The Smart Grid and its Role in a Carbon-Constrained World

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What is the Smart Grid?

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Seven Characteristics of a Modern Grid — *Outcomes*

The *Modern Grid Initiative* has defined the smart grid in terms of seven characteristics that are <u>outcomes</u>:

- Enables active participation by consumers
- Accommodates all generation and storage options
- Enables new products, services and markets
- Provides power quality for the digital economy
- Optimizes assets & operates efficiently
- Anticipates and responds to system disturbances (self-heals)
- Operates resiliently against attack and natural disaster

Primary Assets: the Smart Grid's "Prime Movers"

New, typically distributed resources are engaged by the smart grid to positively affect operations:

- Demand response (DR)
- Distributed generation (DG)
- Distributed storage (DS)
- Distribution/feeder automation (DA/FA)
- Electric & plug-in hybrid vehicles (EVs/PHEVs)

Enabling Assets for the Smart Grid

Cross-cutting technologies that <u>enable</u> many Primary assets & applications:

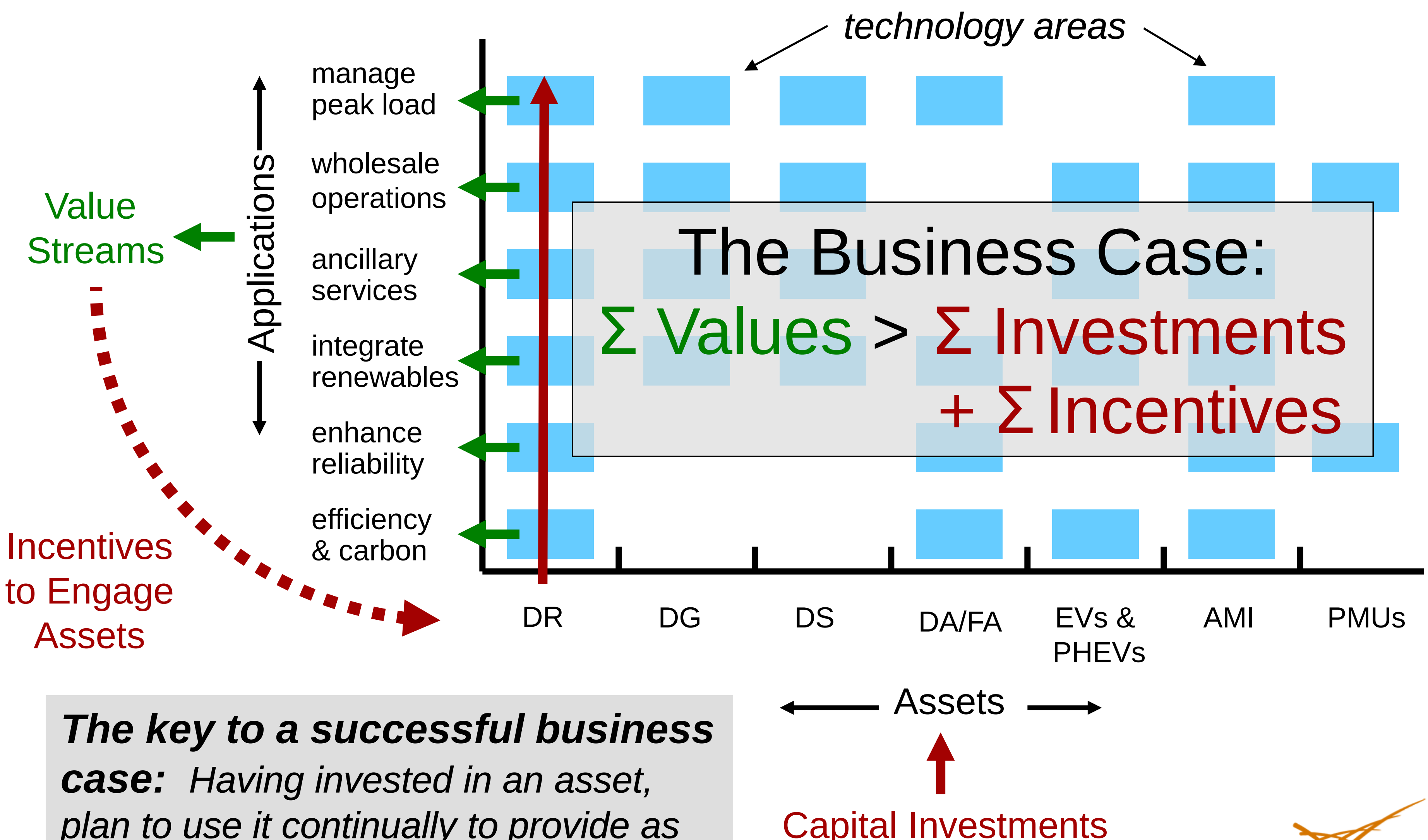
- Communications networks, servers, gateways, etc.
- Smart meters
  - 1 hour→1 min intervals
  - 1-way→2-way communications
  - Instantaneous volts, amps, VARs
  - Auto connect/disconnect
- Home/building/industrial energy management/control systems,
- User information interfaces & support tools
- Utility back office systems
- Transmission wide-area phasor measurement (PMU) networks & visualization tools
- <u>Other key technical ingredients of the smart grid</u>:
  - Cyber-security for all the above
  - Interoperability framework, standards & protocols

Applications: Operational Strategies that Utilize Smart Grid Resources to Create Benefits

Grid control and operational strategies (*applications*) that engage smart grid *assets* to improve cost effectiveness, reliability, and energy efficiency:

- Manage peak load capacity (G, T, & D)
- Reduce costs for wholesale operations
- Provide ancillary services
- Reduce operational costs of integrating renewables
- Provide enhanced reliability/adequate reliability at less cost
- Leverage network for energy efficiency & carbon savings

The Matrix of Assets & Applications Produce the Smart Grid's Values & Define the Business Case



The key to a successful business case: *Having invested in an asset, plan to use it continually to provide as many value streams as possible!*

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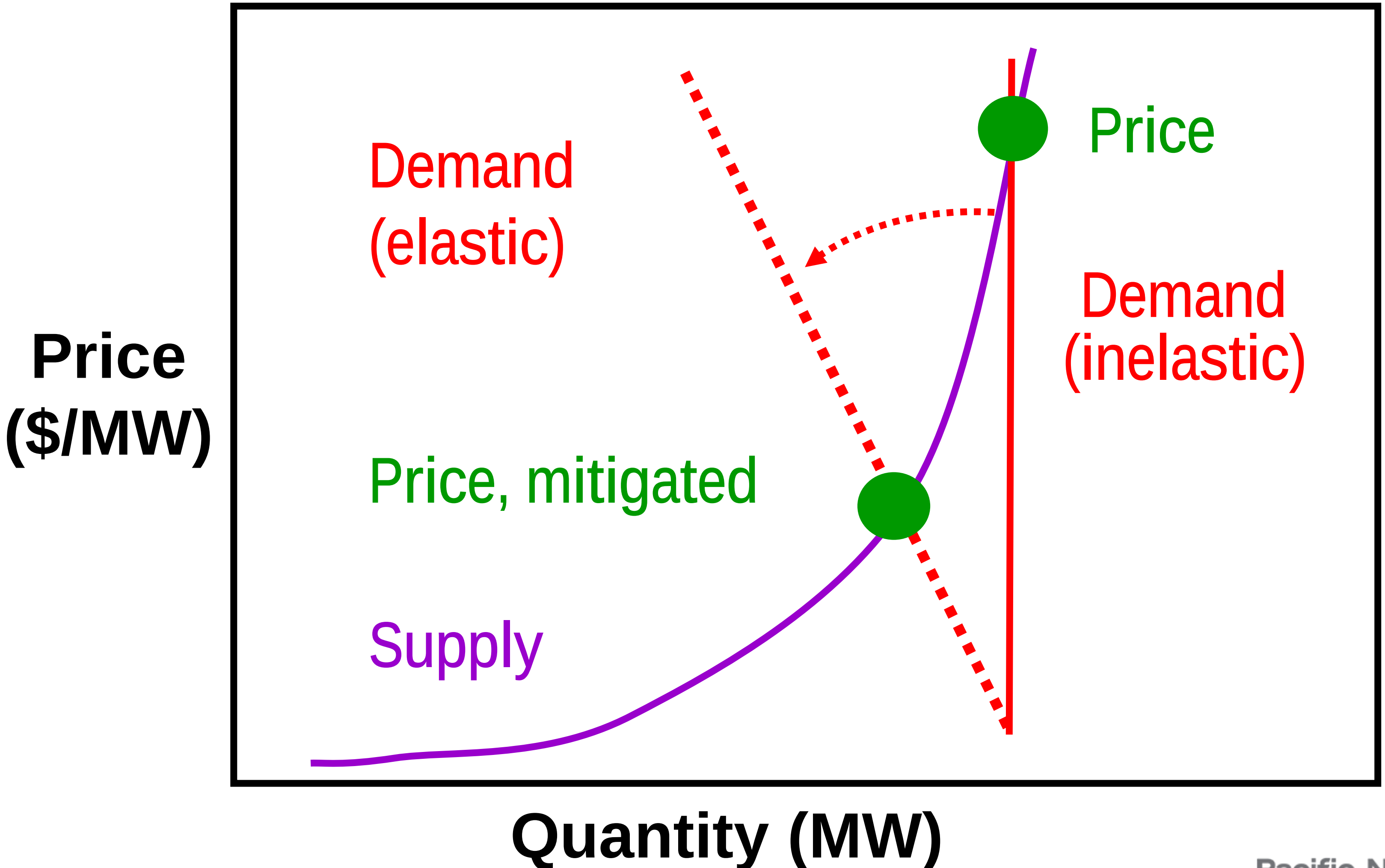
Value of Demand Elasticity: *Lower Peak Demand & Stabilize Prices*



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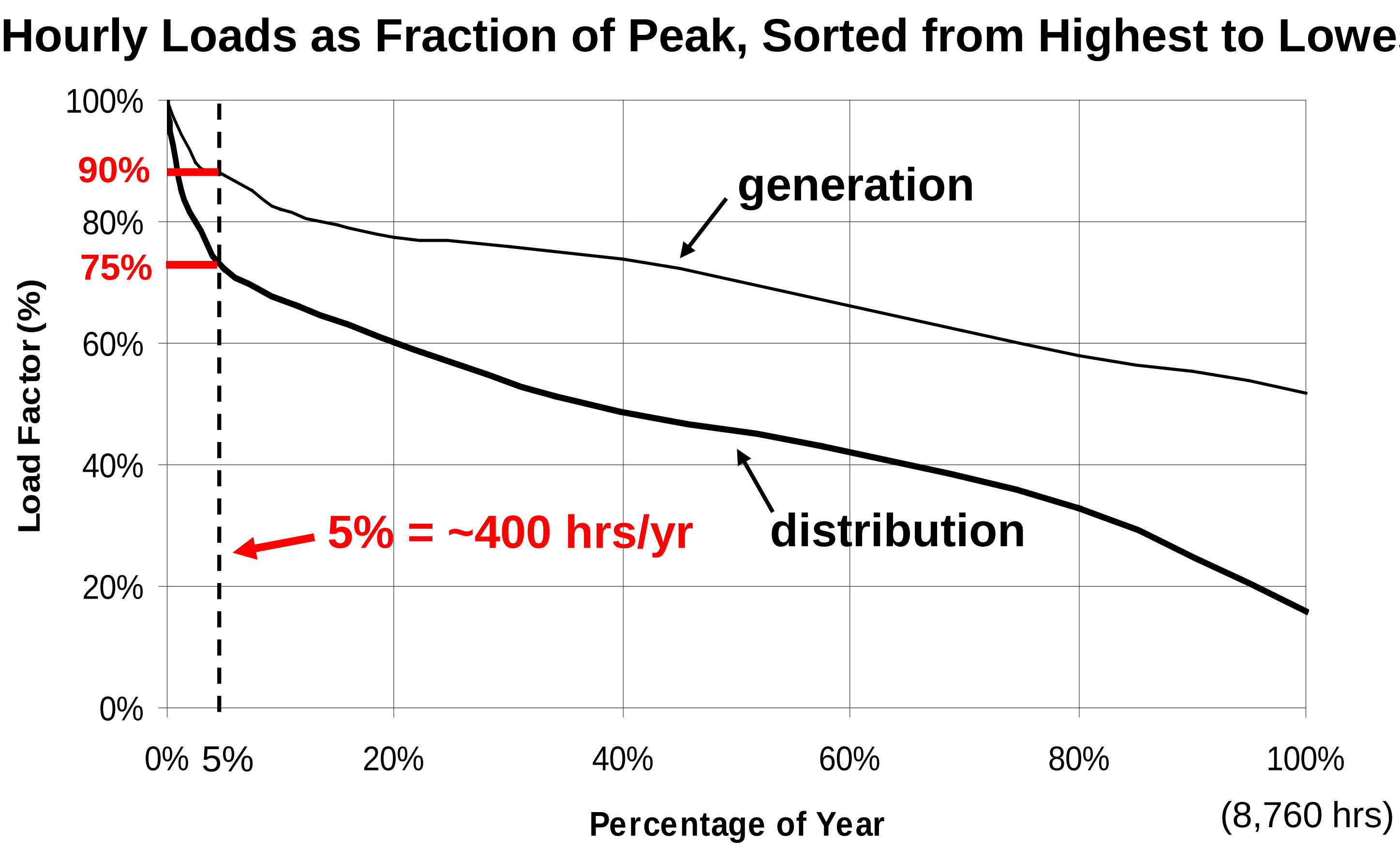
Value of Demand Response: *Lower Peak Demand Reduces Infrastructure Investments*



25% of distribution & 10% of generation assets (transmission is similar), worth of 100s of billions of dollars, are needed less than 400 hrs/year!

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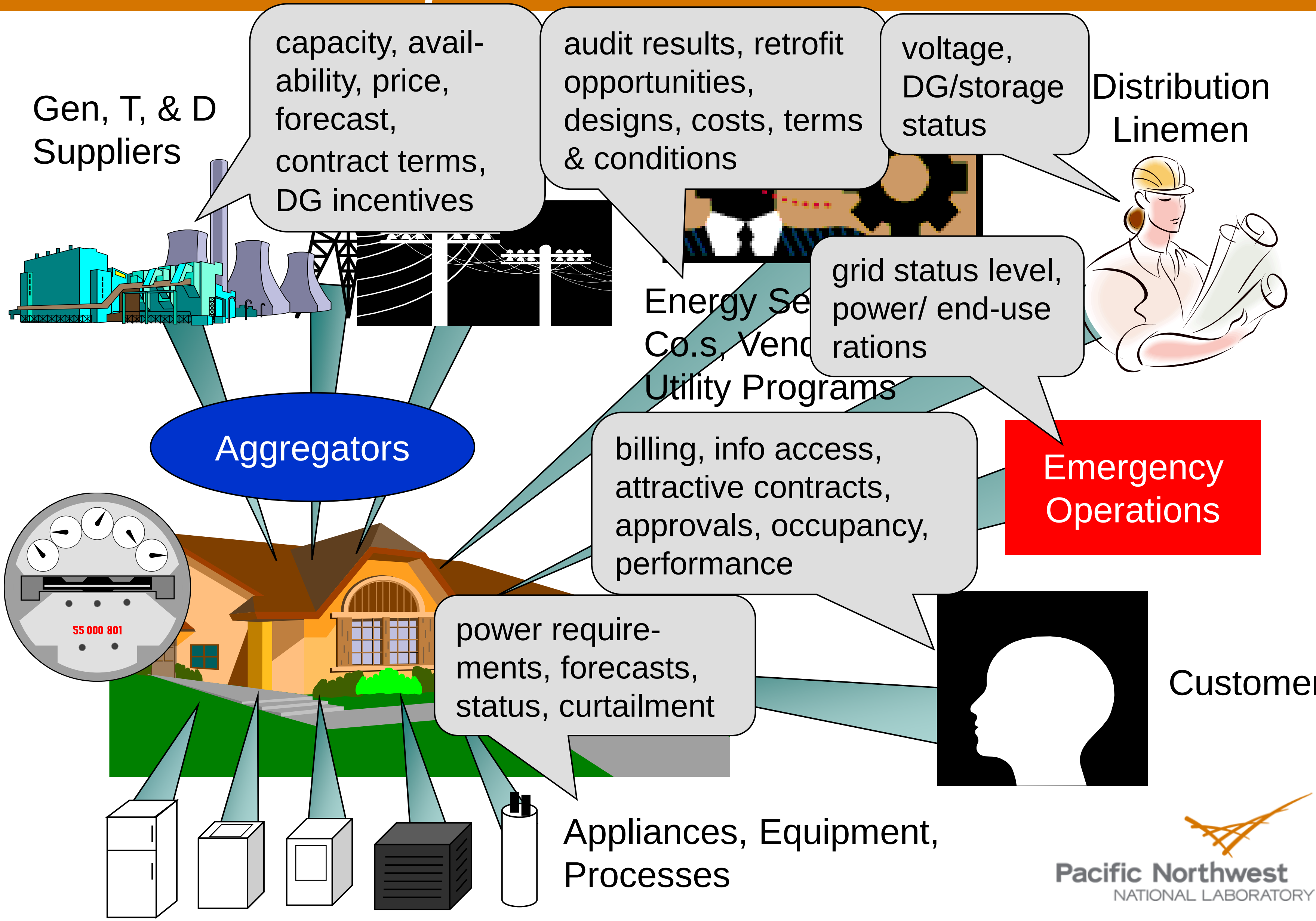
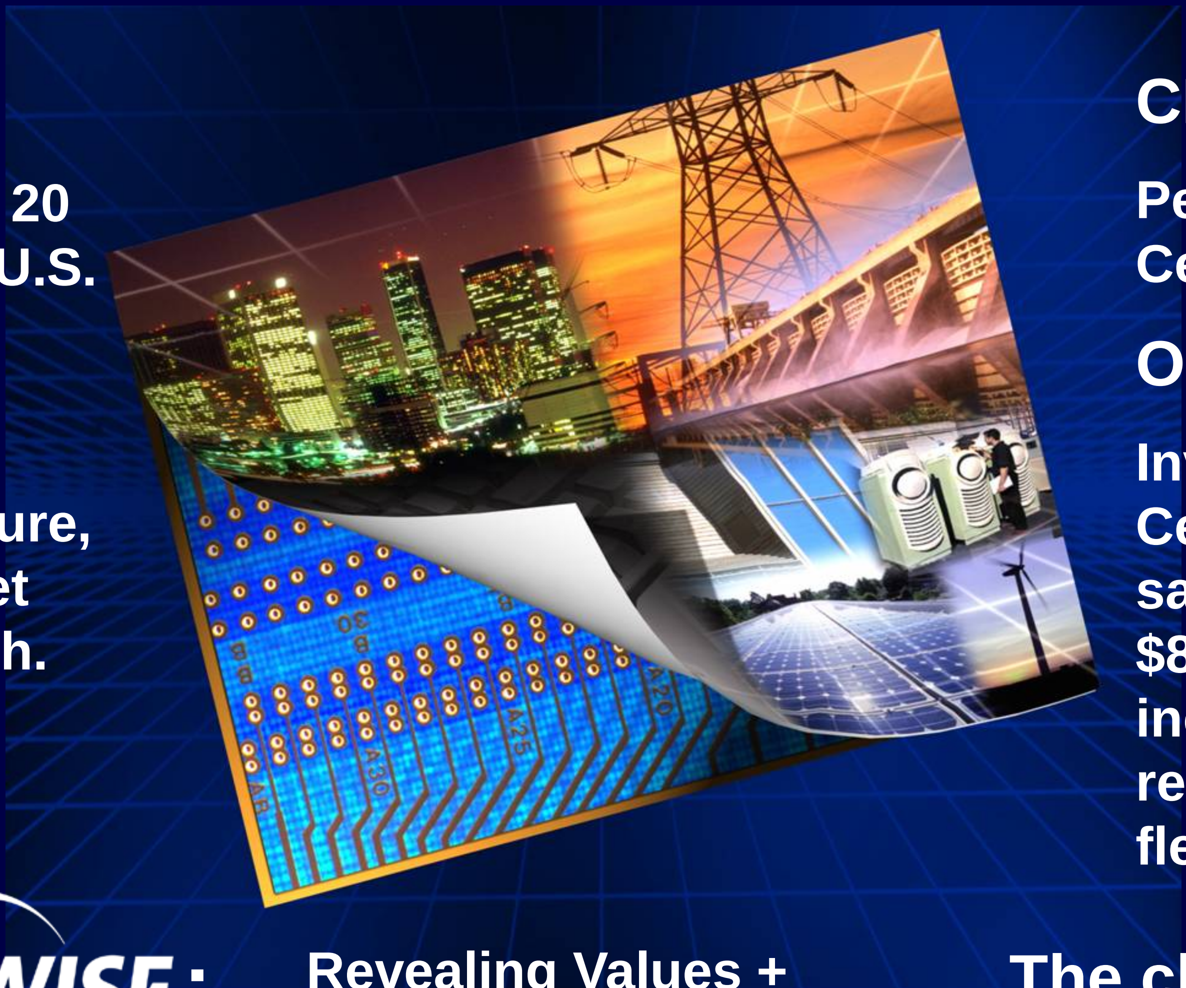
Communicate – With Whom? About What?
A Customer Perspective of the Smart Grid



Information: The Virtual Electric Infrastructure



FACT:

In the next 20 years, the U.S. will spend $450B on electric infrastructure, just to meet load growth.

CHOICE:

Perpetuate a 20th Century solution

OR

Invest in a 21st Century system saving ratepayers $80B while increasing reliability and flexibility.

GRIDWISE™: Revealing Values + Communications + Advanced Controls ≡ Electric infrastructure

The choice is easy because…

$ bits << $ iron

Smart Grid Operational Strategies for Distribution Systems:

Volt-VAR Control
and
Dynamic Feeder Reconfiguration

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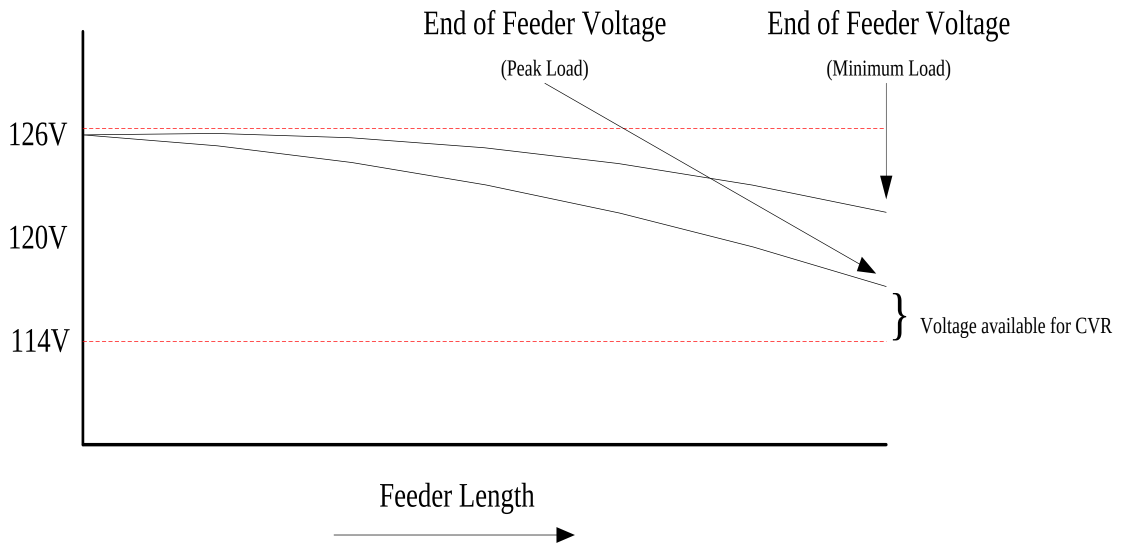
Reducing Loads with Better Voltage Control — *Conservation Voltage Reduction*

Basic voltage control:

- Voltage drops along feeder due to line losses
- Transformer tap changers/voltage regulators compensate at head of feeder:
  - None required (shown at right) <or>
  - Seasonal changes <or>
  - Closed loop control = f(kW)



Conservation Voltage Reduction (CVR):

- Energy efficiency/conservation measure (or can be used only for peak load management)
- Measure voltage with sensor at end of feeder
- Dynamically drop voltage at head of feeder to minimum acceptable level
- Lower voltage reduces end-use loads: ~0.7% to ~0.9% per % voltage drop*
  - Not just resistive, non-thermostatic loads like incandescent lights
  - Winding losses in transformers and motor loads also contribute
  - Benefit <u>will</u> vary from feeder to feeder (~0.4% to 1.5%)

* Reference: *Distribution Efficiency Initiative* (Northwest Energy Efficiency Alliance)
  200 homes with AMI, 13 utilities, 8 field projects

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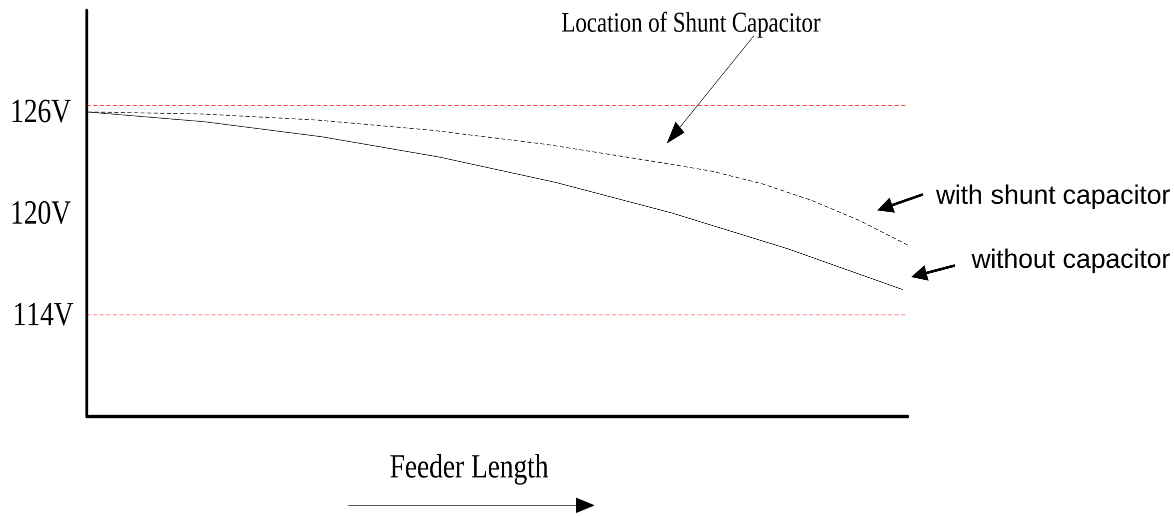
Reducing Loads & Losses — *Volt-VAR Control*

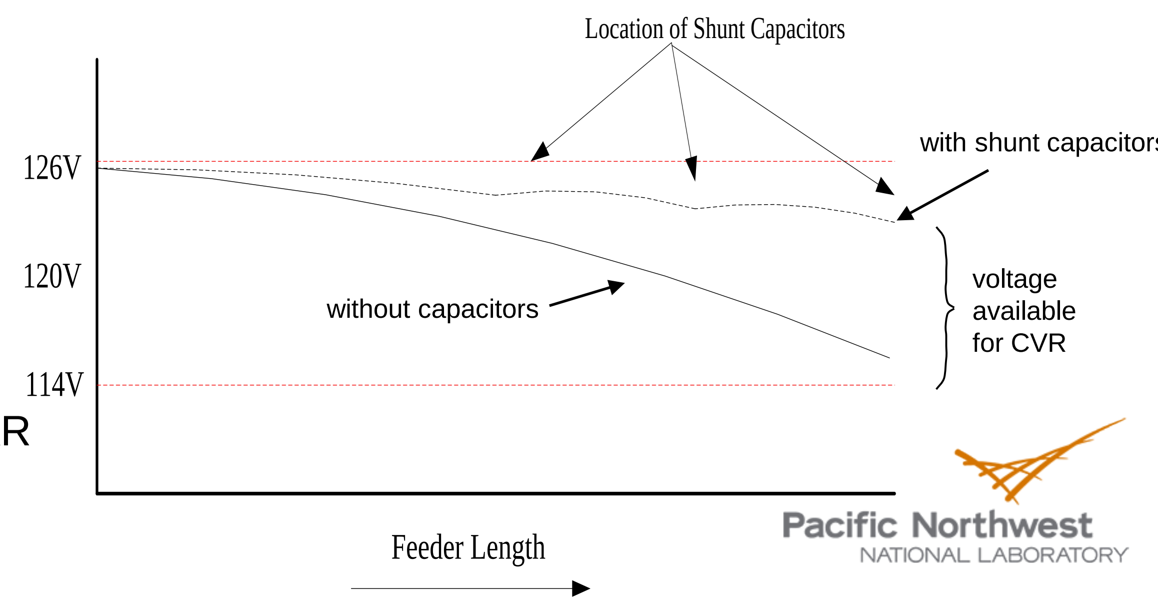
Basic VAR Control:

- Adding a capacitor bank (~2/3 position down feeder) to correct power factor
  - Reducing reactive power (VARs) reduces losses & raises voltage (shown at right)
  - Long, heavily-loaded, often rural feeders
  - Control settings may be changed seasonally



Dynamic VAR Control:

- Adjust capacitance *dynamically* with local power factor measurement
  - <better>: Multiple cap banks (shown at right)



Full Volt-VAR Control:

- Combining CVR *and* Dynamic VAR control increases the potential
  - <better>: Use AMI to optimize

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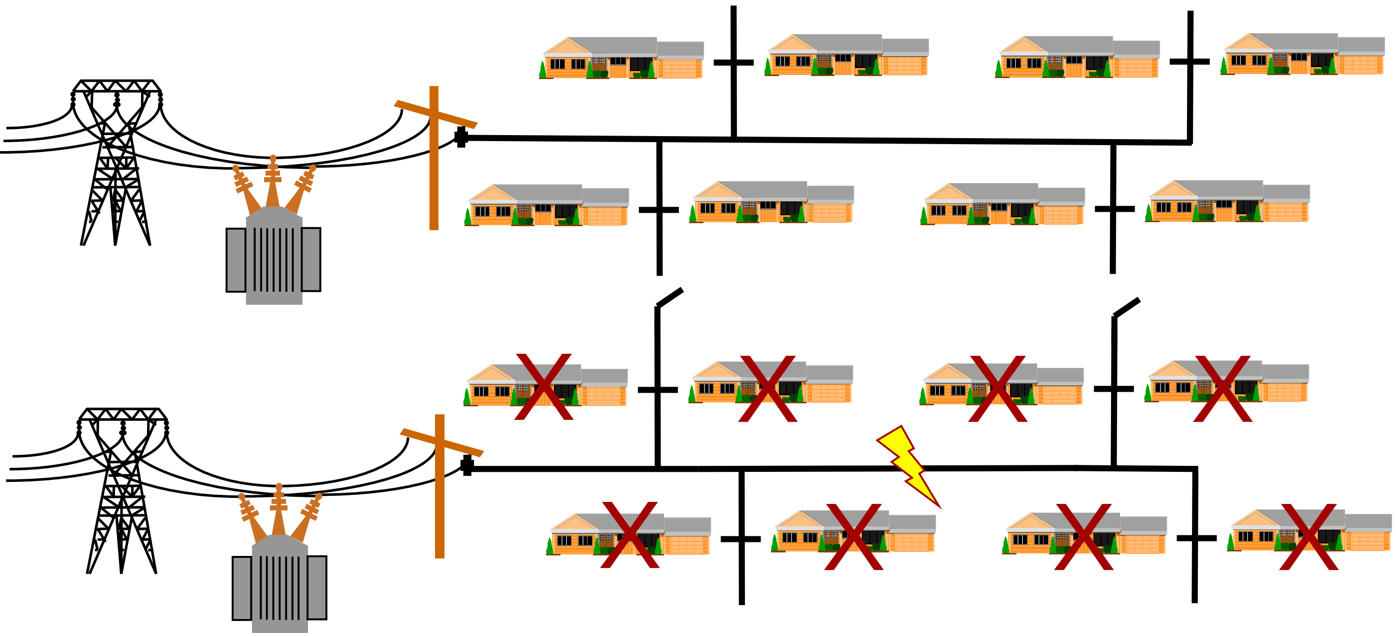
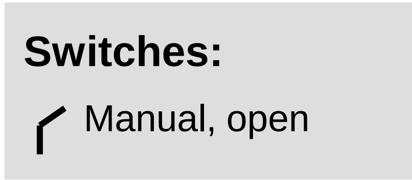
Self-Healing Distribution Systems – *Today's Operations*

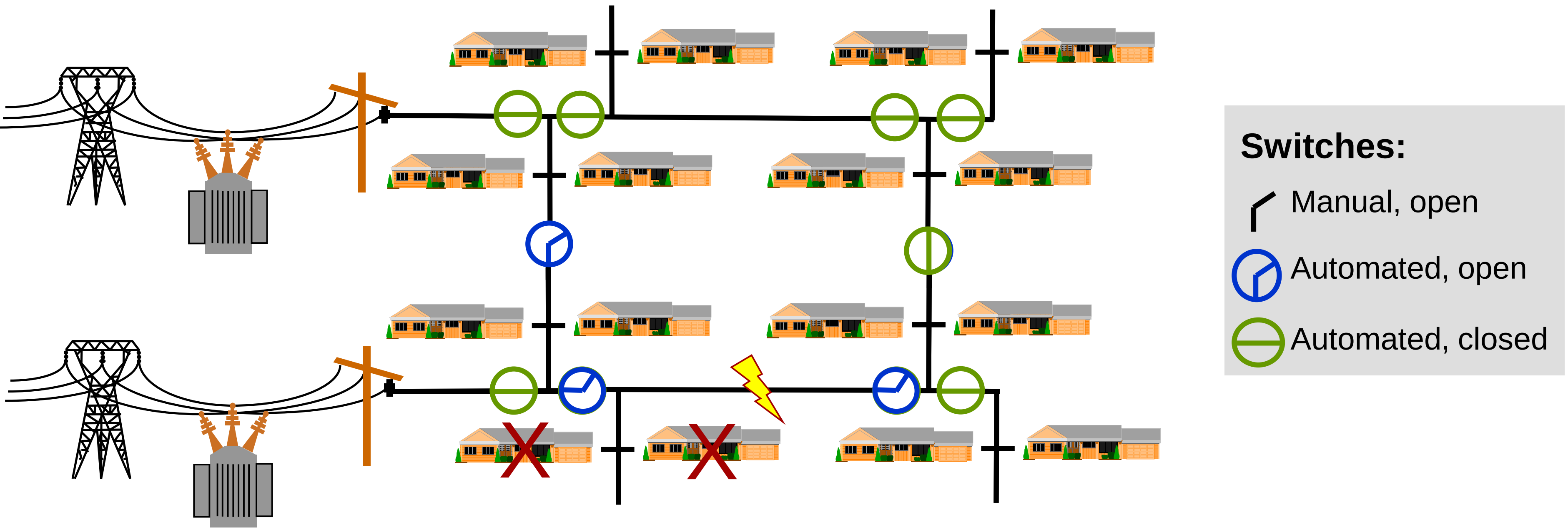




Two adjacent, radial feeders; <u>today's operations:</u>

1. Fault
2. Protective relays/fuses trip
3. Entire feeder outage
4. Dispatch truck/crew to find & isolate fault
5. Outage may last hours

Self-Healing Distribution Systems – *Dynamic Feeder Reconfiguration*



Two adjacent, radial feeders, <u>with dynamic reconfiguration system:</u>

1. Fault trips protection
2. Fault detection system locates fault, sectionalizing switches isolate it
3. Power restored upstream of fault
4. Analyze pickup load of remaining customers
5. Backfeed them from adjacent feeder
6. Power restored for most customers in seconds

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The Smart Grid and Carbon

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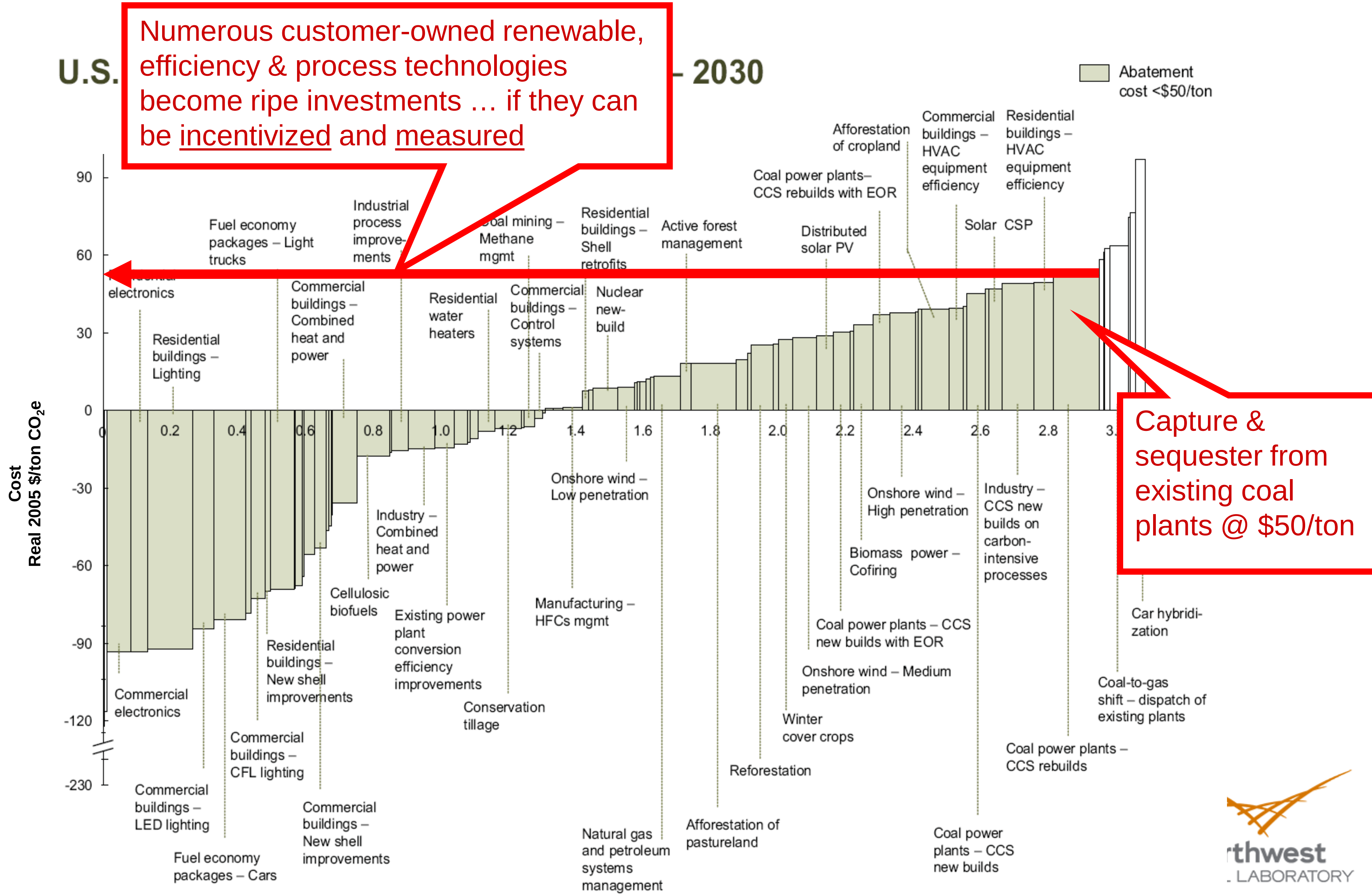
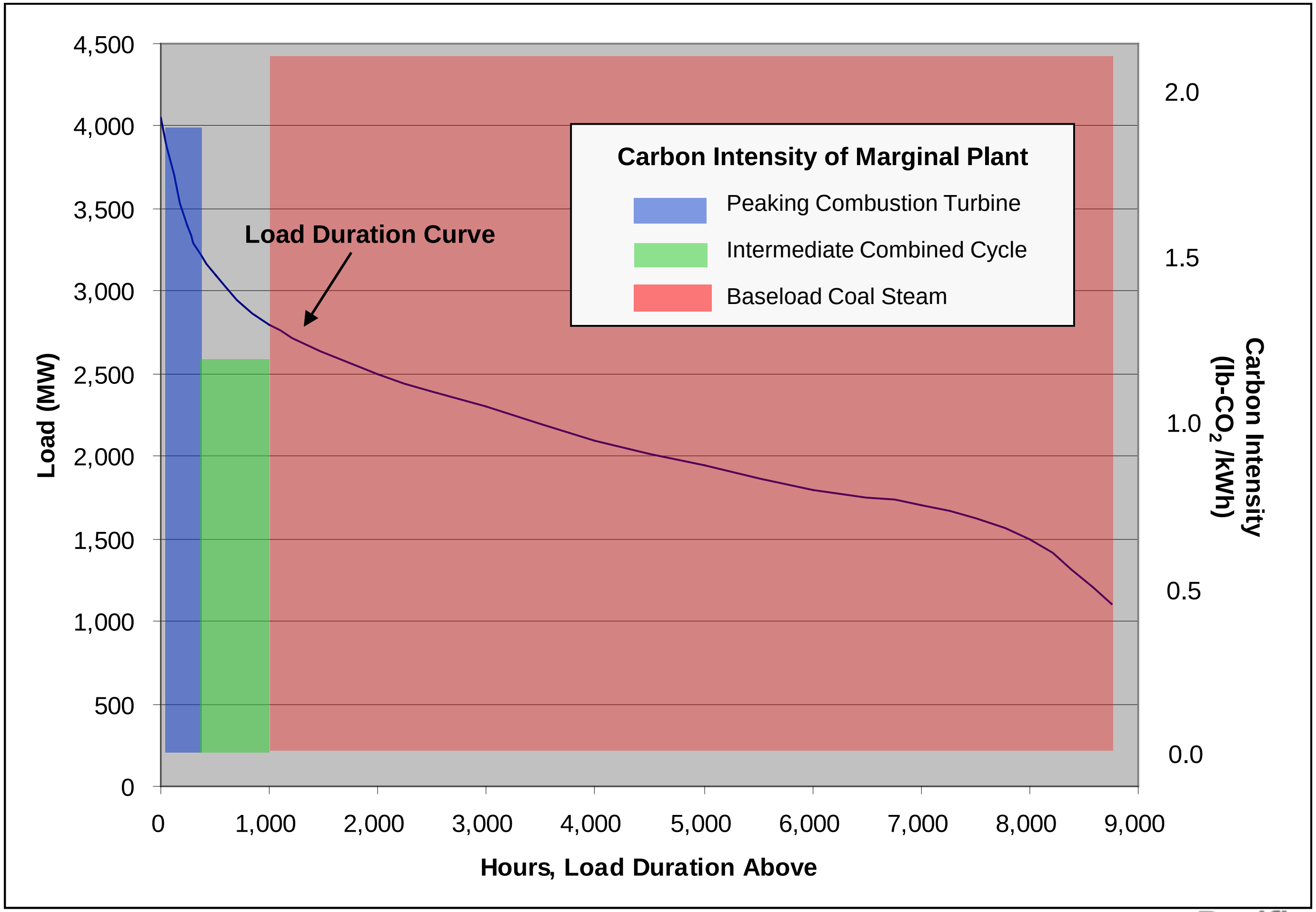
Carbon Supply Curve Suggests Massive Investment in Diverse Set of Resources is Coming



Source: McKinsey analysis

All kWh Are Not Created Equal – DR Load Shifting from Peaking to Intermediate Generation Can Save Carbon

Load Duration Curve and Carbon Dispatch of a Typical Coal-Based Utility



Smart Grid Can Deliver and Enable Carbon Savings – *A Sample of Mechanisms*

A *smart grid* can deliver carbon savings

- End-use conservation & efficiency from demand response controls
- Carbon savings from peak load shifting
- Minimize losses & resistive loads by continually optimizing distribution voltage
- Cost effective & increasingly clean energy for electric vehicles
- Improve & sustain end-use efficiency by delivering continuous, remote diagnostic & commissioning services

A *smart grid* can enable more, lower cost carbon savings

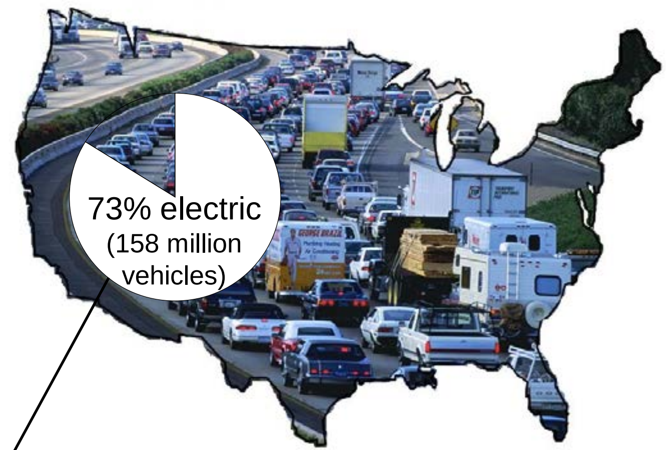
- Lower net cost for wind power by regulating fluctuations with demand response
- Distribution grids capable of safely supporting high penetrations of PV solar
- Lower costs for efficiency programs by leveraging the demand response/AMI network to measure & verifying energy & cost savings – *for each customer, with unprecedented precision, in real-time*
  - Accurate accounting of actual carbon footprint of generation displaced by efficiency & renewables
  - Solid verification enhances value & tradability of carbon offsets (if allowed)

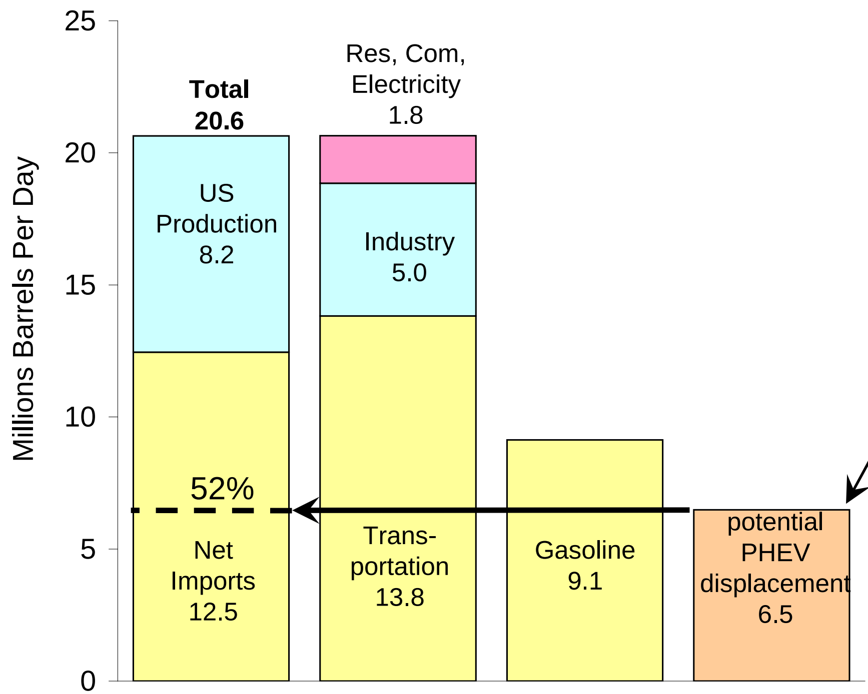
Potential Impacts of High Penetration of Plug-in Hybrid Vehicles (PHEVs) on the U.S. Power Grid*

** PNNL study for DOE Office of Electricity*

The idle capacity of today's U.S. grid **could supply 73%** of the energy needs of <u>today's</u> cars, SUVs, pickup trucks, and vans…

without adding generation or transmission
<u>if vehicles are managed to charge off peak</u>





Source: EIA, Annual Energy Review 2005

- Potential to displace 52% of net oil imports (6.7 MMbpd)
- More sales + same infrastructure = downward pressure on rates
- Reduces CO_2 emissions by 27%
- Emissions move from tailpipes to smokestacks (and base load plants) … cheaper to clean up
- Introduces vast electricity storage potential for the grid

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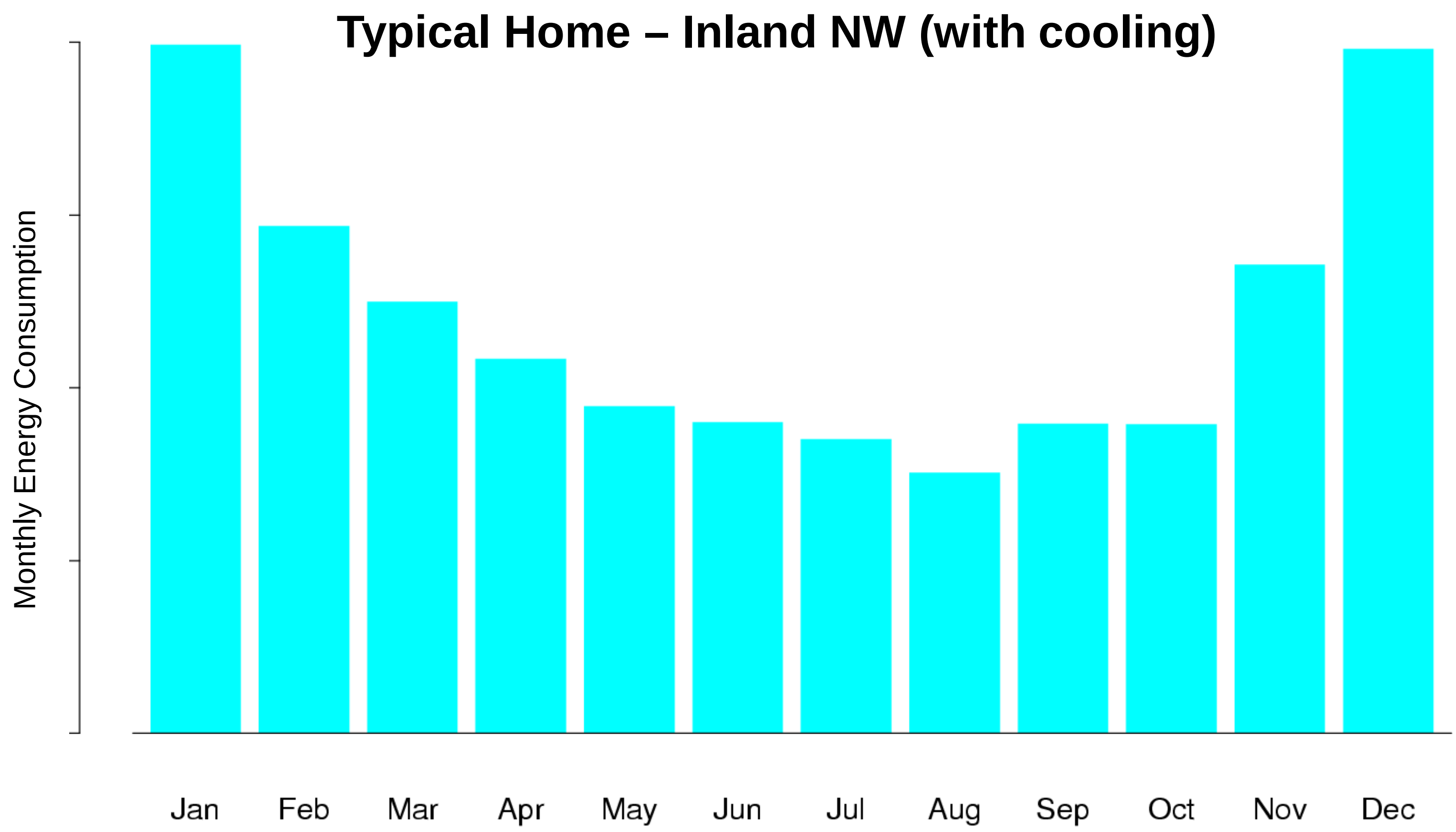
How Does a Smart Grid's Demand Response Capability Deliver Energy Efficiency?

- Customers can use scheduling and control capabilities of DR equipment to save energy in addition to peak
  - Water heater setbacks (especially)
  - Thermostat setbacks: TOU/CPP customers particularly
  - Shifting AC loads to off-peak hours results in run times during cooler morning evening hours when AC is more efficient (higher COPs)
- DR networks can be leveraged to provide remote diagnostics that improve efficiency (and reduce peak)
  - Load or run-time signals from DR load controls can be basis for diagnostics
  - Communications network allows diagnostic services to be provided remotely, universally

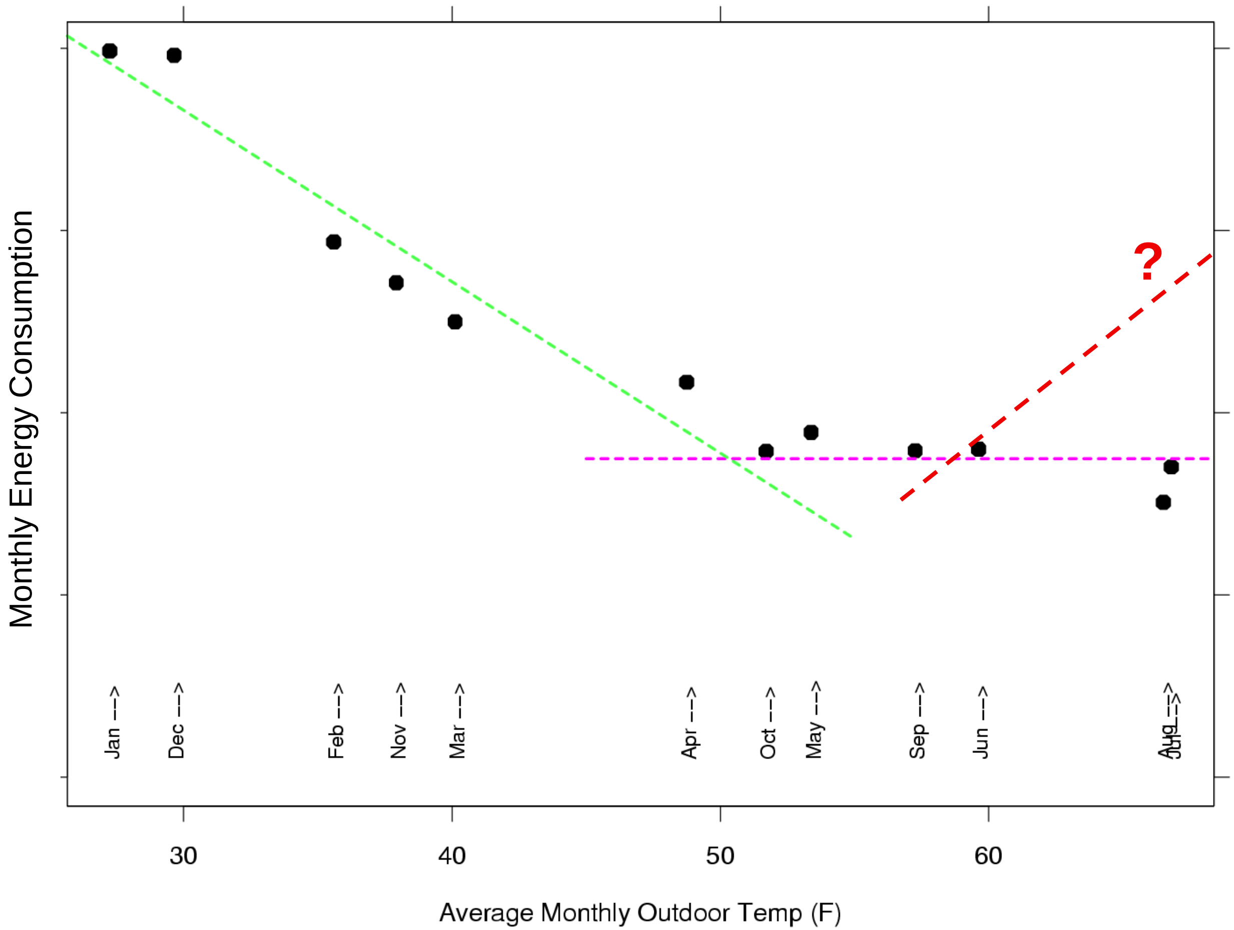
Measurement of Efficiency Savings Today: Basis is 12 Monthly Bills



Using the DR Network to Measure and Verify Savings from Efficiency

- Measure and verify peak, energy, and cost savings, by customer, by end use category
  - Utilize AMR and demand response network and controls to disaggregate load into major end uses
  - Time-series and end-use detail provides much higher validity to savings estimates
  - Build & continually update models of customer loads for use in both verification and diagnostics
- Tabulate renewable, efficiency, and carbon credits by integrating with back office systems
  - Weight consumption by CO_2 footprint of generation in real time to gain carbon benefits of load shift
  - Solid verification enhances value

Analysis of Monthly Billing Data vs. Outside Temperature Yields Minimal Information



- State-of-the-art is 20-yr old PRISM billing data analysis
- Heating vs. base load is apparent, but with significant uncertainty
- Note AC is invisible

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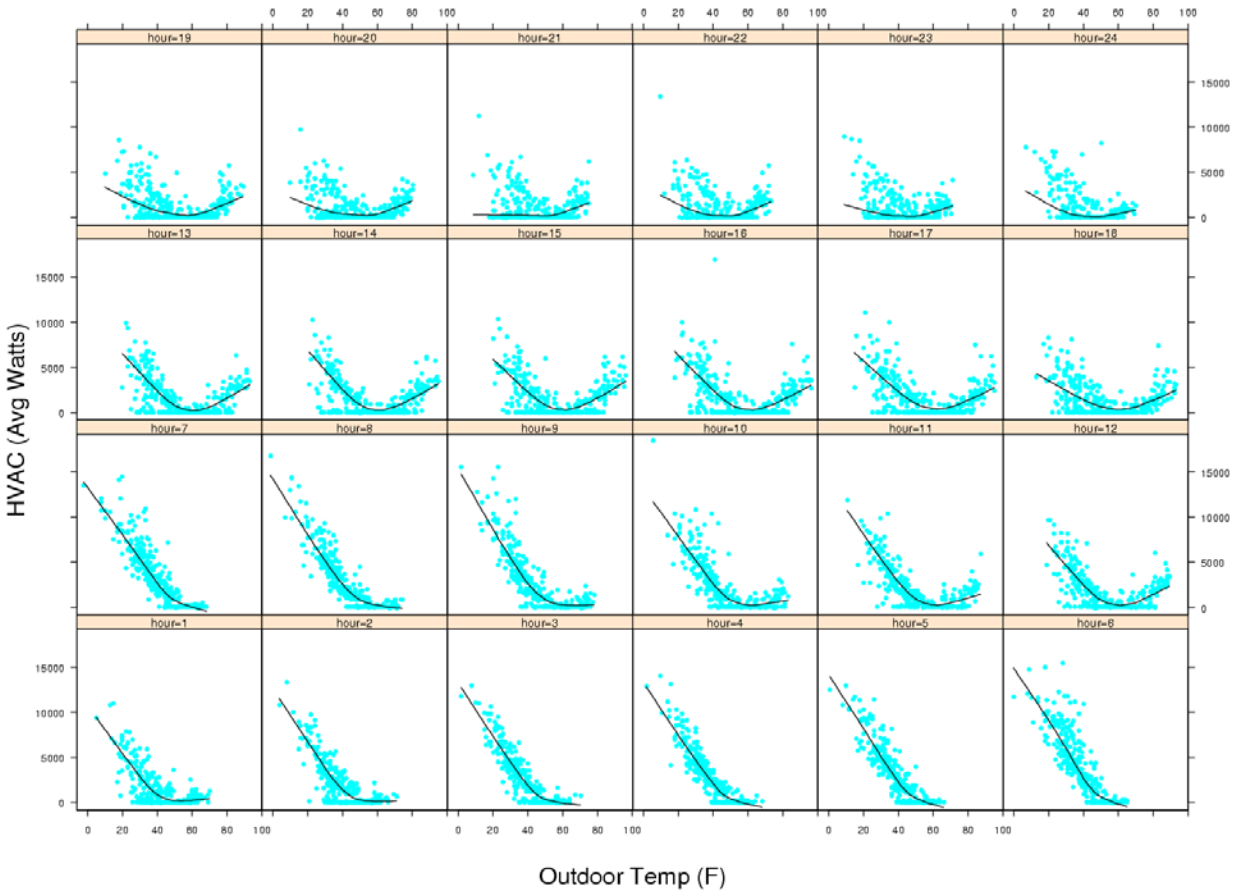
Smart Grid Provides Time-Series Data with End Use Resolution



- Vastly improved resolution allows detailed analysis of end-use savings
- Note AC load is now apparent

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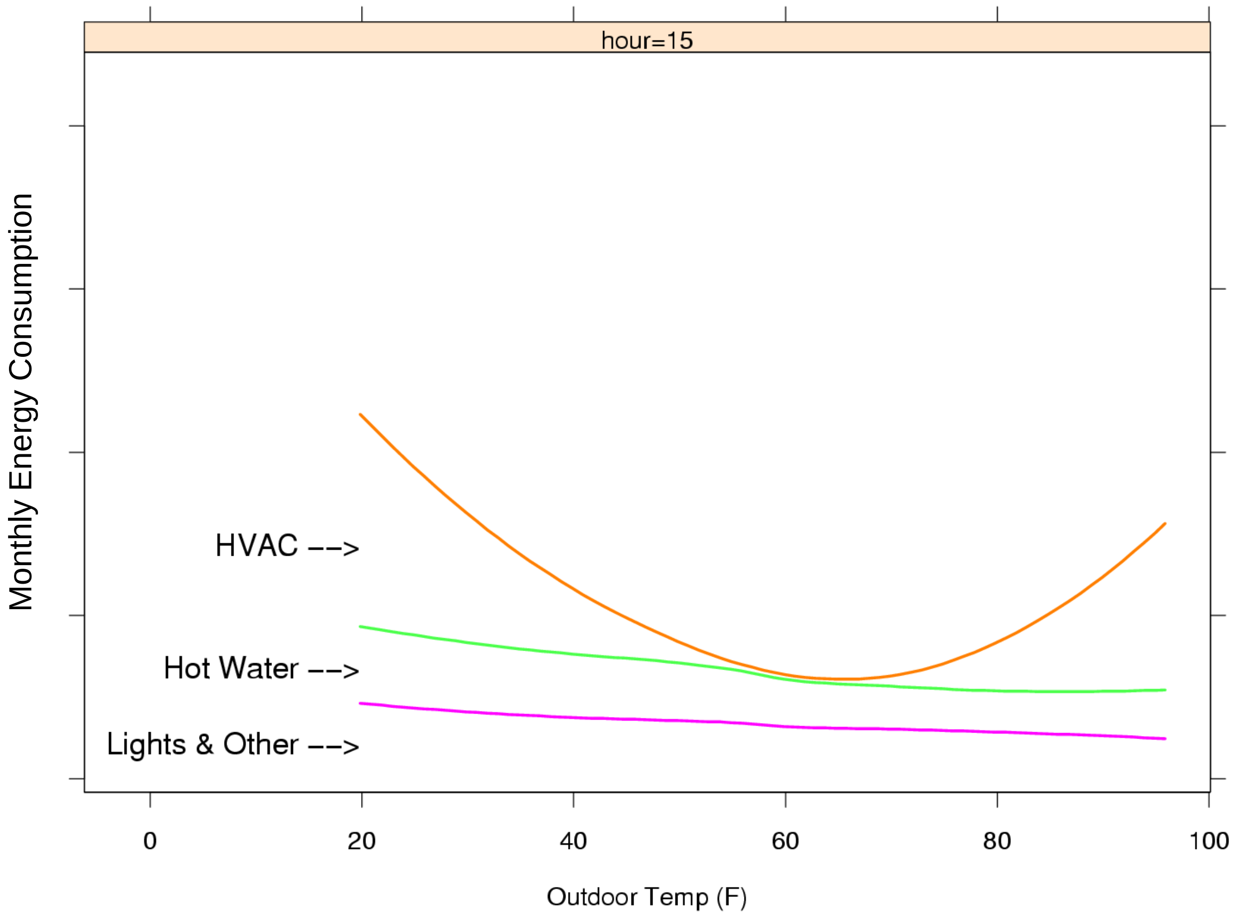
DR Networks Can Support Detailed Analysis of Most Types of Efficiency Savings



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What We've Learned from the Olympic Peninsula Demonstration

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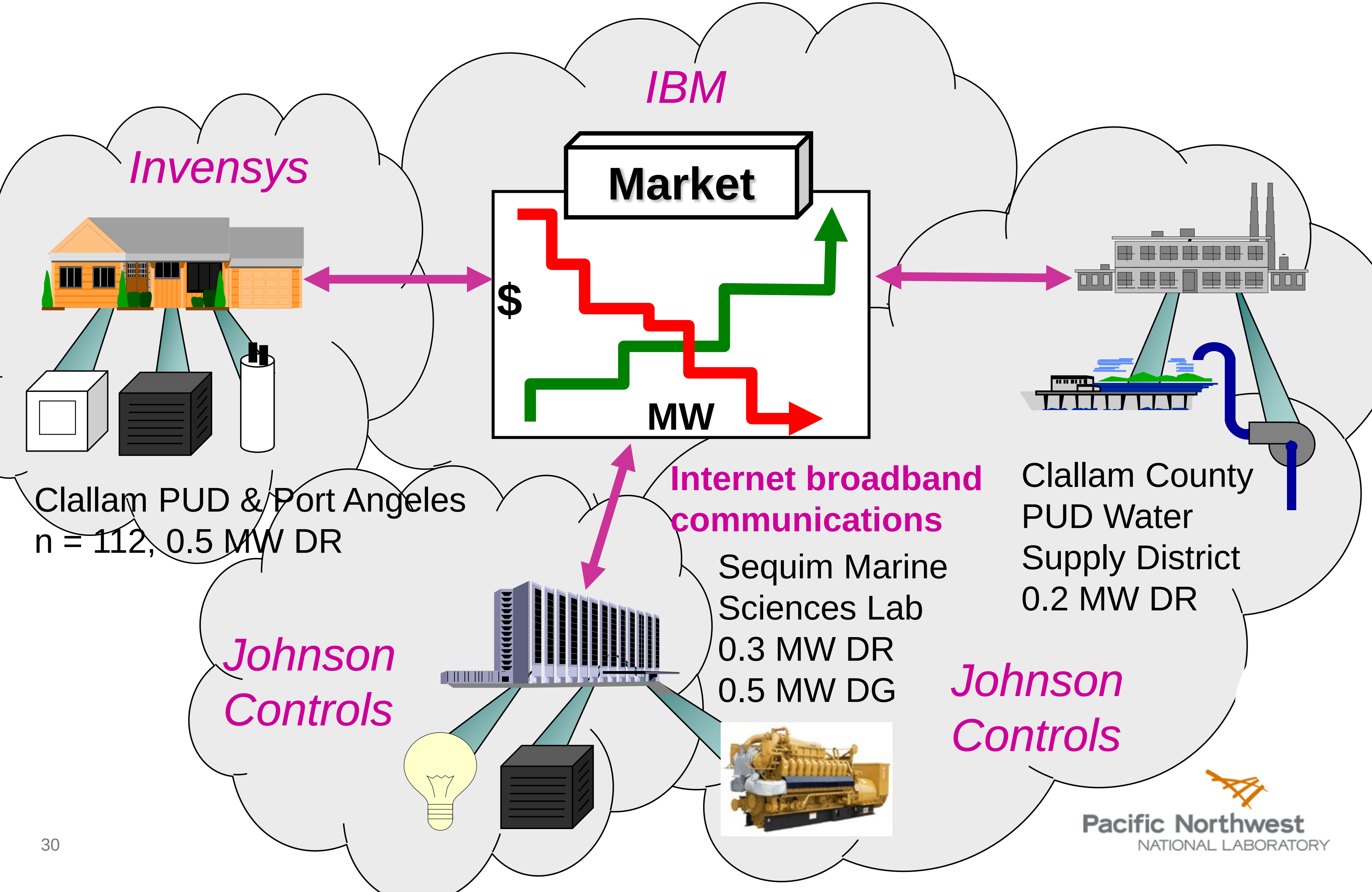
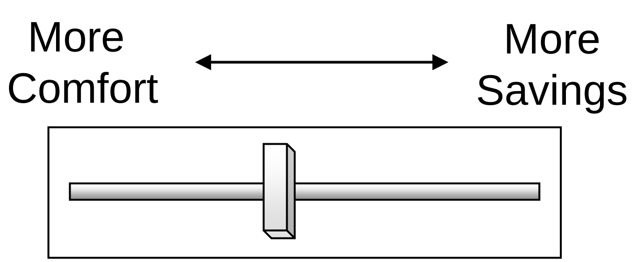
Olympic Peninsula Demonstration



Olympic Peninsula Demo: Key Findings (1)

Customers can be recruited, retained, and will respond to *dynamic pricing* schemes **<u>if they are offered</u>**:

- Opportunity for significant savings (~10% was suggested)
- A “no-lose” proposition compared to a fixed rate
- Control over how much they choose to respond, with which end uses, and a 24-hour override
  - prevents fatigue: reduced participation if called upon too often
- Technology that automates their desired level of response
- A simple, intuitive, semantic interface to automate their response



→ ***Translates to thermostat control parameters***

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Olympic Peninsula Demo: Key Findings (2)

Significant demand response was obtained:

- 15% reduction of peak load
- Up to 50% reduction in total load for several days in a row during shoulder periods
- Response to wholesale prices + transmission congestion + distribution congestion
- Able to cap net demand at an arbitrary level to manage local distribution constraint
- Short-term response capability could provide regulation, other ancillary services adds significant value at very low impact and low cost)
- Same signals integrated commercial & institutional loads, distributed resources (backup generators)