Network Economics: Electricity and Smart Grid Technology

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What do I want you to take home?

- The potential for technological change to reshape the electricity industry is large
  - Capacity utilization/load factor
  - New/different services and business models that benefit consumers and reward entrepreneurs
  - Different platforms
  - Interoperability
- Ability of digital and communications technology to create value

What do I want you to take home?

- The value and importance of distributed knowledge in the electric power network, and how technology can help us harness it and unleash it
- Markets, with active, empowered consumers, engage and protect consumers
- Regulatory institutions currently dampen this potential, but don't have to
- The 21st century, digital electric power industry is clean and green

Technology and the electric power industry

- Physical infrastructure is almost a century old
  - Central generation
  - Grid
  - Metering
- Digital and communications changes have not (r)evolutionized value chain, as has happened in other industries
  - Network intelligence still concentrated in the substation

Structural changes in U.S. economy

- Petroleum/electric 60/40 to 40/60
- New uses of electricity
- Infrastructure investment pressures
- Global competition
- Carbon-constrained future

Challenges to electric power network

- Obsolete technology
- Aging infrastructure
  - Business as usual iron/wires $450 bn over 20 years
  - Inefficiency of fossil-fuel central generation
- Growing electricity demand
- Meeting reliability standards and consumer expectations
- Low capacity utilization
- Lack of consumer participation

Technology can help! Smart grid

- Application of digital communication technology throughout value chain
- Self-healing
  - Automated
  - Proactive
- Motivates and includes consumers and markets
  - Automating end-use devices, prices to devices
- Reliability and security
- Power quality
- Interconnection

Smart grid technologies

- Integrated communication technologies
- Advanced components
- Advanced controls
- Sensing and measurement
- Improved interfaces and decision support

Smart grid benefits

- Reliability
- Security and safety
- Power quality (including differentiated products)
- Enabler of robust competitive markets and consumer choice
- Operational efficiency
- Environmental quality

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The digital, 21st-century network is also clean and green

- Largely through peak smoothing
- Energy efficiency through automated building management systems, end-use metering, etc.
- Peaks disproportionately cause pollution (cycling up and down, spinning reserves)
- Automation of green power bids and offers
- Automation of “dirty” plant cycling down in response to smog alerts

EISA 2007 Sec. 1306 defines smart grid

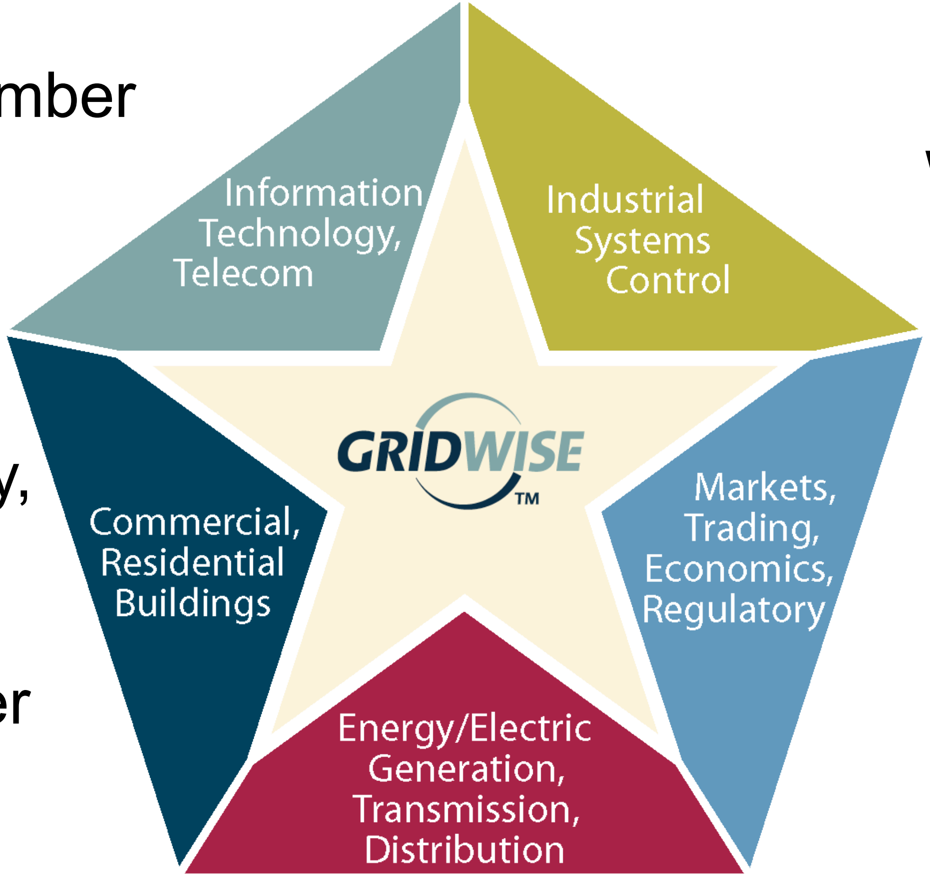
The term Smart Grid Functions shall include:

1. Ability to store, send and receive digital information (prices, costs, electricity uses, time of day, nature of use) through a combination of devices
2. Ability to do above to or from a computer or control device
3. Ability to measure and monitor electricity use as a function of time of day, power quality, source and type of generation, etc
4. Ability to sense and localize disruptions or changes in power flows and communicate on such instantaneously to enable automatic protective responses
5. Ability to detect, respond to, recover, etc relative to security threats, including cyber-sec and terrorism
6. Ability of appliances and equipment to respond without human intervention
7. Ability to use digital information for grid operations that were previously electromechanical or manual
8. Ability to use digital controls to manage and modify demand, congestion, and provide ancillary services
9. Other functions the Secretary may identify

GridWise Architecture Council

What? 13-member council, DOE -supported

Who? Industry, adademic volunteers, subject-matter experts



GRIDWISE™

Information Technology, Telecom

Industrial Systems Control

Commercial, Residential Buildings

Markets, Trading, Economics, Regulatory

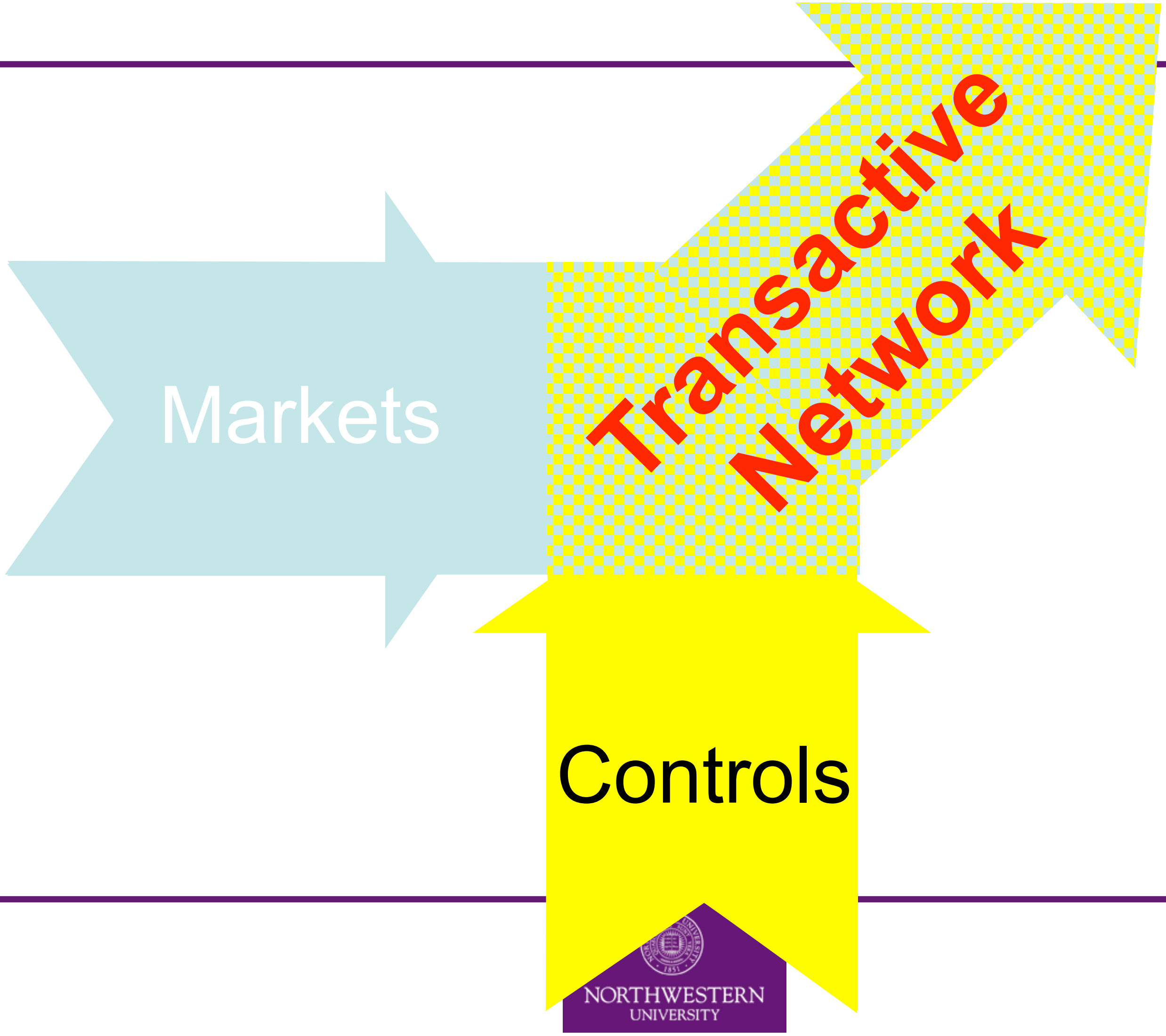
Energy/Electric Generation, Transmission, Distribution

Why? To promote consensus on industry stds. and interoperability to enable grid modernization and (private) investment

Mission

The mission of the Architecture Council is to <u>establish broad industry consensus</u> in support of the technical principles that enable the vast scale of interoperability necessary to transform electric power operations into a <u>system that integrates markets and technology</u> to enhance our socio-economic well-being and security.

Markets and Controls Merge to Form a Transactive Network



Markets

Transactive Network

Controls

What is interoperability?

The ability of two or more networks, systems, devices, applications or components to exchange information and to use that information effectively for action -- with little or no human intervention.

- Interoperability requires interconnectivity and common protocols between hardware and software to enable effective communications, coordination and control.
- Interoperability is achieved when users' *expectations* to exchange and use information among various devices and software applications from multiple vendors or service providers are met or exceeded.

Source: EICTA INTEROPERABILITY WHITE PAPER - 21 June 2004

The impact of interoperability

Look at telecom, internet, banking and finance -- competition and value come from innovative content, functionality, quality, and easy interfaces

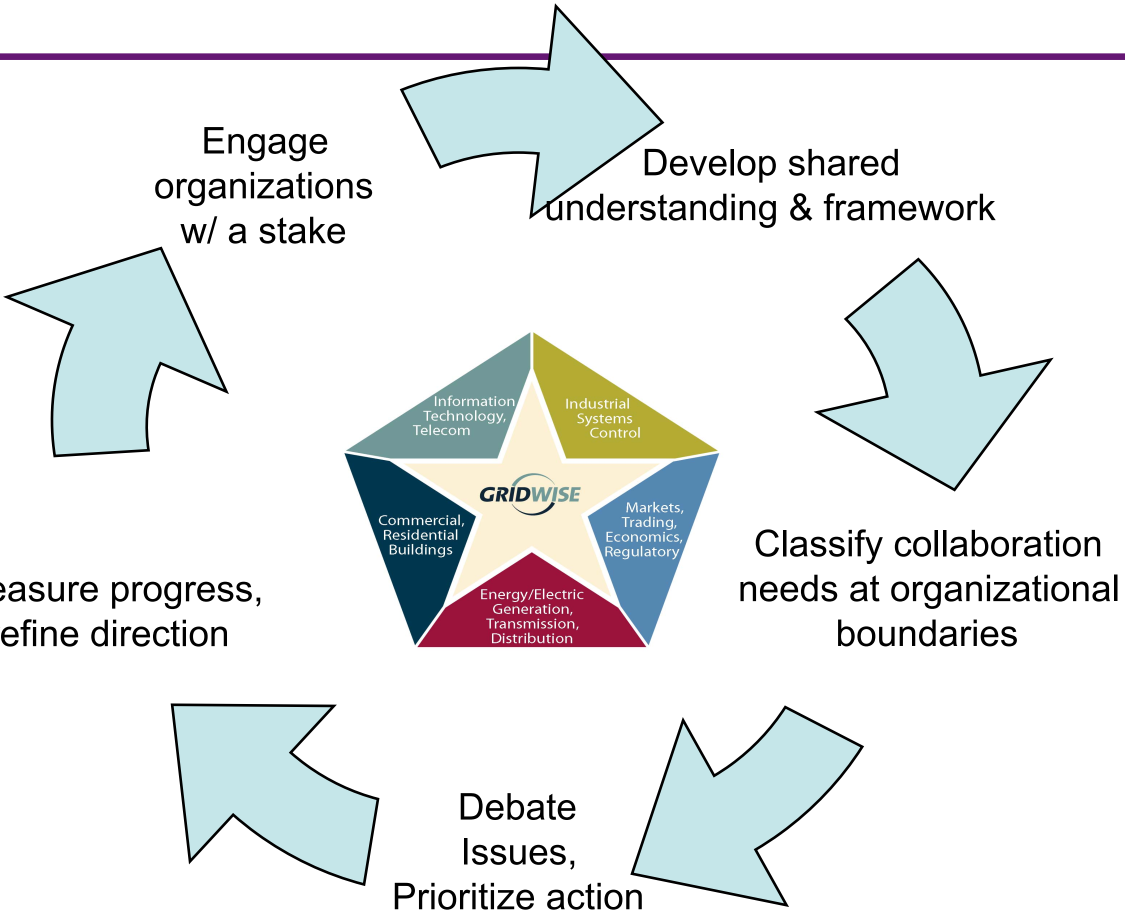
- New value for users from innovative applications, built on a platform of interoperability and interconnectivity
- Technology convergence enabled by planned interoperability and open (non-proprietary) standards, and continued investment
- Continued investment in infrastructure
- Customer access to information about options and costs and ability to act on those choices

What new apps could evolve on the grid if we let them?

The Central Question

- How do we help enable business interaction among participants in the North American electric system and maintain that integration for 30 years and forward?
- Our action plan
  - Establish a consensus building process
  - Foster cross industry segment collaboration
  - Facilitate an interoperability framework
  - Interoperability tools, such as the Interoperability Checklist for Decision-Makers

Interoperability Path Forward



Engage organizations w/ a stake

Develop shared understanding & framework

Classify collaboration needs at organizational boundaries

Debate Issues, Prioritize action

Measure progress, refine direction

GridWise^{TM} Olympic Peninsula Testbed Demonstration

- “Shadow market” layered on existing utility service, with potential to “earn” on average $100 during 1-year project
- 2 hypotheses to test
  - Does the tech/pricing combination change consumer energy use patterns (and therefore system)?
  - Do consumers automate their responses?
- Participants: 126 residential customers, 3 commercial customers w/DG, all broadband

Olympic Peninsula Project Team

U.S. DOE GridWise Program
$2.0M project funding over two years through PNNL, technology innovator, project manager

Bonneville Power Administration
$75K project funding, Non-wires Program resources, in-kind labor

Portland General Electric
$63K project funding over three years, utility site host, in-kind meter installation labor

PacifiCorp
$50K project funding, utility site host, in-kind recruitment labor

Preston Michie and Associates
Energy pricing consultant and valuation analysis

Dr. Lynne Kiesling
Economic experiment design consultant

Whirlpool Corporation
Manufacturer of Sears Kenmore™ HE2 dryer, vendor, in-kind research labor

IBM
Provider of communications technologies, in-kind application development labor and WebSphere™ software provider

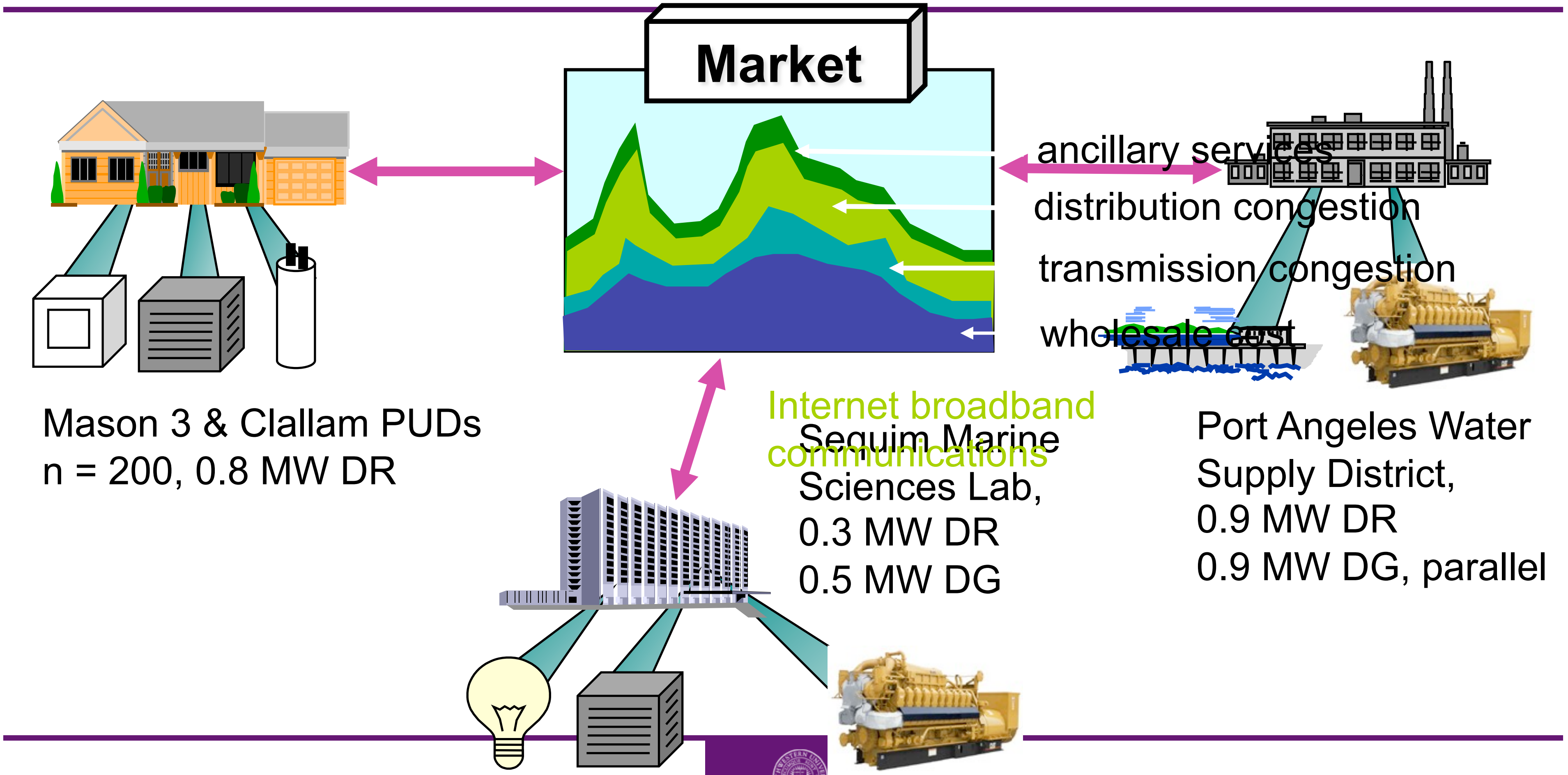
Invensys Controls
Residential communication and control equipment, vendor of GoodWatts™ system

Clallam County PUD
Utility site host, in-kind meter installation labor, in-kind recruitment labor

City of Port Angeles
Utility site host, in-kind meter installation labor, in-kind recruitment labor

Montana Tech
Student labor collaboration

Olympic Peninsula GridWise Demonstration



Market

ancillary services

distribution congestion

transmission congestion

wholesale cost

Internet broadband communications

Mason 3 & Clallam PUDs
n = 200, 0.8 MW DR

Sequim Marine
Sciences Lab,
0.3 MW DR
0.5 MW DG

Port Angeles Water
Supply District,
0.9 MW DR
0.9 MW DG, parallel

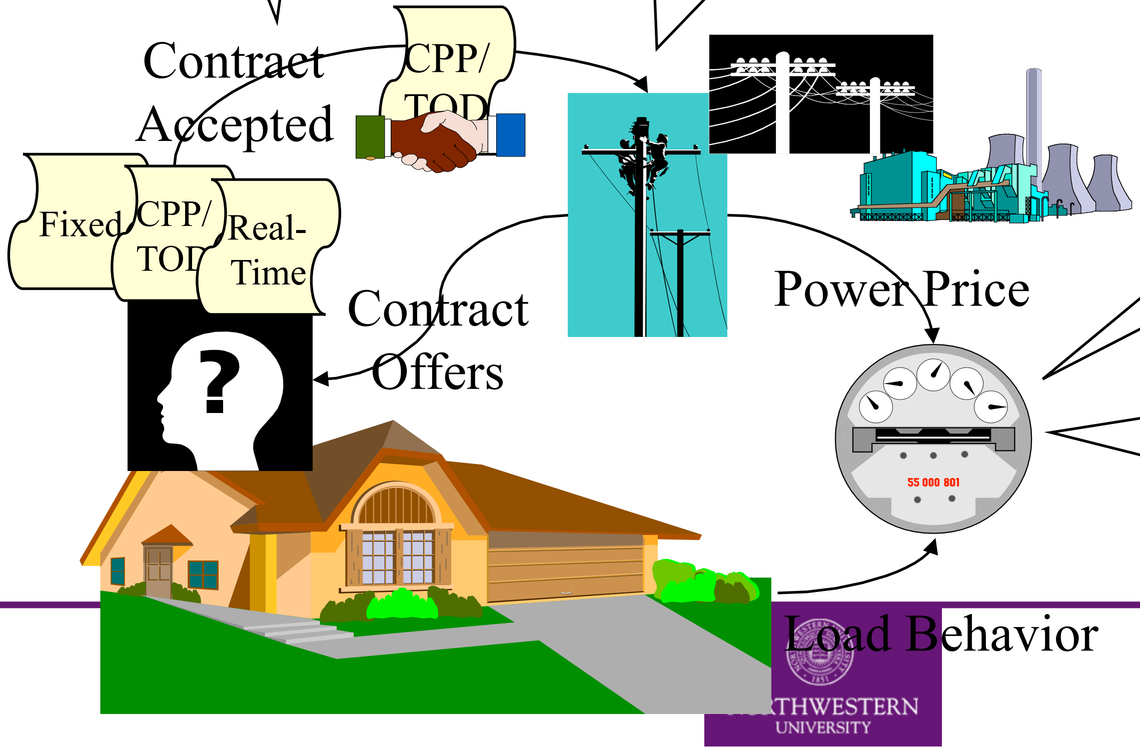
Testing Market-based Customer Incentives

Customer contract choice

Virtual distribution feeder (in software) as if all resources co-located on a single feeder

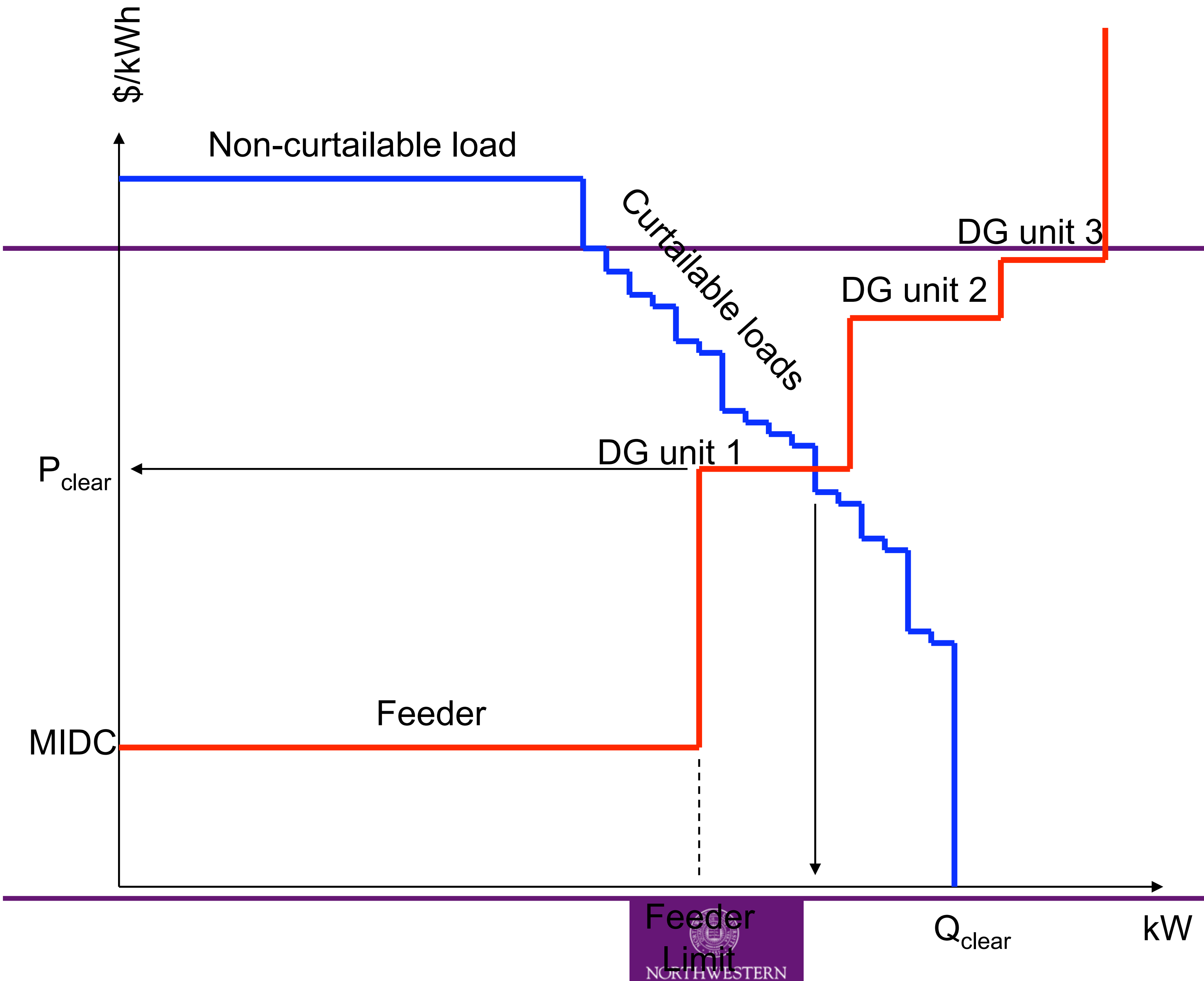
Real-time (5-min.) mkt clearing – real cash deposits & shadow billing; RTP use double auction

Real-time & historical display of resources, costs, prices



Contract choice field experiment, April 2006-March 2007

- 126 broadband-enabled households chose among three contracts: Fixed (n=30), TOU (n=31), RTP (n=30)
- Control group (n=25) got technology (PCT, water heater) but did not participate in contract experiment
- RTP market clearing
  - 5-minute intervals, with price-responsive appliances & ability to automate decisions
  - Designed as a double auction
  - **First ever use of a double auction in a residential retail electricity market**


$/kWh
Non-curtailable load
Curtailable loads
DG unit 3
DG unit 2
DG unit 1
P_{clear}
Feeder
MIDC
Feeder Limit
Q_{clear}
kW

Experiment design

- Experimental groups
  - A – Normal users (no tech, no contract choice)
  - B – Technology only (control group, no contract choice)
  - C – Fixed price (reflects forward price)
  - D – TOU + CPP
  - E – RTP
- Experiment : Ask customers contract choice preference
  - Rank first, second, third preference for contract choice
- Results: 2/3 of households listed RTP as their first choice
  - Contradicts “common knowledge”
  - Reflects willingness to accept price risk when consumers know that they have enabling technology to automate their responses to the price signals
- PNL performed extensive agent-based simulation of system and various parameters (prices, elasticities, etc.) before going live in April 2006

TOU design

- Peak and off-peak rate
  - Peak 6-9 AM & 6-9 PM
  - Did vary twice during year, communicated to households in advance
  - P_{peak}=$0.1215/kw
  - $P_{offpeak}$=$0.04119/kw
- CPP: critical peak price
  - Could be called without warning
  - Called once, November 2006: $350/MW ($0.35/kw)

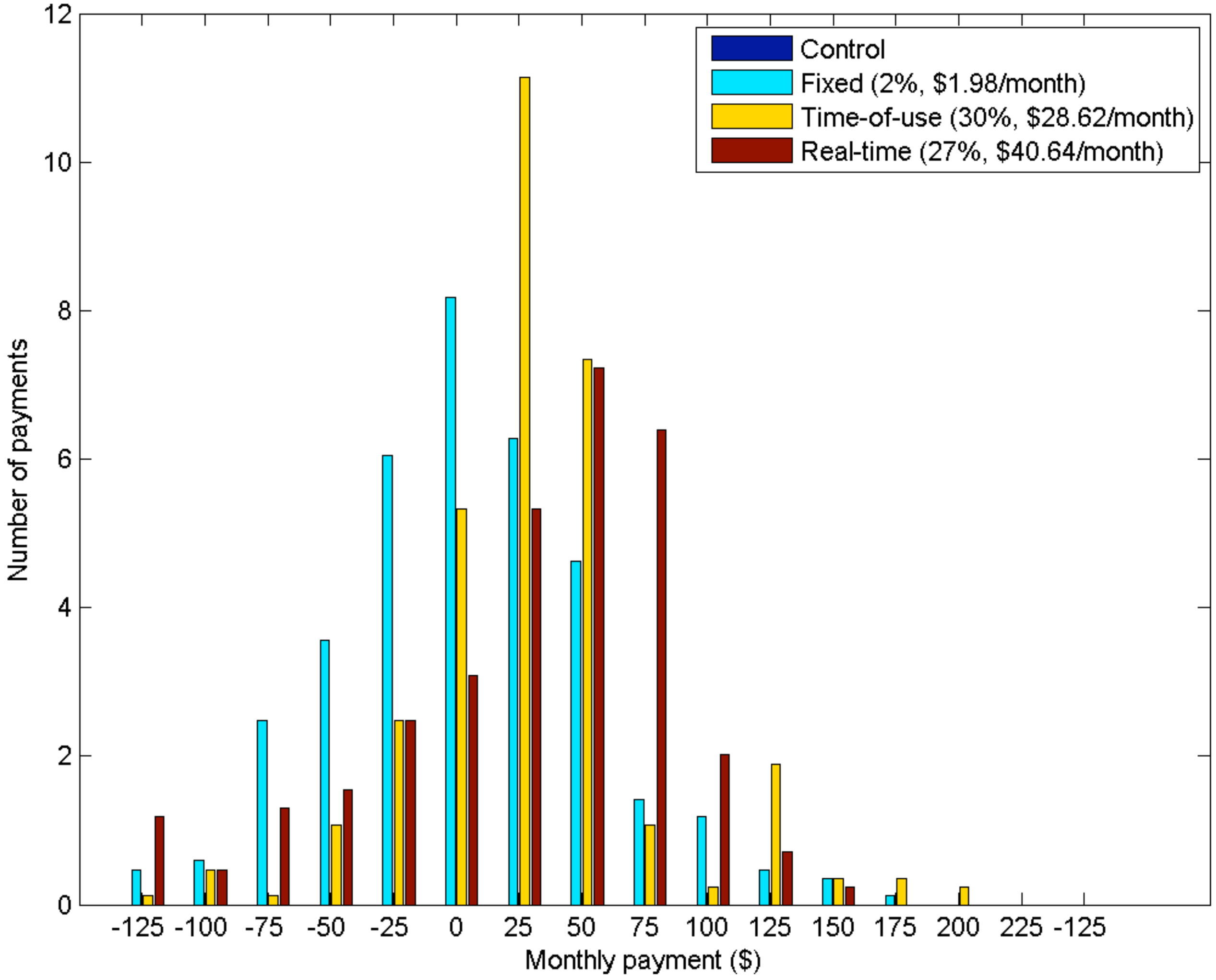
Preliminary results

- Based on hourly aggregation (i.e., for RTP average over 12 mkt clearings)
- Average prices paid by contract type (per MW, s.d. in parens)
  - Fixed: $81 (0)
  - TOU: $63.27 (35.9)
  - RTP: $49.20 (47.16)

Preliminary results (cont.)

- Average hourly consumption per household by contract type (kilowatts, s.d. in parens)
  - Control: 2.116 (1.25)
  - Fixed: 1.79 (0.84)
  - TOU: 1.42 (0.77)
  - RTP: 2.1 (1.0)
- Note low mean and std. dev. for TOU group
- RTP height in part an artifact of granularity of the building and appliance automation

Cost Savings



Preliminary energy use result 1: RTP group

- Peak consumption for RTP group reduced 15-17% relative to counterfactual (what peak would have been without dynamic pricing)
- Consumption for RTP group rose 4% overall
- Note that this is the first implementation of a double auction RTP design

Preliminary energy use result 2: TOU

- Hourly price elasticity of demand

  = -0.17
- Peak consumption reduction of 20% relative to the fixed price group
- TOU pricing induces more conservation, while RTP pricing induces more intertemporal smoothing
  - Behavioral differences among different contract types is an unexplored area of electricity market design and institutional design

Preliminary result 3: RTP & automation

- Fine-grained ability to respond to prices in 5-minute intervals changes the nature of the problem
- Distributed automation + RTP => complex adaptive system
- 5-minute price elasticity seen in submitted bids follows a power law distribution, not a normal distribution
- Implication: these results can scale to larger implementation, and indicate robustness and self-organization

Results summary

- Dynamic pricing + end-use technology
  - Make distributed control possible
  - Reduce pressure on infrastructure, increase reliability
  - Increase time between investments
- Residential consumers are willing to automate behavior and take on price risk
- Behavioral differences across contracts
  - TOU: reduced energy use, conservation
  - RTP: load smoothing

Conclusions

- Digital technology can empower consumers and create new value in this industry as it has in others; can align economic and environmental values
- Technology can't do that in a vacuum, which is why institutional design and research matter
  - Regulatory change to reduce barriers to new technology innovation and implementation
  - Dynamic pricing, rate redesign are crucial
- Highly distributed automation changes the nature of the question to one of complex adaptive systems
- The current system was built for centralized control, but we show that it is capable of distributed control driven by consumers

How can we bring this smart network into being?

- Testbeds/demonstrations
- Regulatory innovation-remove barriers to technological change, to interoperability, and to technology deployment
- Regional start-ups, centers of smart network innovation
- Nodes that are dispersed will grow together, linked by telecom into virtual smart energy networks