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CITIES

Integration of distributed energy resources and demand response in energy systems

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NREL – ESI - PSEC

Energy Systems Integration

Golden, CO

NREL

PSEC

I

NREL - Develops renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations

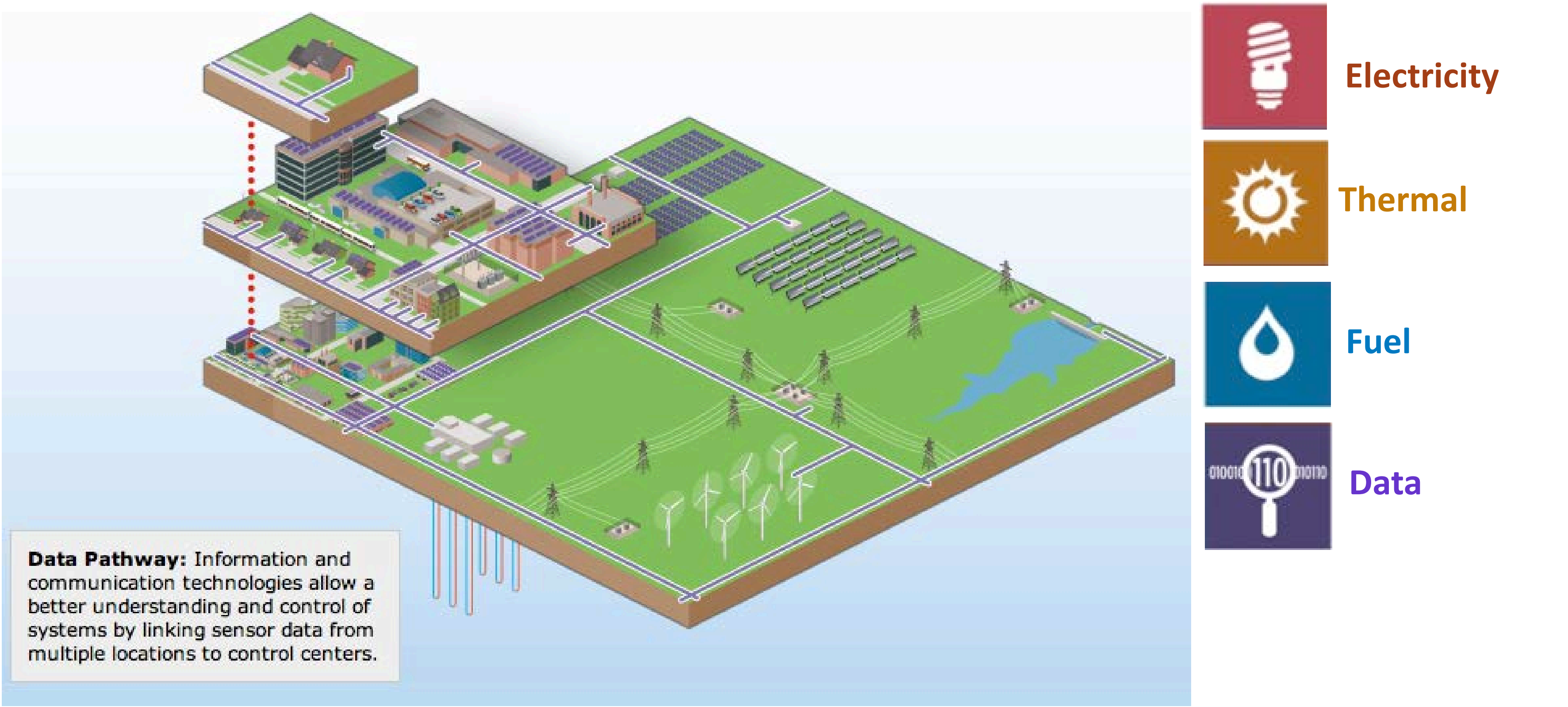
Power Systems Engineering Center (PSEC) - Leads research in integrating high levels of clean energy technologies into electric power systems

Energy Systems Integration (ESI) - Optimizes energy systems across multiple domains (electricity, thermal, fuels, water, communication) and physical scales (local to regional)

What is Energy System Integration?

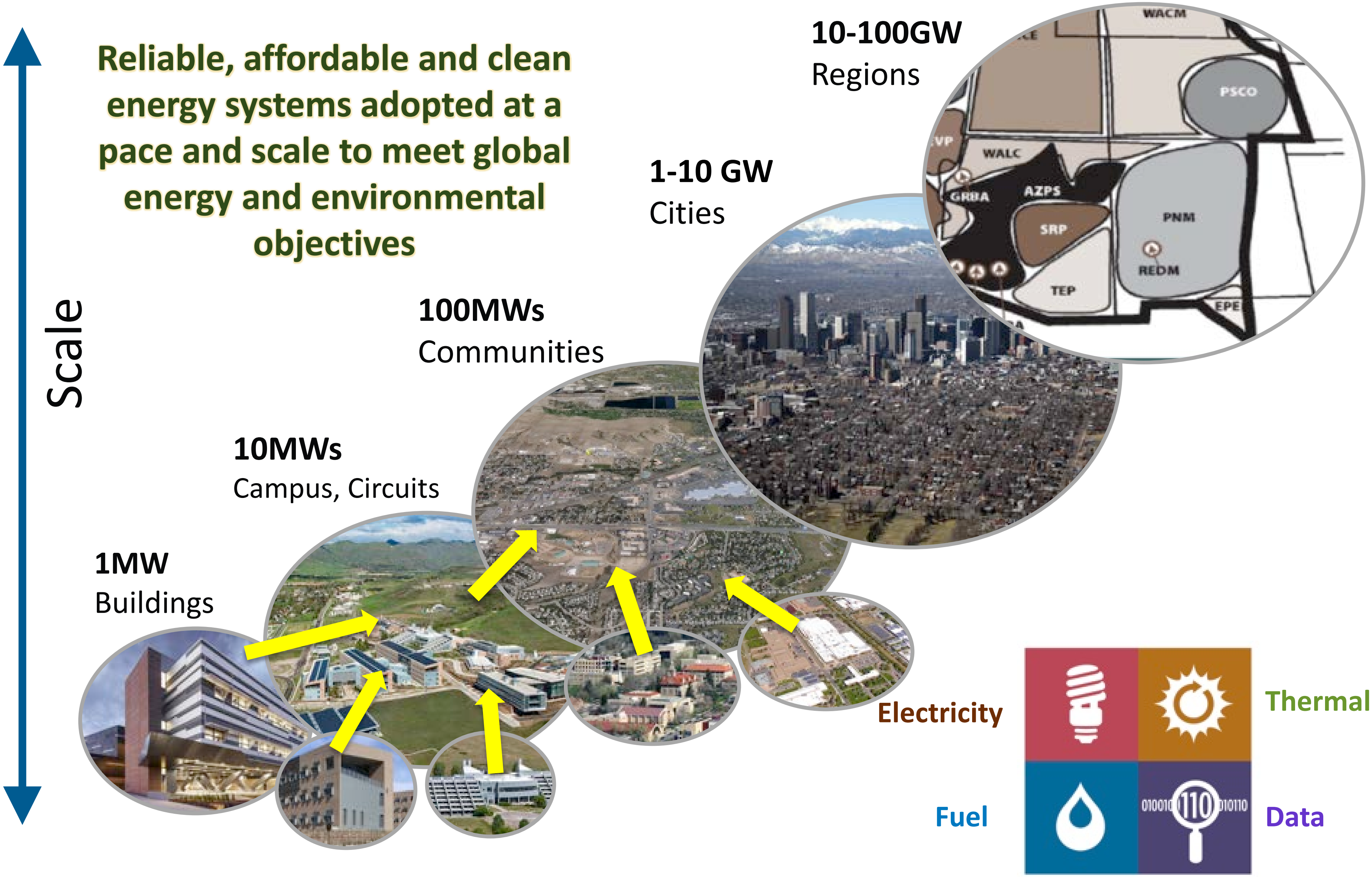
Energy Systems Integration

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

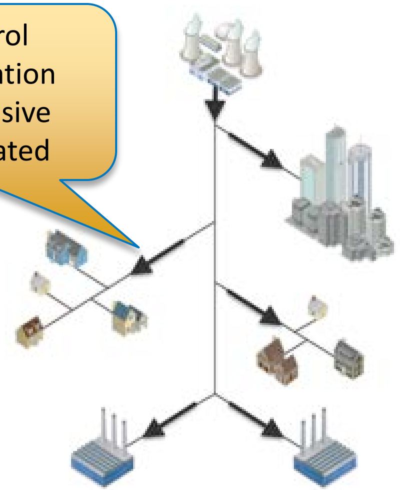


Evolution of the Power System

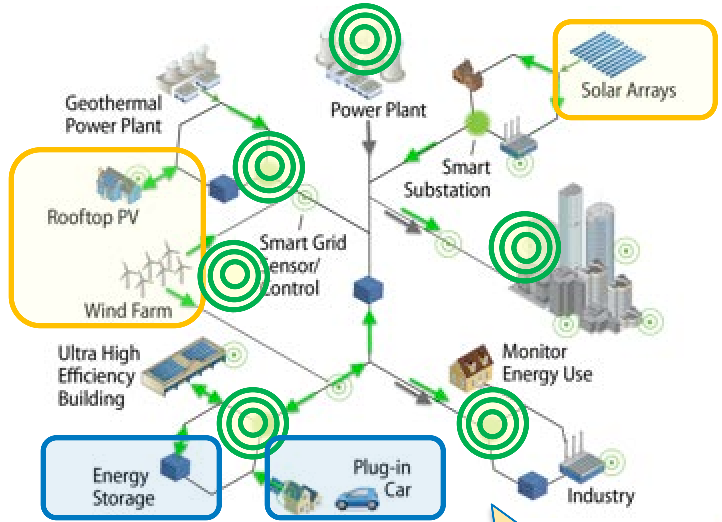
Energy Systems Integration

Current Power System

- Central Control
- Large Generation
- Carbon Intensive
- Highly Regulated



Future Power Systems



New Challenges in a Modern Grid

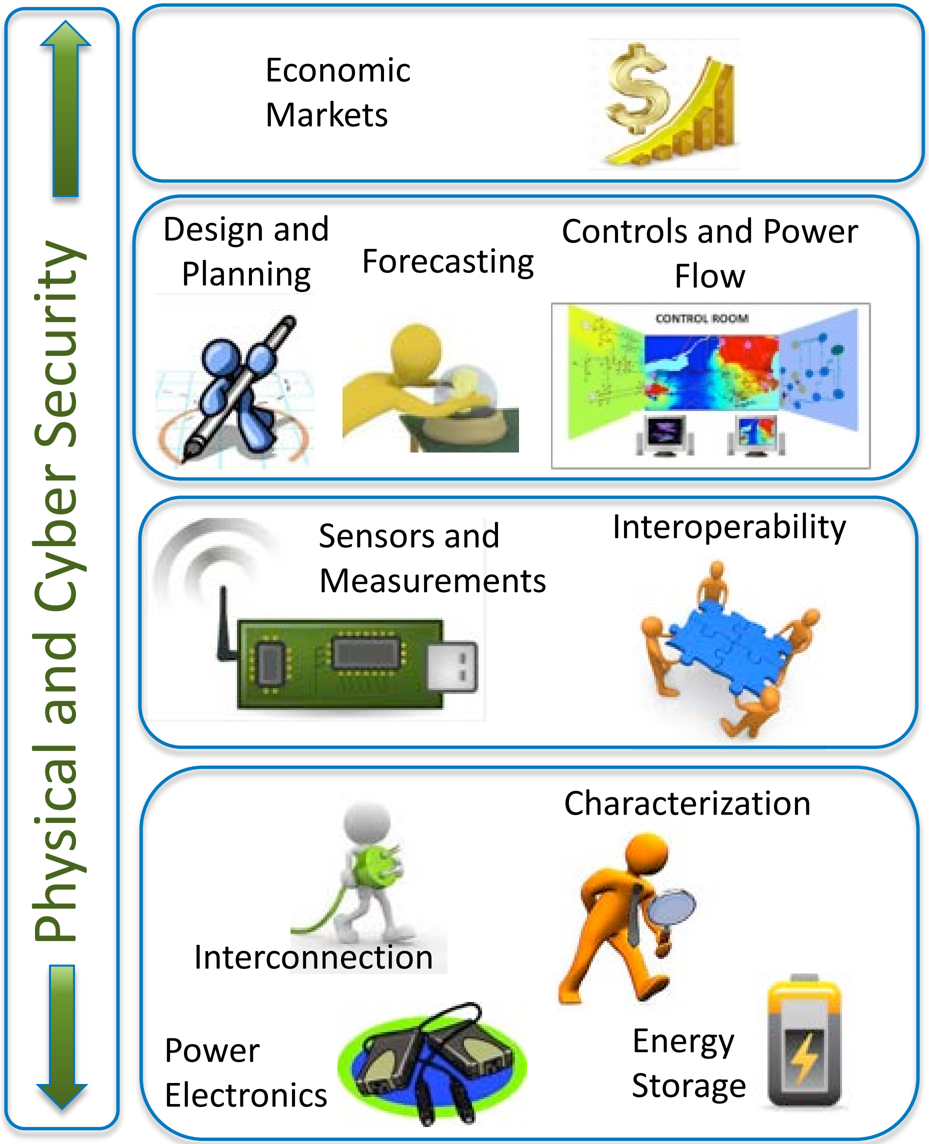
- Increasing penetration of variable renewables in grid
- Increasing energy efficient buildings and controllable loads
- New communications and controls (including DR)
- Electrification of transportation
- Integrating distributed energy storage
- A modern grid needs increased system flexibility
- Capitalize on interactions between electricity/thermal/fuel systems

DRIVERS

- Increased variable gen
- More bi-directional flow at distribution level
- Increased number of smart/active devices
- Evolving institutional environment

PSEC – Providing Solutions

Energy Systems Integration



Economic Markets

- Understanding the impacts of Market Design
- Analysis of markets for flexibility and other ancillary services

Planning, Operations, and Forecasting

- Bulk-System Planning and Operations
- Distribution System Planning and Operations
- Solar, Wind, and Load Forecasting

Sensing and Measurements

- Grid sensing – PMUs, DMUs
- Solar and meteorological sensing and measurements
- Interoperability Standards

Grid device development and integrated system testing

- PV inverters, Wind inverters, EV inverters development and testing
- Energy storage systems (battery + inverter)
- Interconnection Standards
- Ancillary Service Characterization

Energy Systems Integration Facility (ESIF)

Energy Systems Integration

http://www.nrel.gov/esif

NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

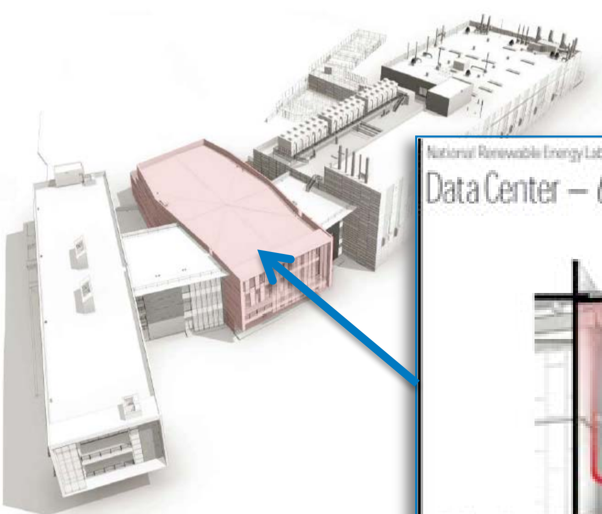
Unique Capabilities

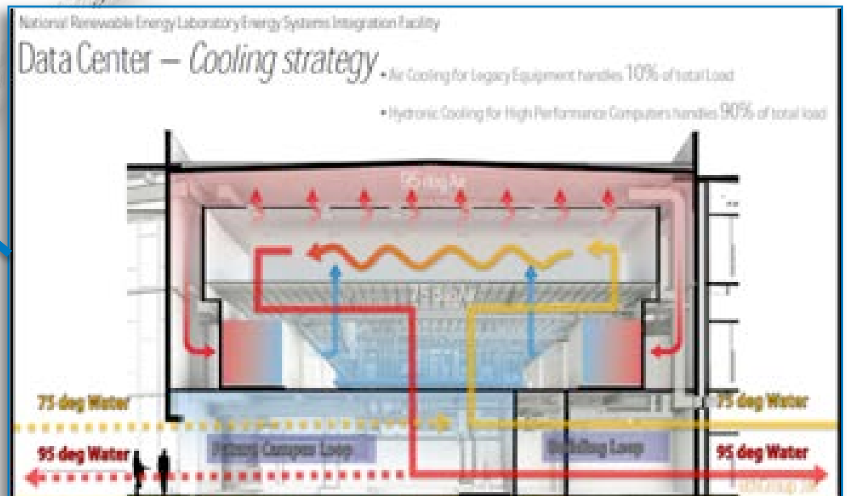
- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced 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 – HPC/DC

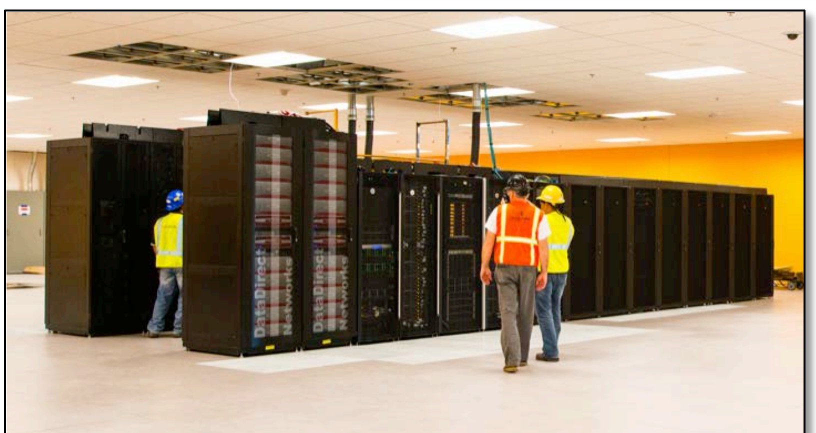
Energy Systems Integration





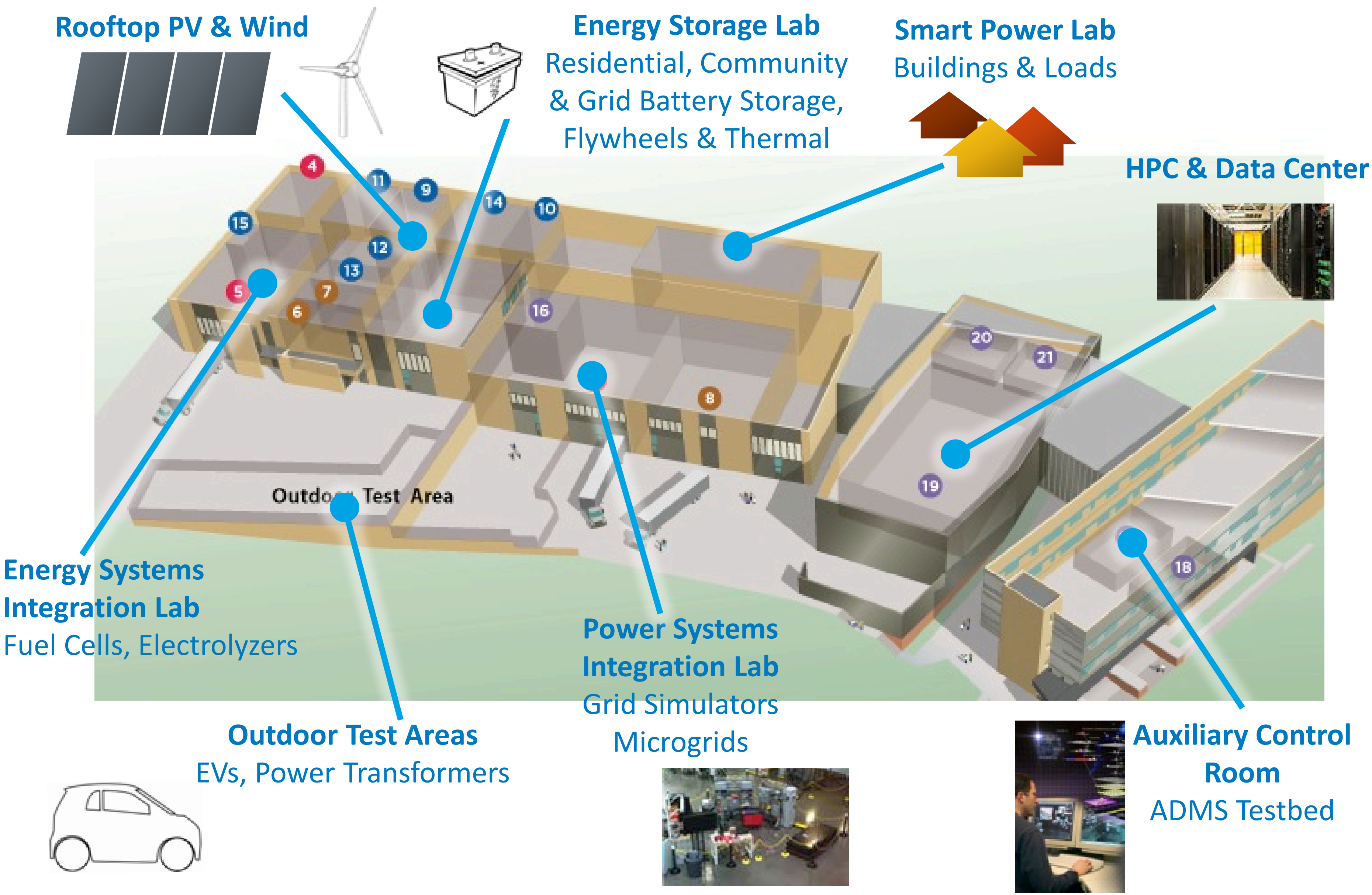
HPC – DC Showcase Facility

- 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!

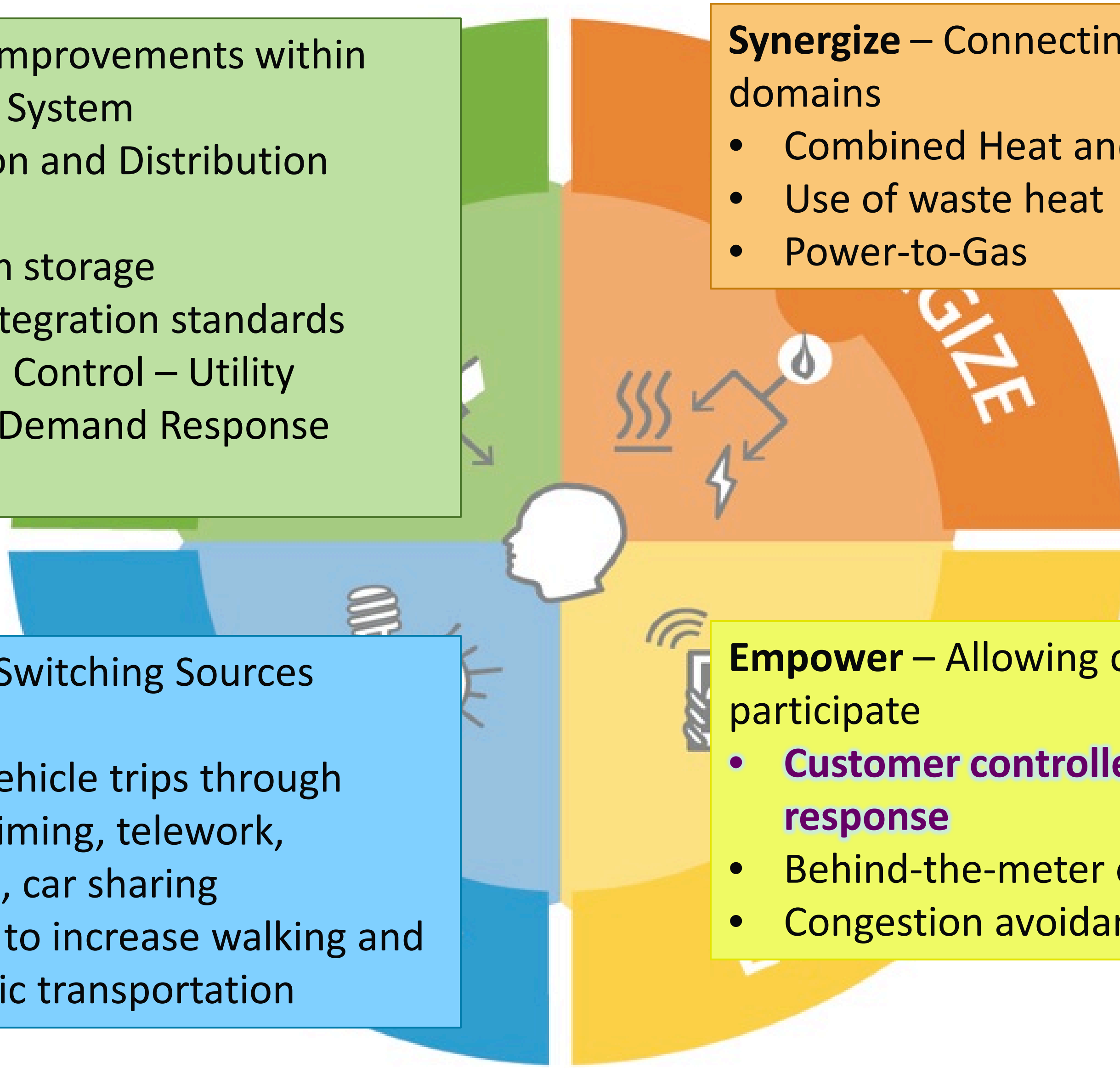


PUE = Power Usage Effectiveness

ESIF Laboratories



ESI Opportunity Areas



Streamline – Improvements within Todays Energy System

- Transmission and Distribution upgrades
- Bulk-system storage
- Updated integration standards
- Direct Load Control – Utility Controlled Demand Response

Synergize – Connecting energy domains

- Combined Heat and Power
- Use of waste heat
- Power-to-Gas

Mode-Shift - Switching Sources

- Daylighting
- 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

- **Customer controlled demand response**
- Behind-the-meter energy storage
- Congestion avoidance and pricing

Inclusion of Energy-Shifting Demand Response in Production Cost Models

Super Market Refrigeration

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National Renewable Energy Laboratory

Understanding Load Shifting Appliances – Supermarket Refrigeration

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

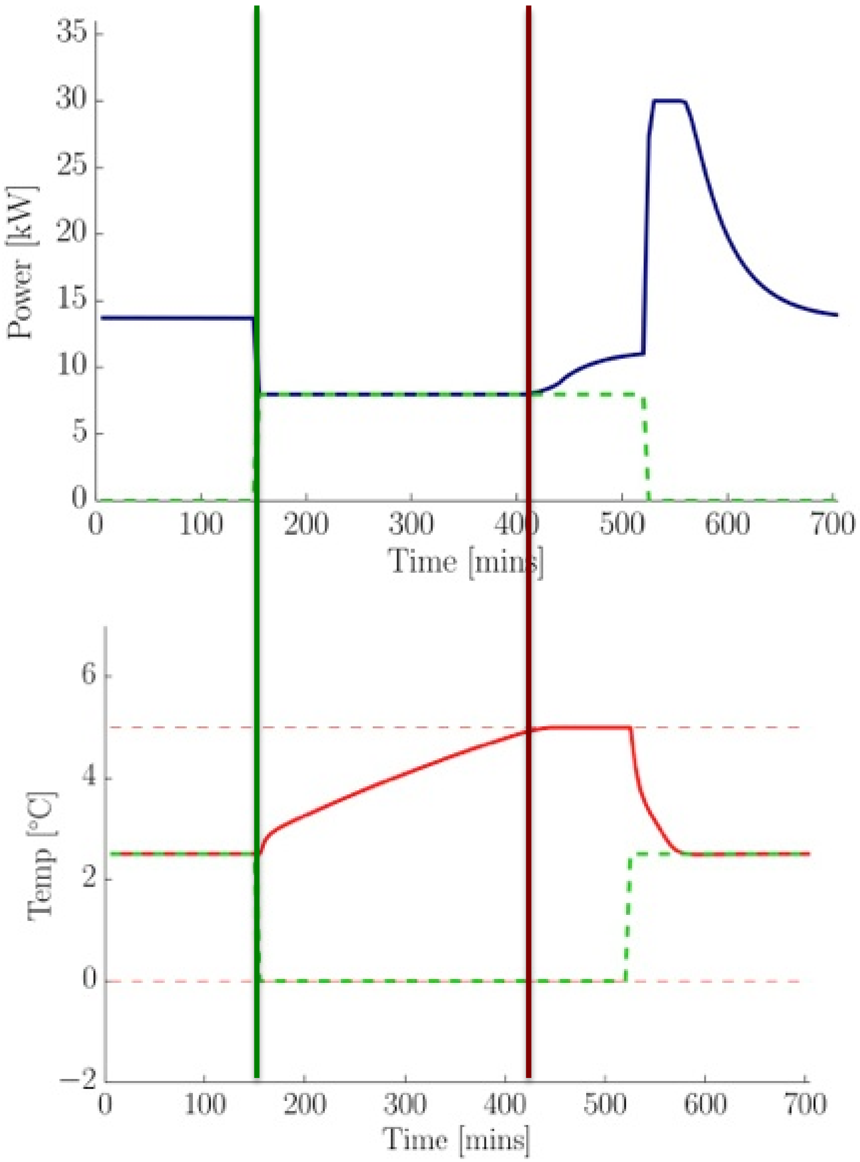
Supermarkets operate at a low profit margin, incentivizing them to pursue opportunities for cost savings. Energy costs account for 1% of the operating costs of a supermarket, but if demand response can offer easily accessible cost savings, it can be expected that this profit-driven enterprise would adopt an operating paradigm that facilitates load shifting demand response.

The structure of a supermarket chain lends itself to the formation of an aggregator. While individual supermarkets are considered large commercial loads, the flexibility they offer is likely below the threshold for participation on many electricity markets. By aggregating a number of supermarkets and offering their combined flexibility as a single product, this threshold can be overcome.

- **Characterizing Demand Response through the Saturation Curve**
- **Resource Efficiency**
- **Seasonality in the Demand Response Resource**

Response Saturation in Refrigerator

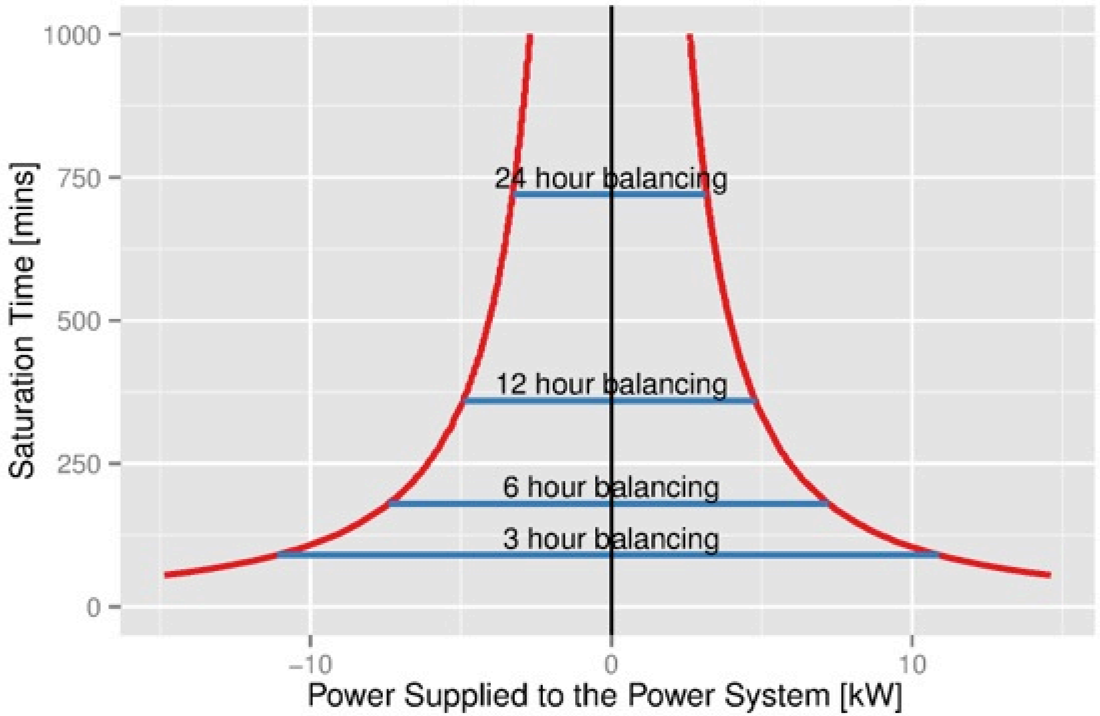
- Top figure shows that the power consumption is steady until it is reduced from 14kW to 8kW.
- The reduction of 6kW can be maintained until the temperature in the refrigeration system reaches its upper bound (as seen in Bottom Figure).
- Once the upper temperature limit is reached the prescribed reduction can no longer be maintained, at this point it is said that the response has saturated.
- When the power reference is no longer active, the system will recover the energy lost during the response event by increasing consumption to the maximum allowable level.



Maximum flexibility of a load shifting device

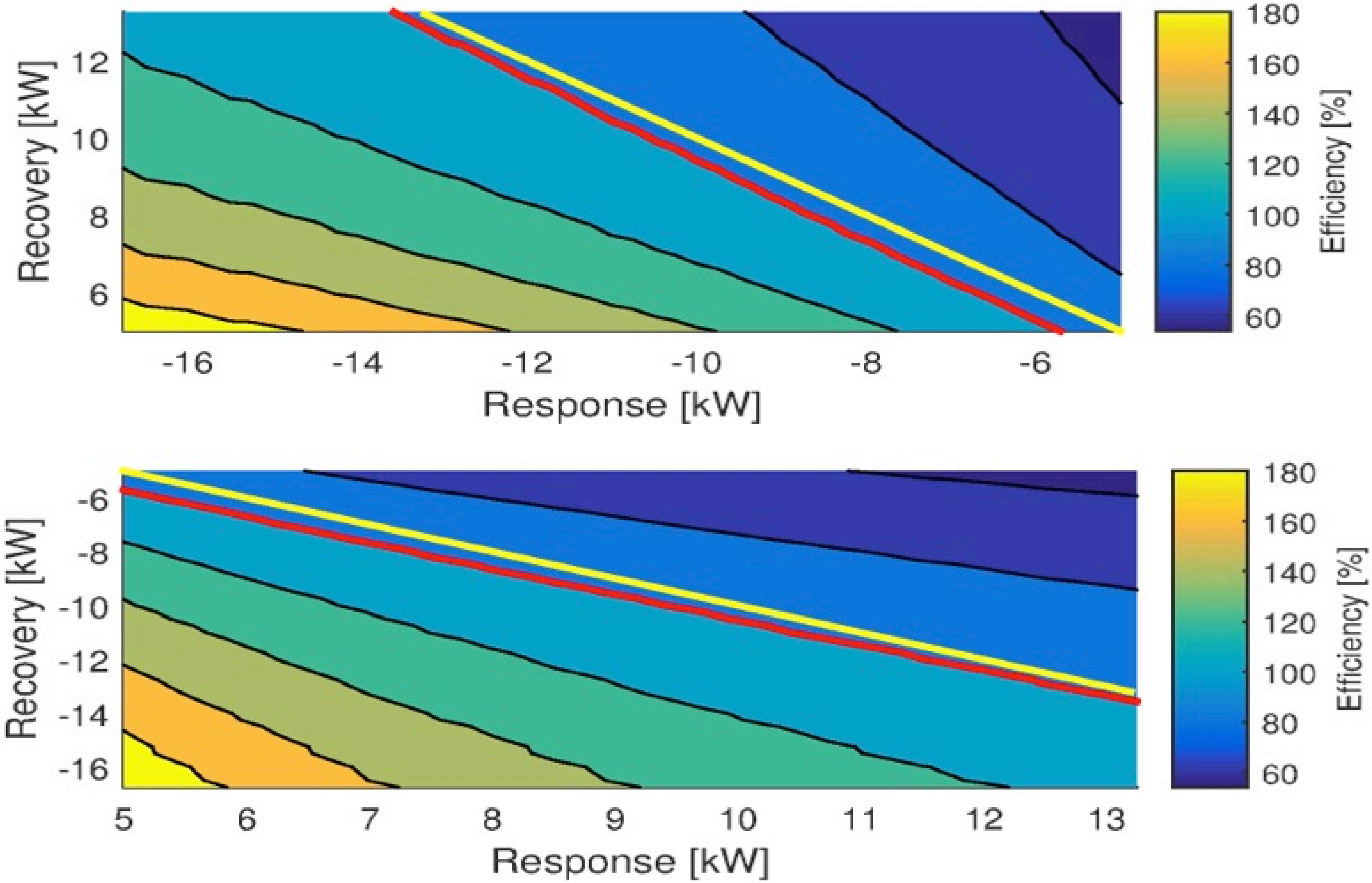
- **Saturation Curve -** The relationship between a power adjustment in a flexible load and the duration for which the adjustment can be maintained

- It is not suitable for direct inclusion in a power system model or market clearing algorithm because it is non-linear

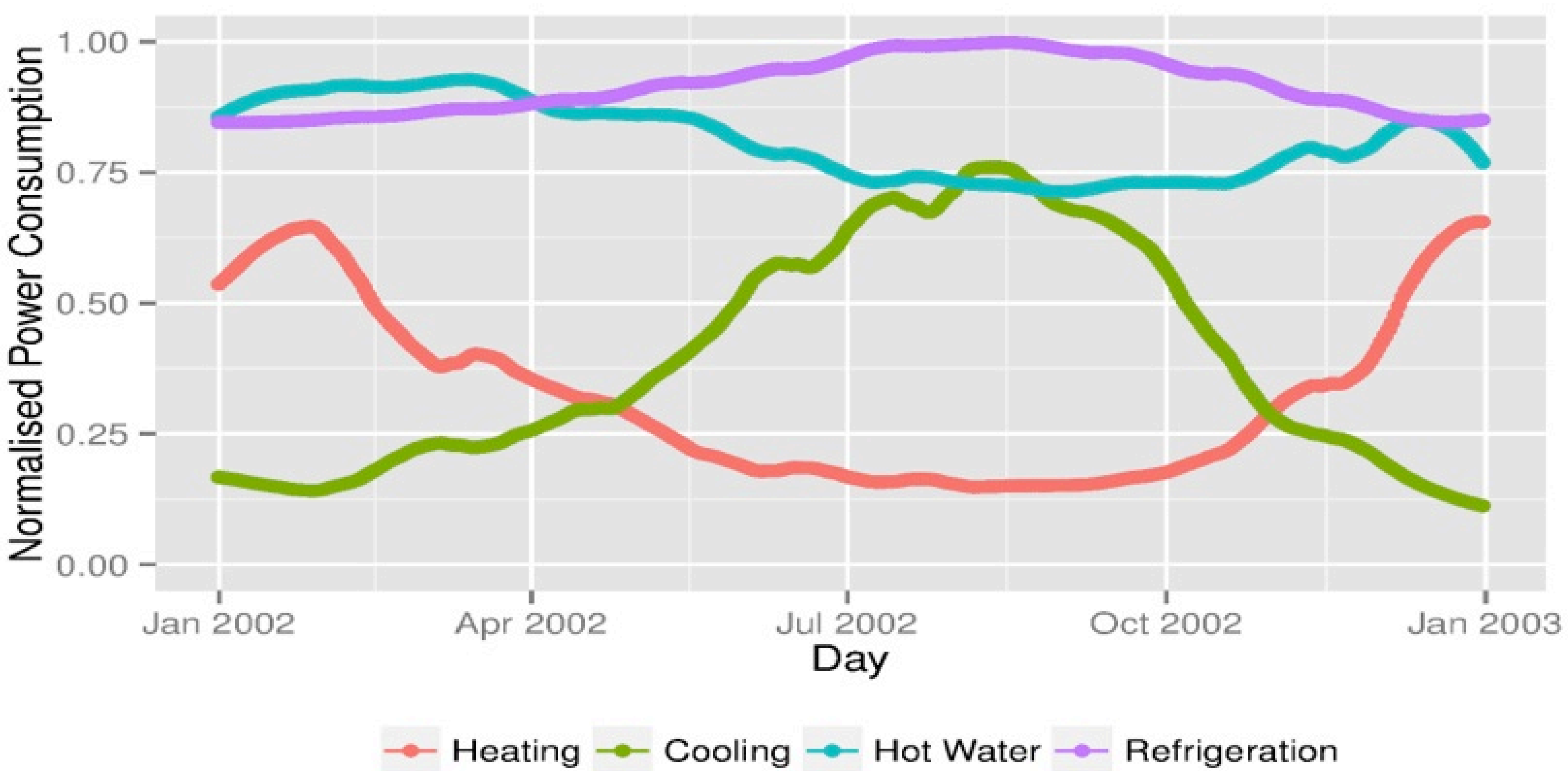


Round-Trip Efficiency of DR

Round trip efficiency of a demand response event. The red lines show the 100% efficiency contours, and the yellow lines show the efficiency of symmetric events, i.e. a response and recovery of the same power magnitude.



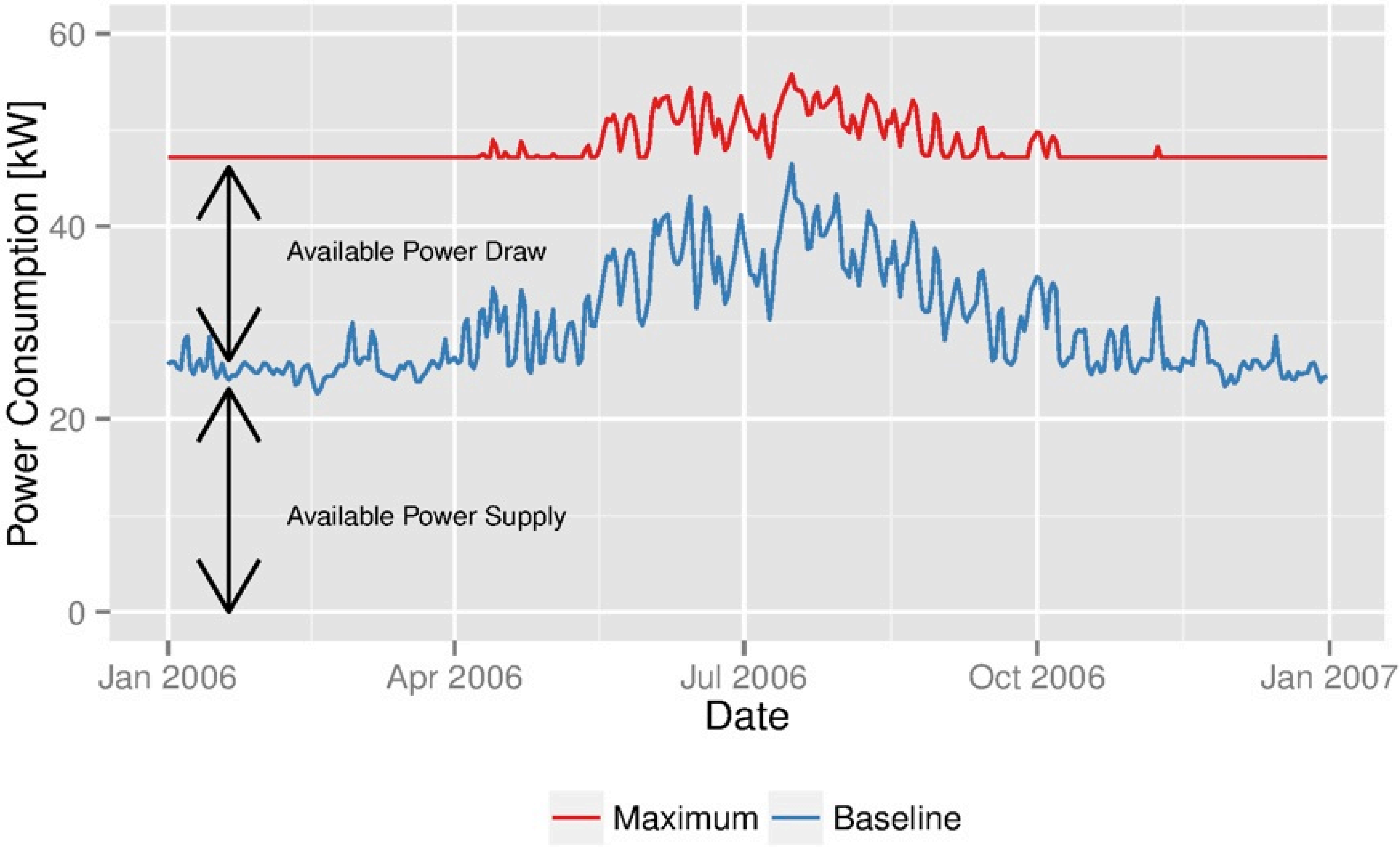
Seasonality of Loads



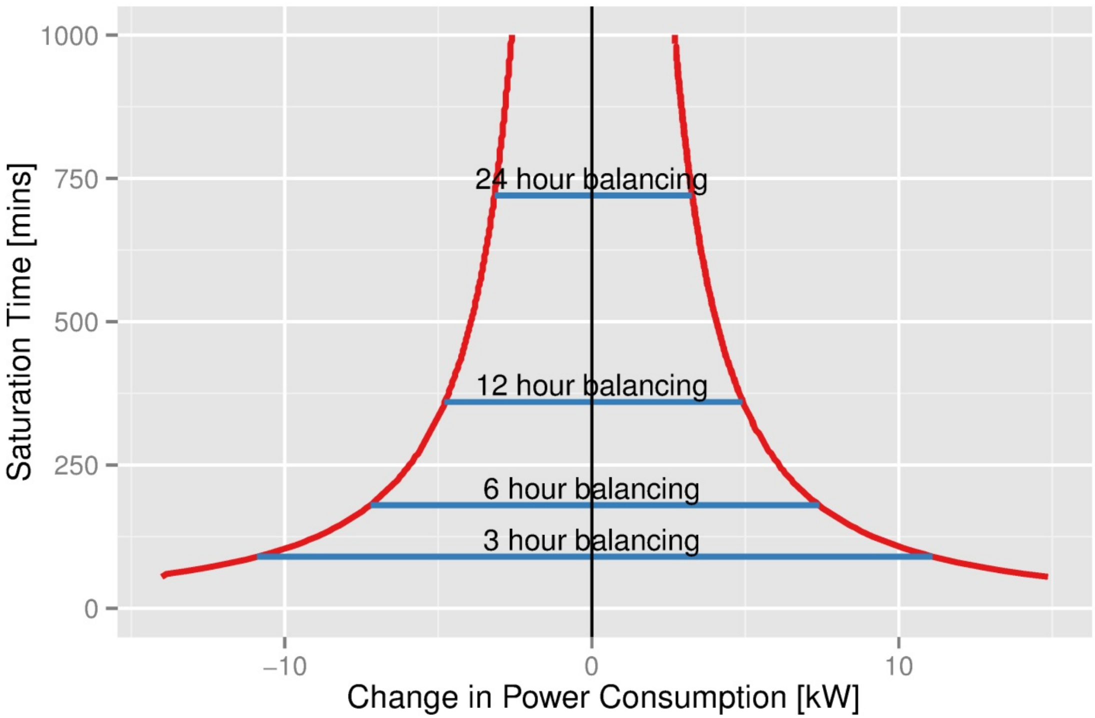
When considering thermal end-end uses for the provision of load shifting demand response, there are three key characteristics to consider:

- baseline power consumption
- maximum possible power consumption
- energy required to achieve a given temperature change

Variations in available flexibility at the device level



Representation of DR for use in Power System Models

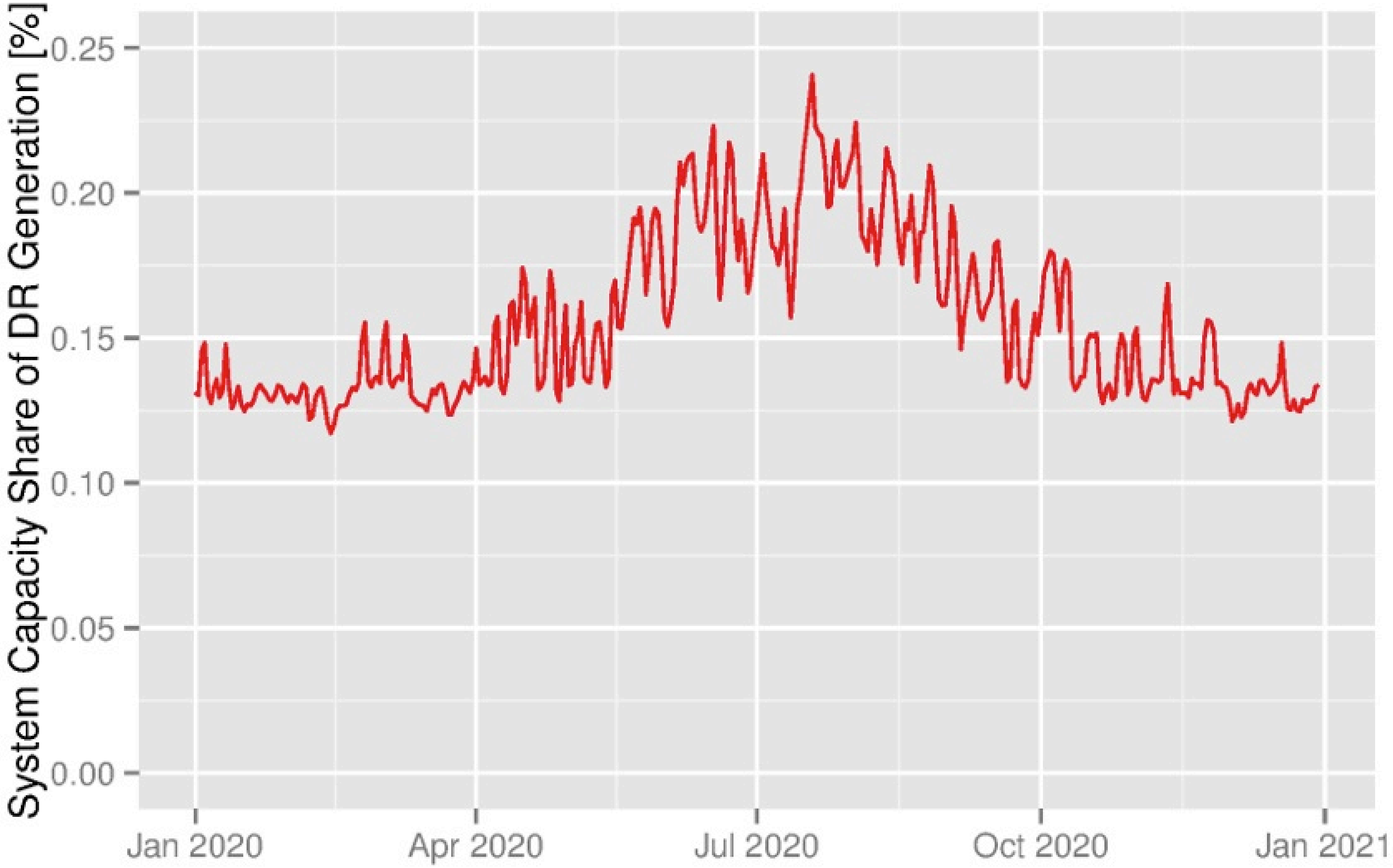


- Each population of flexible devices can offer a number of demand response products
- Each product resembles a battery sufficiently to use this description in a power system model, subject to some additions
- Each product has a defined maximum power supply to and draw from the grid, and a period within which the response and recovery must balance.
- Products are mutually exclusive
- Possible extensions include the limitation on the number of DR calls per day/week etc.

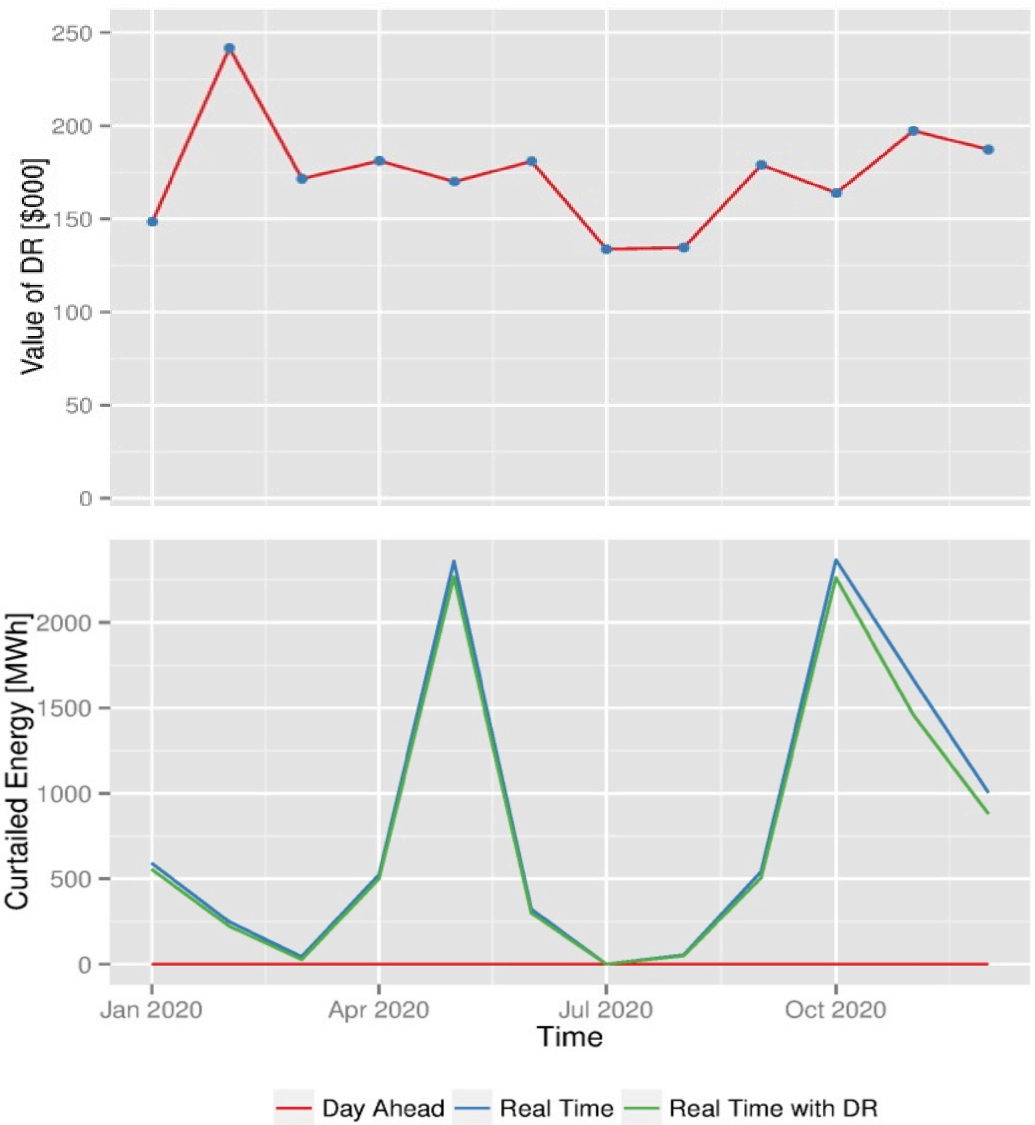
Case Study – Rocky Mt. Power Pool

- DR Model framework is suitable for large scale power system studies spanning substantial geographic and temporal scales
- RMPP test system (Colorado and Wyoming) is employed for a demonstration of the DR model capabilities
- The value of DR is assessed through the reductions is brings about in power system operational costs.
- DR is considered a flexible resource and dispatched at real-time to aid the balance of forecast errors in load and renewables
- The DR resource represent the population of all supermarkets located in Colorado, and are clustered according to supermarket size: small (482, 30kW), medium (178, 50kW) and large (140, 80kW).
- For the purposes of evaluating the DR resource, it is considered free. This is a benchmarking exercise to determine the maximum feasible investment in DR.

DR Capacity

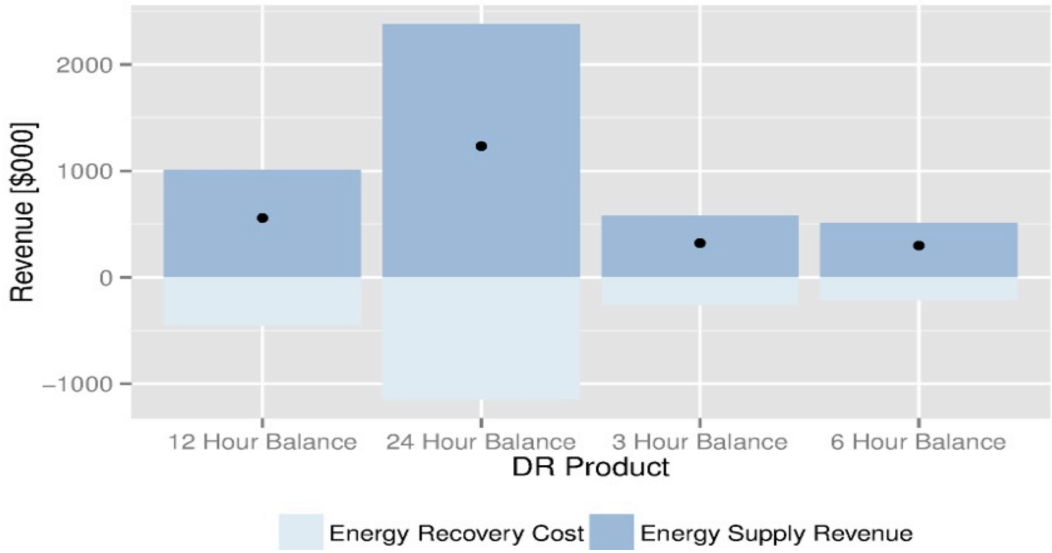

System Capacity Share of DR Generation [%]
0.25
0.20
0.15
0.10
0.05
0.00
Jan 2020
Apr 2020
Jul 2020
Oct 2020
Jan 2021

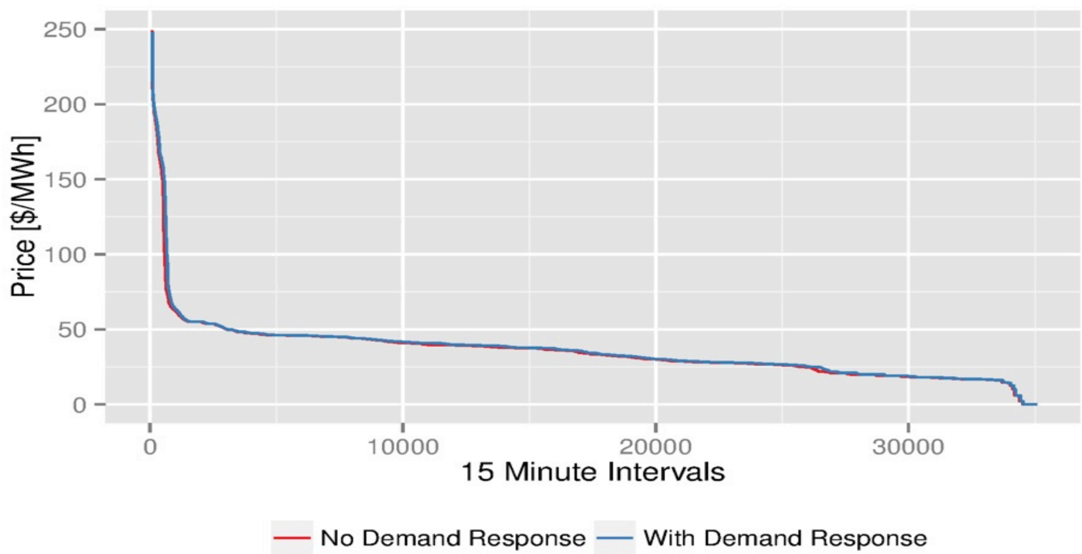
The Value of DR



- DR Value:
  - $2.089M/year
  - $32.85/kW-year
  - $4980 per large supermarket
  - Reduces total system cost by 0.0144%.
- There is a seasonal trend in the value of DR, with lowest value during the warmer months, though it is not as extreme as could be expected.
- Much of the value that DR offers is due to its ability to avoid the curtailment of renewables. Despite being a tiny resource on the system, its impact on curtailment is not insignificant – 693 MWh avoided in test year, 2020.

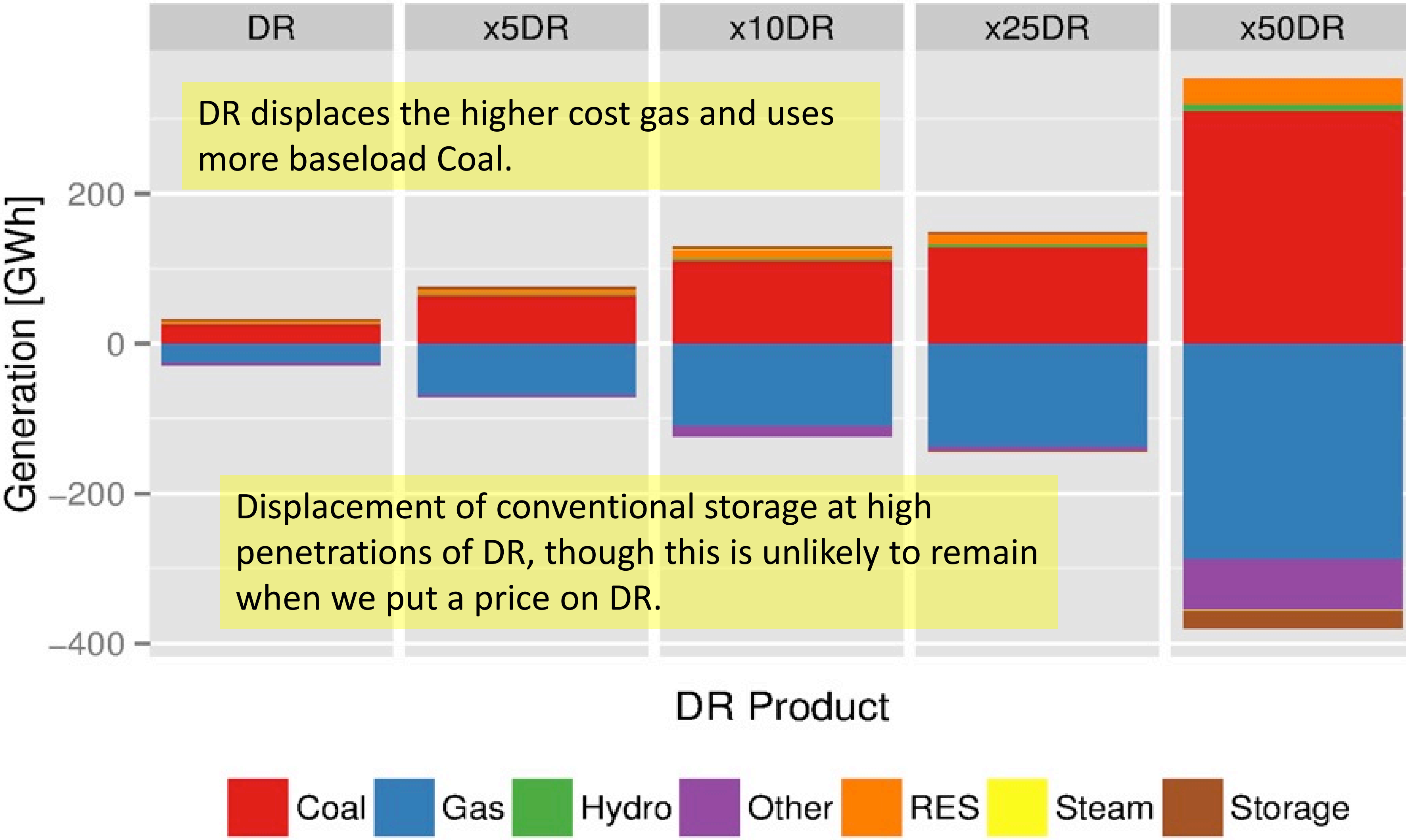
Revenue of DR





- DR net revenue composed of
  - revenue generated from the sale of energy
  - the cost of recovering energy
- 24 hour product has the most flexibility to arbitrage, using range of price over a day, resulting in greater net revenue
- Impact on the price duration curve is negligible at small penetrations of DR, except slight increase in lower prices due to the energy recover , which increases load a low priced hours.

Impact of More DR

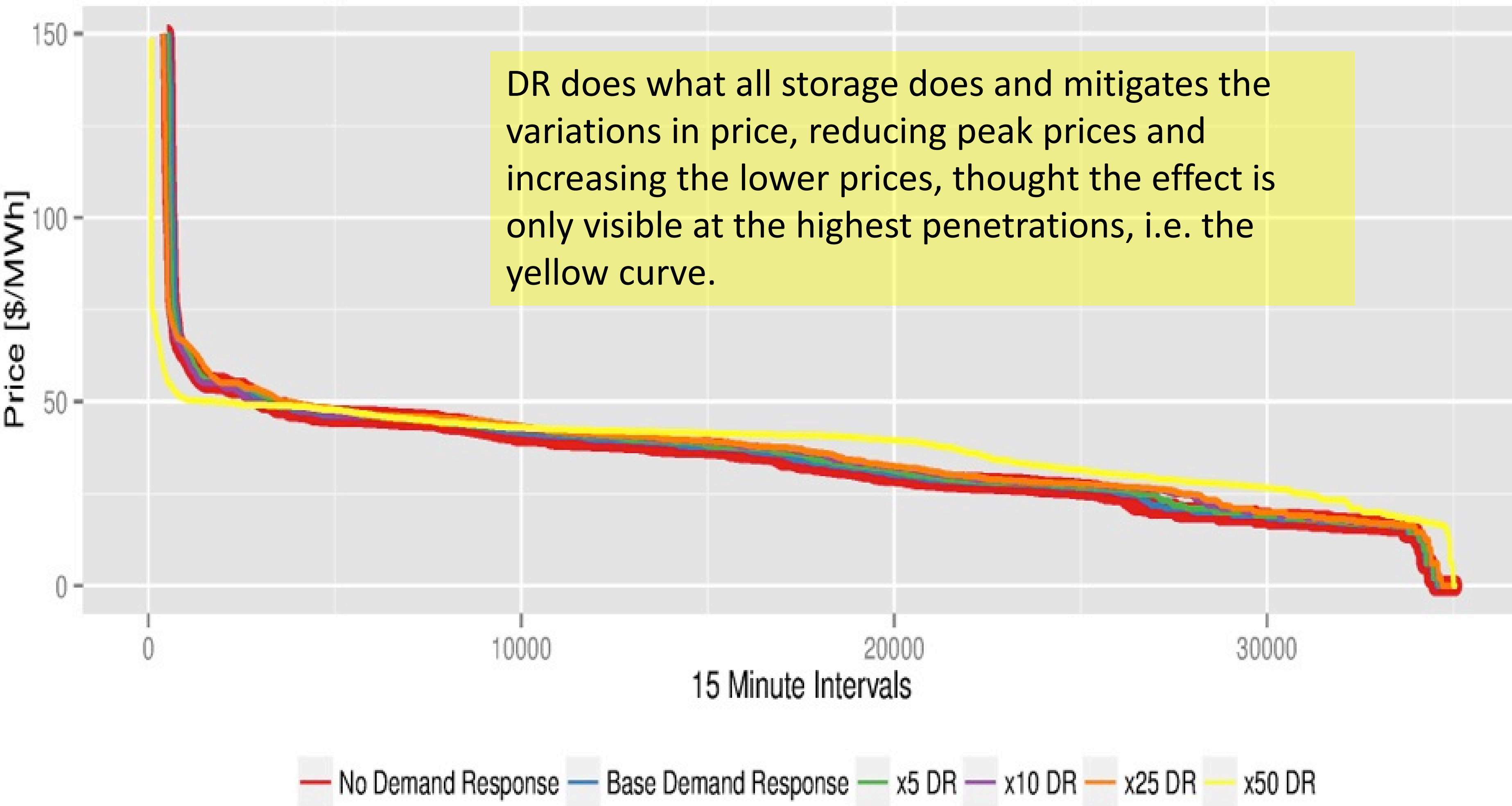


DR displaces the higher cost gas and uses more baseload Coal.

Displacement of conventional storage at high penetrations of DR, though this is unlikely to remain when we put a price on DR.

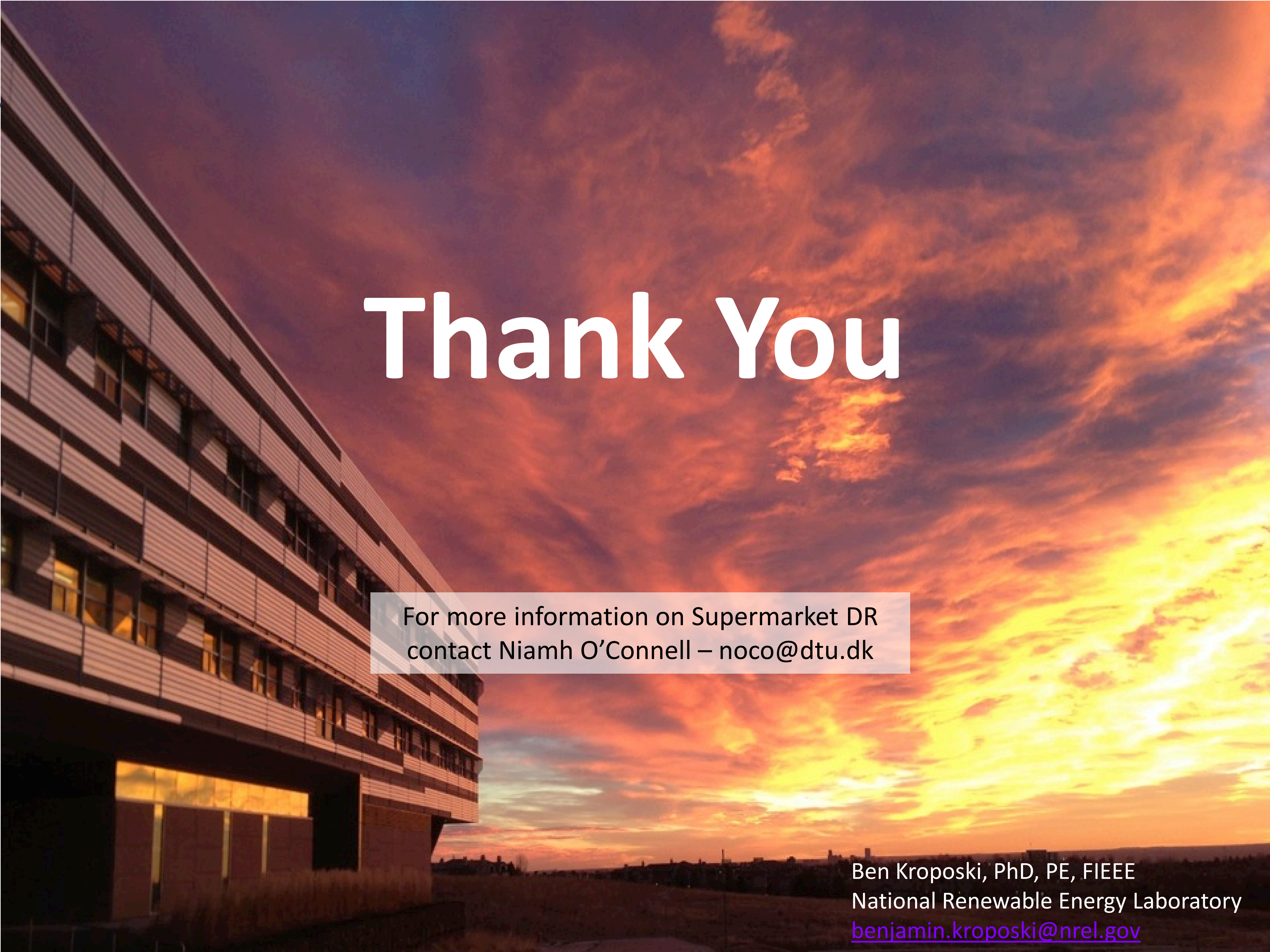
New Load Curves

DR does what all storage does and mitigates the variations in price, reducing peak prices and increasing the lower prices, thought the effect is only visible at the highest penetrations, i.e. the yellow curve.



Conclusions

- A bottom-up model was developed for use in power system analysis
- Facilitates an assessment of the power system operational cost reductions offered by DR over a year time period
- A case study was conducted on supermarket refrigerators in the Rocky Mountain Power Pool and was found to have a value of $32.85/kW-year.
- The capacity of the population of supermarkets modelled was very small, representing a maximum of 0.02% of the generation capacity on the system. Consequently the absolute value it offers per year is very low, at $2.089M, or $4890 for each large supermarket providing demand response.
- Sensitivity studies revealed that the per unit value of demand response reduces as the capacity of the resource increases.



Thank You

For more information on Supermarket DR contact Niamh O’Connell – noco@dtu.dk

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