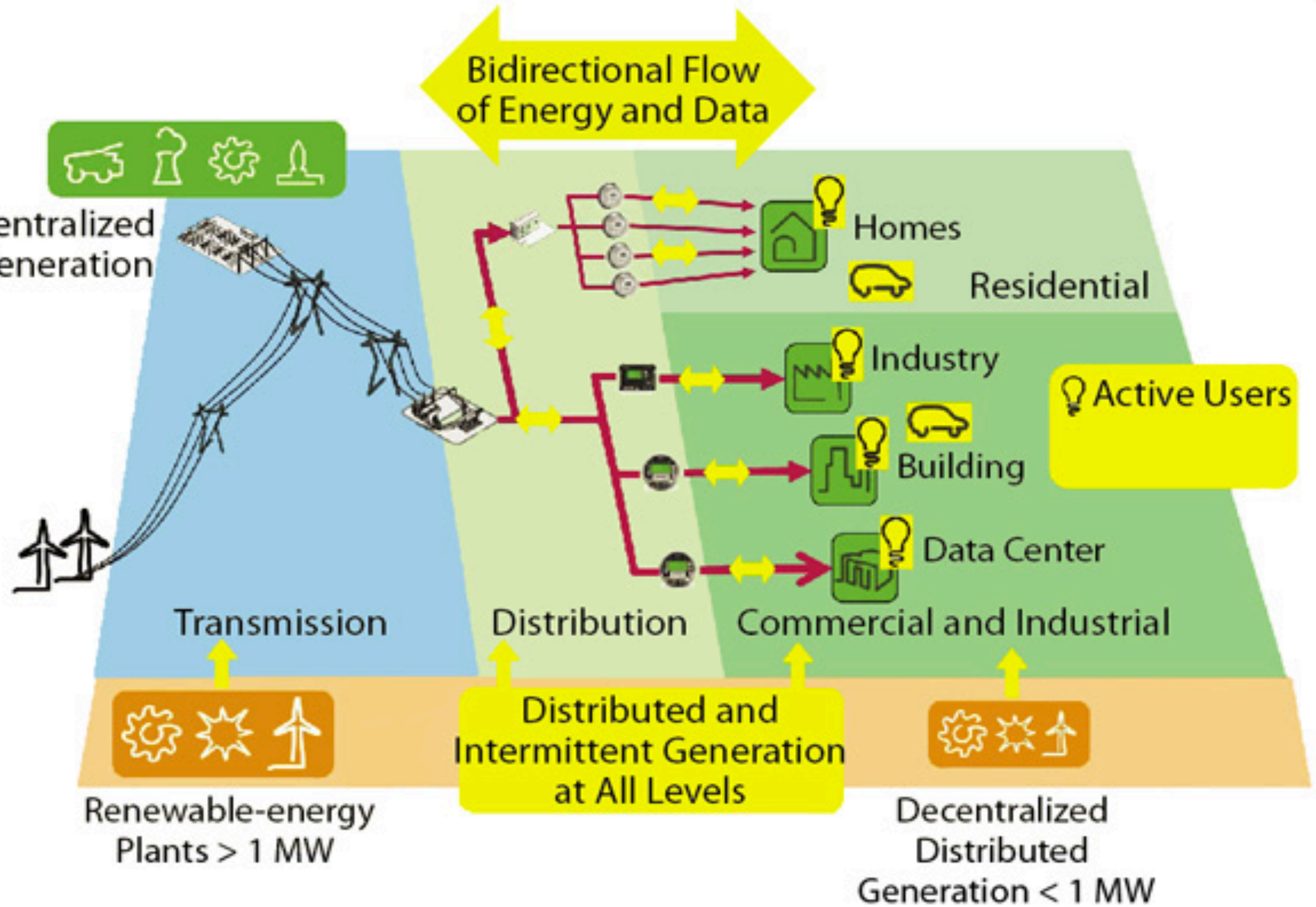
THE ECONOMICS OF GRID DEFECTION | 7

- **RMI showed that PV + Battery systems (and diesel generator backup for commercial) are projected to achieve cost parity with grid electricity in the coming decades**

Source: Rocky Mountain Institute "The Economics of Grid Defection When and Where Distributed Solar Generation Plus Storage Competes with Traditional Utility Service" February 2014. http://www.rmi.org/electricity_grid_defection

ESI Opportunities

- Active engagement of all energy consumers - increases complexity but can also increase system flexibility.



"Demand response: the power program that pays you back :How manufacturers can take the energy bull by the horns", Phil Davis, Green Manufacturer, 2011

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 -** Increase energy sustainability, reduce carbon intensity, and encourage adoption of clean energy technologies by allowing for seamless integration of variable renewable generation and optimizing operations of RE and non-RE sources
- **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.

Concluding Thoughts

- The potential for integration to reduce energy use and increase capital efficiency is large
- Improving system performance, increasing flexibility at end-use, and cross-system integration are methods to realize that potential
- Improvements in both planning and operations will be necessary