U.S. National Academy of Engineering
Grand Engineering Achievements of the 20th Century

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration

11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum/Petrochemical Tech
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials
Electricity Use and Human Development

Per Capita Electricity Consumption (MWh/yr)

Human Development Index

Japan, U.S., China, India, Zambia, Sierra Leone, Panama, Morocco, Estonia, New Zealand, Norway, Kenya, Australia, New Zealand

Dr. Louie

Annual Consumption: 3886 TWh
Sources of U.S. Electricity Generation, 2011

- Renewable 13%
- Nuclear 19%
- Natural Gas 23%
- Coal 42%
- Petroleum <1%

Source: U.S. Energy Information Administration, Electric Power Monthly (February 2012). Percentages based on Table 1.1, preliminary 2011 data.
1879: Edison patents light bulb

1886: Stanley patents transformer

1890: First use of electric chair

1896: Niagara Falls power plant generates AC

1880: Pearl St. station opens

1888: Tesla patents induction motor

1900: Westinghouse AC powers World’s Fair

1907: Sam Insull forms ComEd

Source: Ayers and Warr, “Accounting for Growth: The Role of Physical Work”
1900

1965
New York City blackout

1978
PUPRA enacted

1979
Three mile island disaster

1980
First wind farm opens

1973
OPEC embargo

1979

1978

2000

2010

2011

2012

1900

2008

2009

2010

2011

2012

Installed Capacity (GW)

Wind Plant Capacity

2008 2009 2010 2011 2012

0 10 20 30 40 50 60 70

Installed Capacity (GW)
RENEWABLE PORTFOLIO STANDARDS

Source: Center for Climate and Energy Solutions
Locational Marginal Prices in the Midwest ISO

Negative Prices!

BPA Balancing Authority Load & Total Wind Generation, Last 7 days

Based on 5-min readings from the BPA SCADA system for points 45588, 79687
Balancing Authority Load in Red, Wind Generation in Blue; Installed Wind Capacity=1459 MW
BPA Technical Operations: Roy Ellis (rcollis@bpa.gov)
American Recovery and Reinvestment Act
Provides the U.S. Department of Energy with $4.5 billion to modernize the electric power grid.

American Recovery and Reinvestment Act of 2009
U.S. Department of Energy Smart Grid Programs


- Smart Grid Investment Grants
- Smart Grid Demonstration Projects
- Standards Interoperability & Cybersecurity
- Workforce Training

- Guidance
- Planning
- Recipient Reporting Deployment of Assets and Costs
- Recipient Reporting Grid Impacts and Technology Performance
- DOE Analysis Technologies, Benefits and Lessons Learned

American Recovery and Reinvestment Act
Smart Grid Demonstration Projects

Smart Grid Demonstration Projects. Total Value of $1.6 Billion.

American Recovery and Reinvestment Act
Smart Grid Investment Grants

Smart Grid Investment Grant Projects. Total Value of $0 Billion.

Source: smartgrid.gov
Demand Response

Objectives

- Reduce peak demand
- Reduce overall demand

Benefits

- Deferral of supply-side capital investments
- Lower fuel costs
- Avoided emissions
- Lower cost to customers
**Demand Response Enablers**

**Advanced Metering Infrastructure**

**CUSTOMER SYSTEMS**

**Information**
Web portals, in-home displays (IHD)

**Control**
Programmable Communicating Thermostat (PCT) and Direct Load Control (DLC)

Source: DOE, *Demand Reductions from Applications of Advanced Metering Infrastructure, Pricing Programs, and Customer-Based Systems—Initial Results*

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**Demand Response Pricing Schemes**

- **Time of Use (TOU):** pre-defined rates and schedules, based on time of day
- **Real-Time:** dynamic prices
- **Variable Peak Pricing (VPP):** peak period times are scheduled, but rates may vary
- **Critical Peak Pricing (CPP):** fixed or dynamic pricing during critical event periods
- **Incentive Programs:** utility control of customer load (hot water heaters, air conditioners, etc)
Oklahoma Gas & Electric Program

- Participants: 5000 residential and 1200 small commercial customers (all opt-in)
- Compared various pricing and technology schemes

<table>
<thead>
<tr>
<th>Price Level</th>
<th>Residential VPP-CPP</th>
<th>Residential TOU-CPP</th>
<th>Number of days in summer 2011 at each price level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low and off-peak</td>
<td>4.5¢/kWh</td>
<td>4.2¢ per kWh</td>
<td>63</td>
</tr>
<tr>
<td>Standard</td>
<td>11.3¢/kWh</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>High</td>
<td>23.0¢/kWh</td>
<td>23.0¢/kWh</td>
<td>28</td>
</tr>
<tr>
<td>Critical</td>
<td>46.0¢/kWh</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Critical peak event</td>
<td>46.0¢/kWh</td>
<td>46.0¢/kWh</td>
<td>7 (included in the above)</td>
</tr>
</tbody>
</table>

Source: DOE, "Demand Reductions from Applications of Advanced Metering Infrastructure, Pricing Programs and Customer-Based Systems—Initial Results

Example Critical Event

“Rebound effect”
Oklahoma Gas & Electric Program Results

- Bill reduction US$150 over the summer
- 30% peak reduction on average
- 1.8kW maximum peak reduction
- Effects of In-Home Displays decreased after one year
- Increasing to 150,000 customers
- Prevent/delay construction of 210 MW gas fired plant

Marblehead Municipal Lighting Department (MMLD)

- 532 participants
- Critical Peak Pricing scheme

<table>
<thead>
<tr>
<th>Price Level</th>
<th>Residential CPP Price</th>
<th>Number of days in summer 2011 at each price level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>9.0¢ per kWh</td>
<td>89</td>
</tr>
<tr>
<td>Critical peak event</td>
<td>105.0¢ per kWh</td>
<td>3</td>
</tr>
</tbody>
</table>

• Customer information systems only
Example Critical Event

Marblehead Municipal Lighting Department (MMLD) Program

- Average reduction 0.74 kW during peak events (37%)
- All customers saved money
- Web portal usage was low 39% used it
Sioux Valley Energy Program

- Critical Peak Pricing scheme
- Compared:
  - opt-in
  - opt-out
  - technology only (not subject to CPP rates)
  - control groups (no technology, no CPP rates)

Sioux Valley Energy Results

Peak Demand Reductions

<table>
<thead>
<tr>
<th>Reduction (%)</th>
<th>Opt-In</th>
<th>Opt-Out</th>
<th>Technology-Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>25</td>
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<td>10</td>
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<td>0</td>
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</tbody>
</table>
Demand Response Observations

• Large reduction of peak-demand possible (up to 37%)
• Technology + Rates are most effective
• Some customers are more responsive than others
• Customer Control Systems more effective and long lasting than Customer Information Systems

SmartGridCity—A Cautionary Tale

• Started in 2008 by Xcel Energy
• +20,000 smart metered customers
• Smart Grid infrastructure
  • Communication
  • Sensing
  • Automation
SmartGridCity Early Praise

“It's so smart that the number of customer-voltage complaints — about either surges or drops — went from 70 in 2007 to zero so far this year.”

“It's so smart that it identified a transformer that was overloaded and needed to be replaced — before it got fried.”

Source: Mark Jaffe, Boulder’s SmartGridCity brings Xcel up to speed on electric picture, The Denver Post, Sept. 9, 2009.

SmartGridCity

• Total Project cost: $100 million
• Original Xcel cost: $15.3 million
• Final Xcel cost: $44.5 million
• Only 101 of 1850 in-home devices installed
Lessons Learned

• Customer benefits were over-promised and under-delivered
• Some success in testing technologies
• Business case was unclear
• Public Utility Commission denied US$16.6M in cost recovery
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• +30,000 members
• +40 conferences/yearly
• Transactions
  – Smart Grid
  – Sustainable Energy
  – Power Systems
  – Energy Conversion
  – Power Delivery

PES Membership Trends

Three PES Chapters
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South: Neville Watson (n.watson@elec.canterbury.ac.nz)
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- Insulated Conductors
- Nuclear Power Engineering
- Power System Analysis, Computing and Economics
- Power System Communications
- Power System Instrumentation and Measurements
- Power System Relaying
- Stationary Battery
- Substations
- Surge Protective Devices
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- Transmission & Distribution
- Power Engineering Education
- Power System Dynamic Performance
- Power System Operations
- Power System Planning and Implementation

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