Smart Grid Technologies and Applications for the Industrial Sector

Tariq Samad
Honeywell Automation and Control Solutions

Sila Kiliccote
Lawrence Berkeley National Laboratory

With contributions from Ed Koch (Honeywell Akuacom) and Petr Stluka (Honeywell Prague Laboratory)

Honeywell

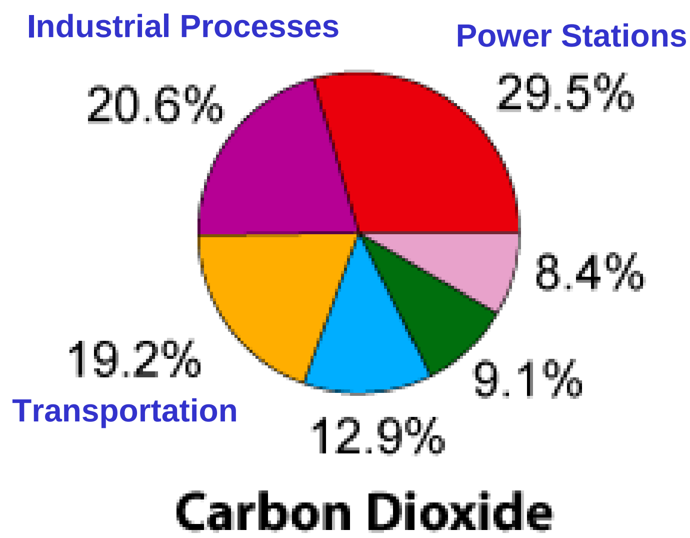
Savannah, GA, 10 Jan. 2012

Outline

- Smart grid background
- Electricity and the industrial sector
- Power markets
- Smart grid “technologies” and case studies
- Engaging the process operations research community in smart grids
- Conclusions

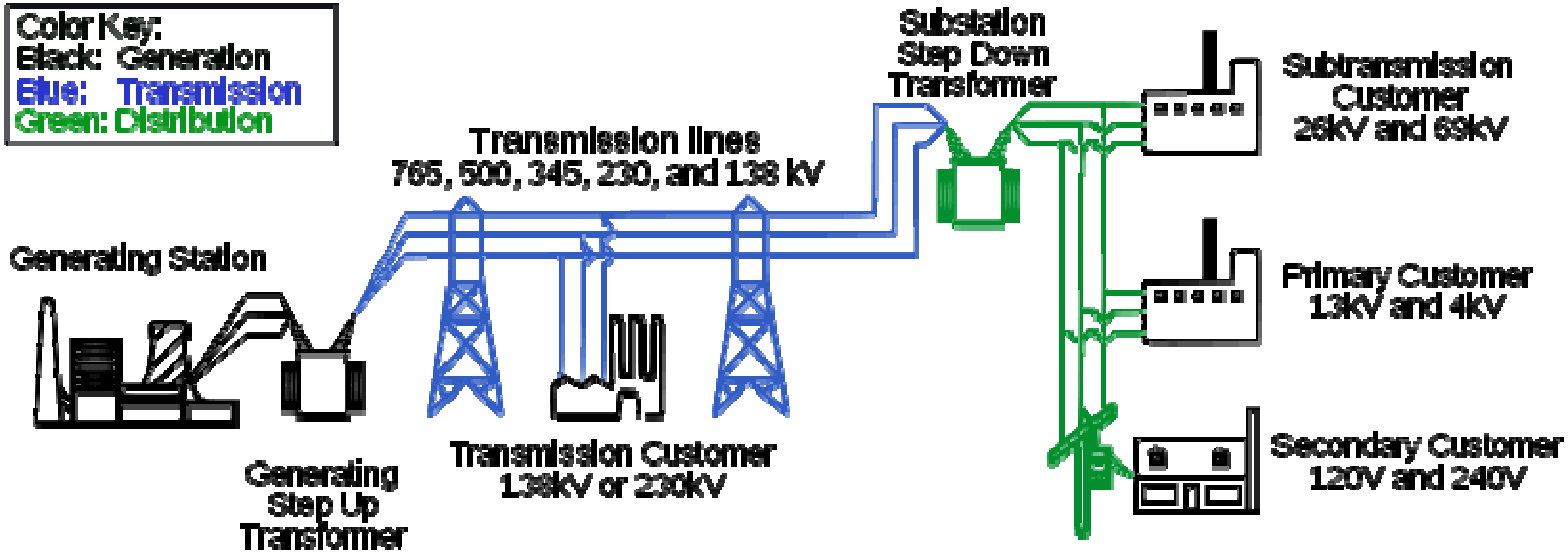
Global and Regional Priorities

- Motivations for smart grids are similar worldwide
  - reduce fossil fuel, especially coal, use; increase renewables penetration
  - reduce dependence on imported oil and gas
  - reduce energy costs for utilities and customers
- Countries and regions have different priorities
  - US: efficiency
  - Europe: renewables integration
  - Japan: microgrids



[Robert A. Rohde, Global Warming Art; http://www.globalwarmingart.com/wiki/Image:Greenhouse_Gas_by_Sector_png]

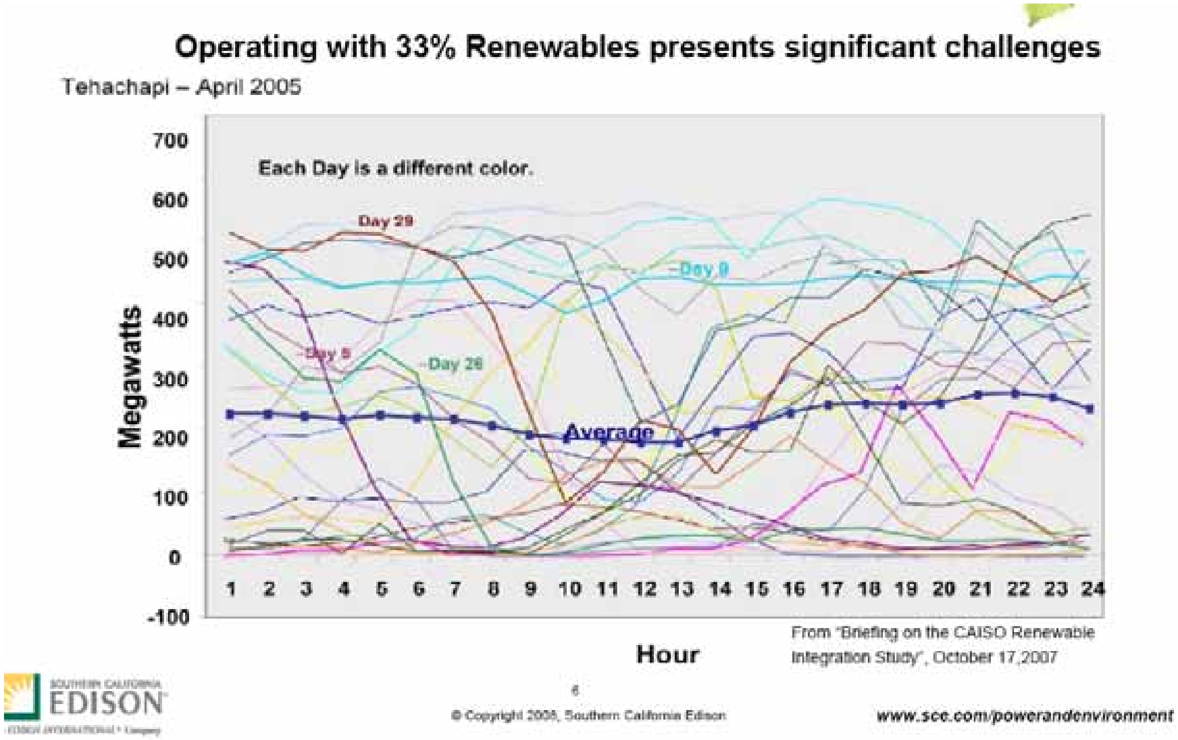
Electrical Power Systems (Traditional View)

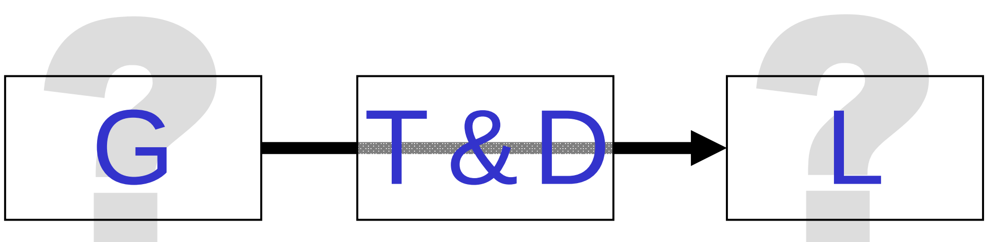


Simplified, N. America (FERC, 2004)

- Fraction of U.S. energy needs met by electricity has grown substantially (Galvin et al., 2009)
  - 2% (1900) →11% (1940) → 20% (1960) → 40% (today)

One smart grid motivation—renewables



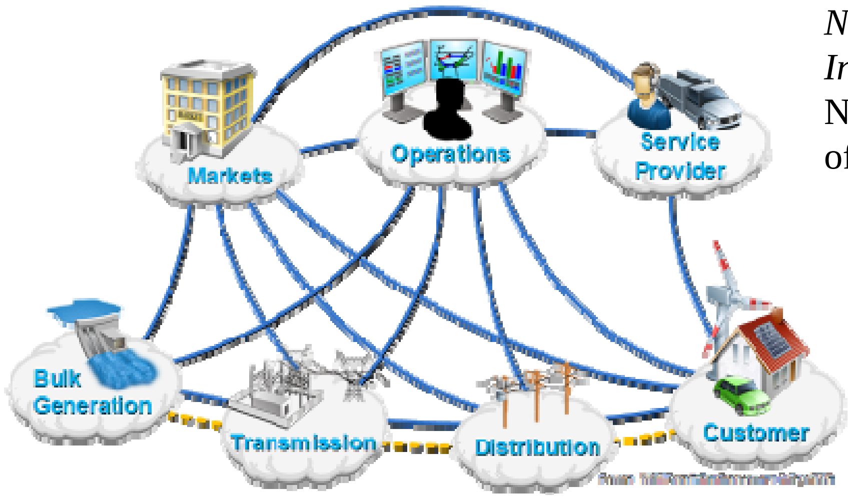


Large proportion of renewable sources (especially wind and solar) limits control of generation

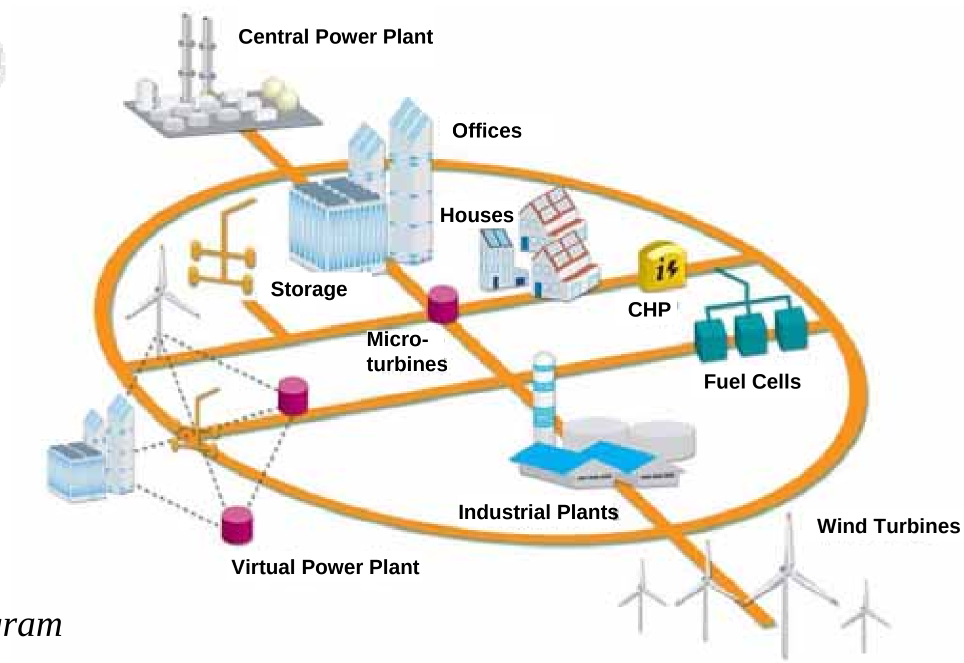
Uncertainty not just in loads, but now in generation as well

A more active role for consumers—demand-side management

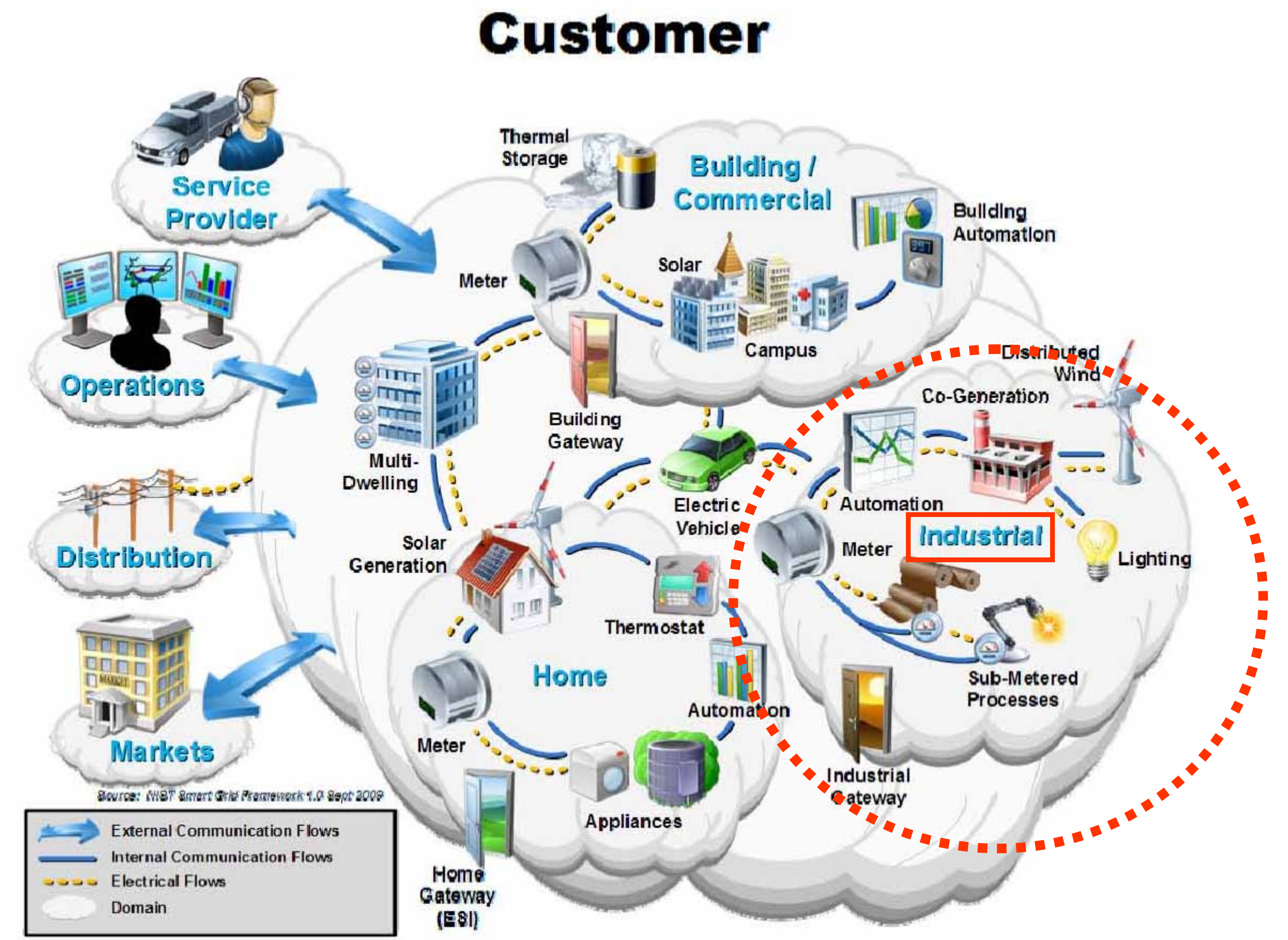
Smart Grids—Systems of Systems



NIST Framework and Roadmap for Smart Grid Interoperability Standards. Special Publication 1108, National Institute of Standards and Technology, US Dept. of Commerce



SmartGrids European Technology Program


Customer
Service Provider
Operations
Distribution
Markets
Thermal Storage
Building / Commercial
Building Automation
Meter
Solar
Campus
Multi-Dwelling
Building Gateway
Electric Vehicle
Solar Generation
Thermostat
Home
Meter
Automation
Appliances
Home Gateway (ESI)
Distributed Wind
Co-Generation
Automation
Meter
Industrial
Lighting
Sub-Metered Processes
Industrial Gateway
Source: NIST Smart Grid Framework 1.0 Sept 2009
External Communication Flows
Internal Communication Flows
Electrical Flows
Domain

Industrial sector—power use diversity

http://www.eia.doe.gov/emeu/mecs/mecs2006/pdf/Table11_1.pdf

Industry sector	Total electricity used (10^6 kWh)
Chemicals	207,107
Primary Metals	139,985
Paper	122,168
Food	78,003
Petroleum and Coal Products	60,149
Transportation Equipment	57,704
Plastics and Rubber Products	53,423
Nonmetallic Mineral Products	44,783
Fabricated Metal Products	42,238
Machinery	32,733
Wood Products	28,911
Computer and Electronic Products	27,542
Textile Mills	19,753
Beverage and Tobacco Products	17,562
Printing and Related Support	13,089
Electrical Equip., Appliances, and Components	12,870

(plus smaller contributors)

- Electricity use in industry
  - electrically driven equipment
  - process heating
  - non-process purposes
- High per-plant consumption as well
  - annual U.S. refinery average > 300 million kWh
  - peak load in large metals plants > 500 MW
- Industrial plants often connect directly to transmission grids

Industrial energy management—complexities

- Industrial plants can be high consumers of electricity
  - up to 100s of MW at peak load and 100Ms of kWh annual consumption
- Connections to the grid can be at high voltage levels
  - direct to transmission (138 kV and 230 kV) and distribution (4 kV – 69 kV) grids
- Large manufacturing facilities can have substantial on-site generation
  - nationwide industrial generation: 142 B kWh, about 15% of net electricity demand
  - sales and transfers offsite: 19 B kWh
- Large plants can play important roles for grid reliability and frequency regulation
  - automatic generation control (AGC) and ancillary services
- Some processes require high-speed meter data
  - real-time, not “near-real-time”—milliseconds in some cases
- Industrial users have high interest in ownership and protection of usage data
  - load information is often highly confidential and competition-sensitive
- Manufacturing processes can be inflexible with respect to time
  - interdependencies in process must be respected, for performance and safety
- Many customers require dynamic pricing models for process optimization
  - forecasted pricing and special tariffs from utilities in many cases

Domain knowledge essential for load management

Electricity Markets

- Wholesale: large variations, usually hidden from consumers
  - increasing volatility; as high as $1000s / MWh; as low as < $0 / MWh
  - congestion and reliability overheads (locational marginal pricing [LMP])
  - ancillary services for grid balancing—large loads can participate
- Retail: rates fixed or overseen by public utility commissions
  - average U.S. residential rate ~11.5 ¢ / kWh
  - dynamic pricing tariffs for large industrial and commercial customers
  - deregulated markets allow large customers to directly negotiate rates with utility
- Market designs and rate structures vary significantly
  - in U.S. by state, utility, ISO / RTO / balancing authority, . . .

Texas Heat Wave, August 2011: Nature and Effects of an Electricity Supply Shortage - Today in Energy - U.S. Energy Information Administration (EIA) - Mozilla Firefox

File Edit View History Bookmarks Tools Help

India 53/1 (12.0 ov, R Dravid 7*, G Gam... | Texas Heat Wave, August 2011: Nature ...

www.eia.gov/todayinenergy/detail.cfm?id=3010

Most Visited | Getting Started | Latest Headlines | Save to Connectbeam

Email Updates

RSS Feeds

Twitter

Add us to your site

Have a question, comment, or suggestion for a future article? Send your feedback to todayinenergy@eia.gov

Archive

January 2012

December 2011

November 2011

October 2011

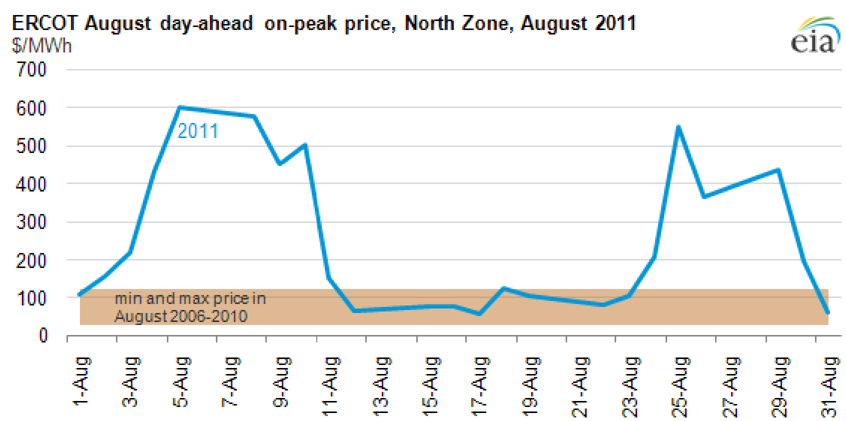
September 2011

August 2011

July 2011

SEPTEMBER 9, 2011

Texas Heat Wave, August 2011: Nature and Effects of an Electricity Supply Shortage



Source: U.S. Energy Information Administration, based on SNL Energy.
Note: ERCOT North Zone includes Dallas/Fort Worth metro region and surrounding areas of Northeast Texas. On-Peak refers to the 16-hour time block from hours ending 7:00 a.m. to 10:00 p.m. CDT on weekdays, excluding NERC holidays.
Download CSV Data

A prolonged August heat wave in Texas produced two periods of very high wholesale prices in the Electric Reliability Council of Texas (ERCOT), the wholesale market operator for most of the State. Day-ahead, on-peak wholesale power prices for August 2011 rose far above the range of prices seen during the previous five Augusts (see chart above).

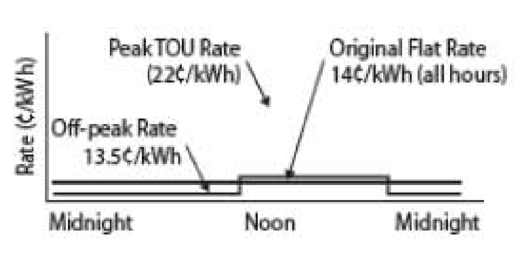
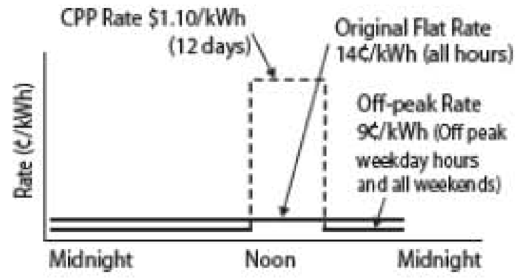
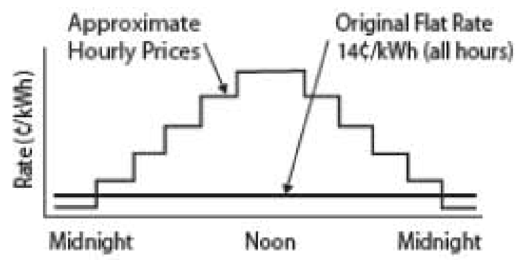
The increase in wholesale prices may appear in retail bills more quickly in Texas than they would in other states, as Texas mandates that most retail customers choose a competitive electricity supplier – thus removing the traditional cost-of-service retail rate regulatory process which often delays the blow of high wholesale prices.

http://www.eia.gov/todayinenergy/detail.cfm?id=3010

Honeywell

Retail markets: Alternatives to flat rates

Figure 3. Time Varying Electricity Pricing with Example Rates

TIME-OF-USE (TOU) RATES	• Rates increase above flat rate during pre-set daily peak periods by 100%. • The most common in the past; easy to understand, predictable, and bill impacts most moderate. However, least efficient and impactful.	
CRITICAL PEAK PRICING (CPP)	• On 12 days selected by the utility, each one day in advance, prices are raised during the peak period by ~500%. • Utility notifies customers one day in advance that peak prices will be in effect the following day. • Can also be invented to offer peak time rebates. • More impactful than TOU rates.	
REAL-TIME PRICING (RTP)	• Prices change every hour to reflect true hourly production costs and/or market prices. • To reduce uncertainty, hourly prices are set one day in advance and made public. • Most accurate and impactful, but also most complex and volatile. Usually applied only to large customers.	

Source: Fox-Penner (2009), page 41.

- Dynamic prices available for large commercial and industrial consumers
- ToU and other dynamic rates for residential in some regions—increasing with smart meter deployment

A. Faruqui et al., The Brattle Group

Outline

- Smart grid background
- Electricity and the industrial sector
- Power markets
- Smart grid “technologies” and case studies
- Engaging the process operations research community in smart grids
- Conclusions

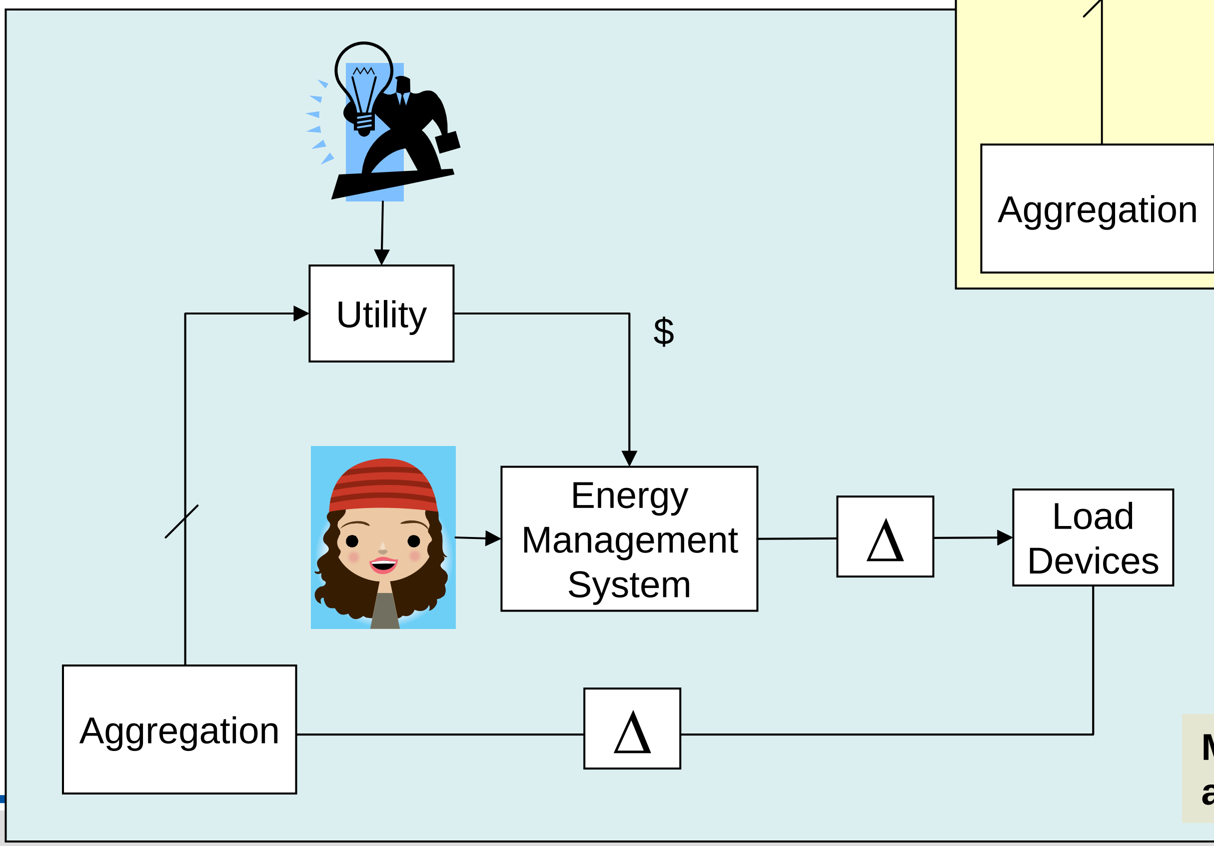
Customer-centric Smart Grid "Technologies"

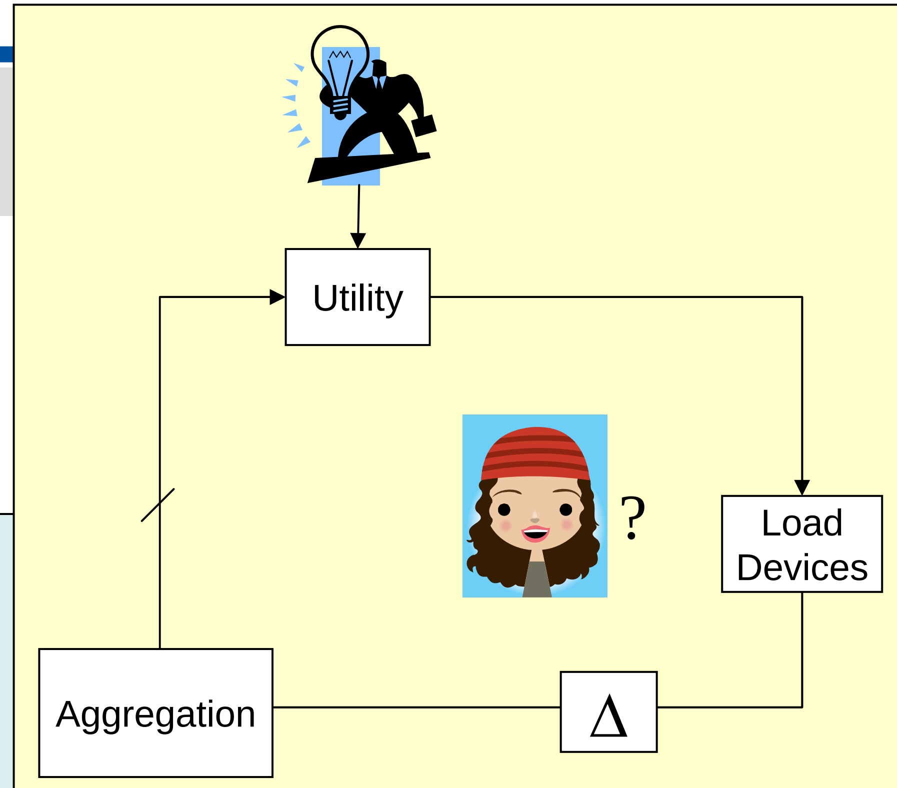
- Automated demand response
- Storage
- Microgrids
- Energy efficiency
- Direct load control
- Distributed generation

What Is Automated Demand Response (Auto-DR)?

- Imbalances in the grid may cause reliability issues or energy price fluctuations, both of which may result in the need to actively balance grid supply/demand
- Options for dealing with imbalances include:
  - purchasing power from another state/country (expensive)
  - starting up old generation plants (AQMD issues)
  - building new power plants (very costly)
  - black outs, brown outs (high customer impact)
  - voluntary customer power reductions (demand response)
- Auto-DR is a well defined, automated, voluntary reaction to a DR event called by utilities and ISOs requiring energy consumption/ reduction during an anticipated period of imbalance in the grid

***Automated demand response*—**
customer is in control; demand management based on utility signals (e.g., prices)

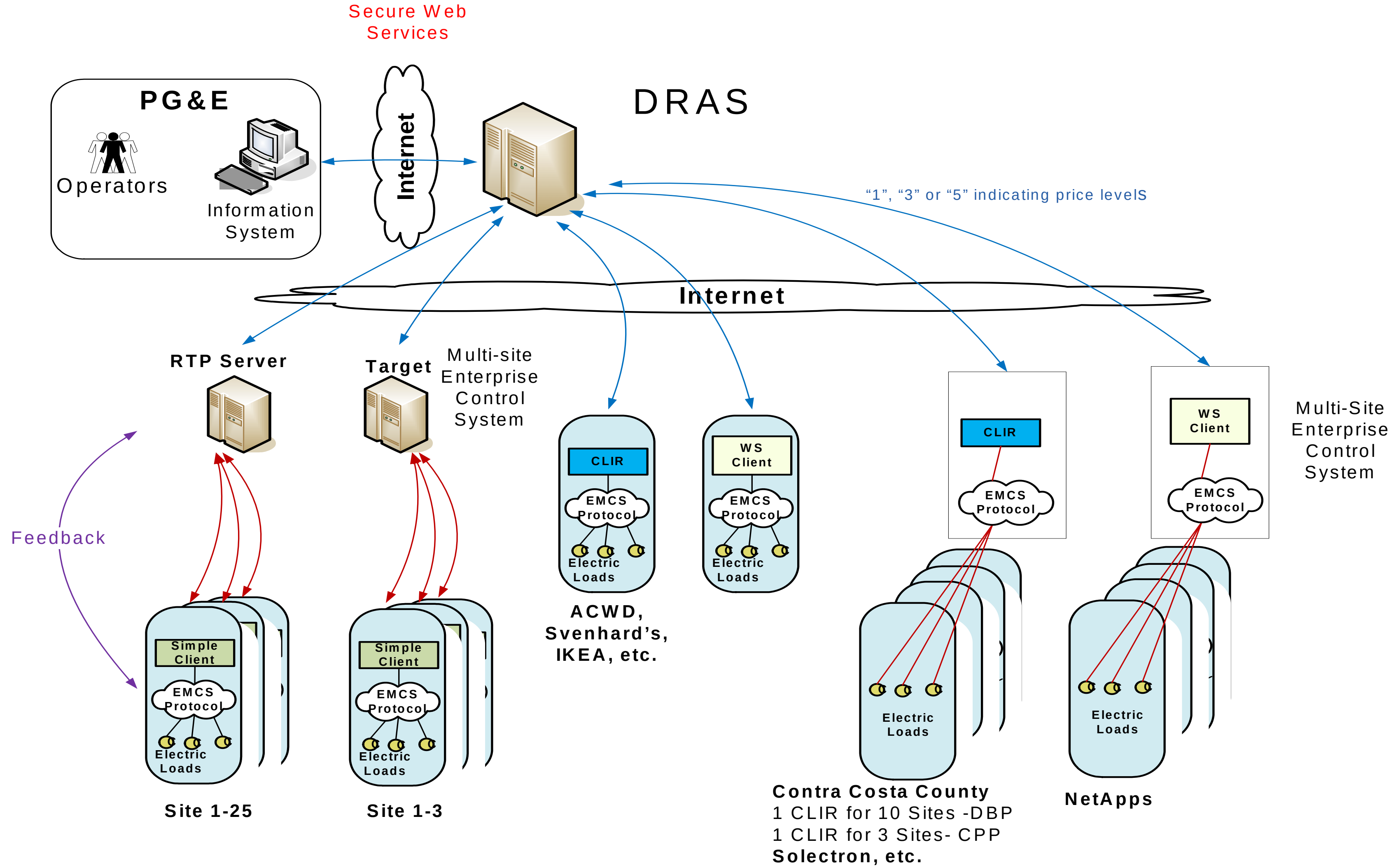




***Direct load control*—**
utility controls devices in facilities

Many commercial applications; few in industrial

PG&E Auto-DR System Architecture



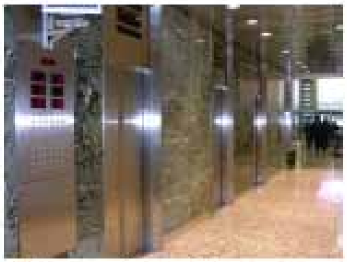
DR Shed Strategies

		HVAC											Lighting					Other
	Building use	Global temp. adjustment	Duct static pres. Increase	SAT Increase	Fan VFD limit	CHW temp. Increase	Fan qty. reduction	Pre-cooling	Cooling valve limit	Boiler lockout	Slow recovery	Extended shed period	Common area light dim	Office area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-critical process shed
ACWD	Office, lab	X	X	X		X			X	X		X						
B of A	Office, data center		X	X	X	X			X									
Chabot	Museum	X						X										
2530 Arnold	Office	X									X							
50 Douglas	Office	X									X							
MDF	Detention facility	X																
Echelon	Hi-tech office	X	X	X			X						X	X	X	X		
Centerville	Junior Highschool	X						X										
Irvington	Highschool	X						X										
Gilead 300	Office			X														
Gilead 342	Office, Lab	X		X														
Gilead 357	Office, Lab	X		X														
IKEA EPaloAlto	Furniture retail	X																
IKEA Emeryville	Furniture retail	X																
IKEA WSacto	Furniture retail																	
Oracle Rocklin	Office	X	X															
Safeway Stockton	Supermarket																X	
Solectron	Office, Manufacture	X													X			
Svenhard's	Bakery																	X
Sybase	Hi-tech office														X			
Target Antioch	Retail	X					X											
Target Bakersfield	Retail	X					X											
Target Hayward	Retail	X					X						X				X	
Walmart Fresno	Retail	X															X	

Shed strategies defined manually today—a need for model-based optimization informed by load characteristics (including dynamics)

Example of a Typical Event

GRID STRESS ⟶ Notification ⟶ Client Actions

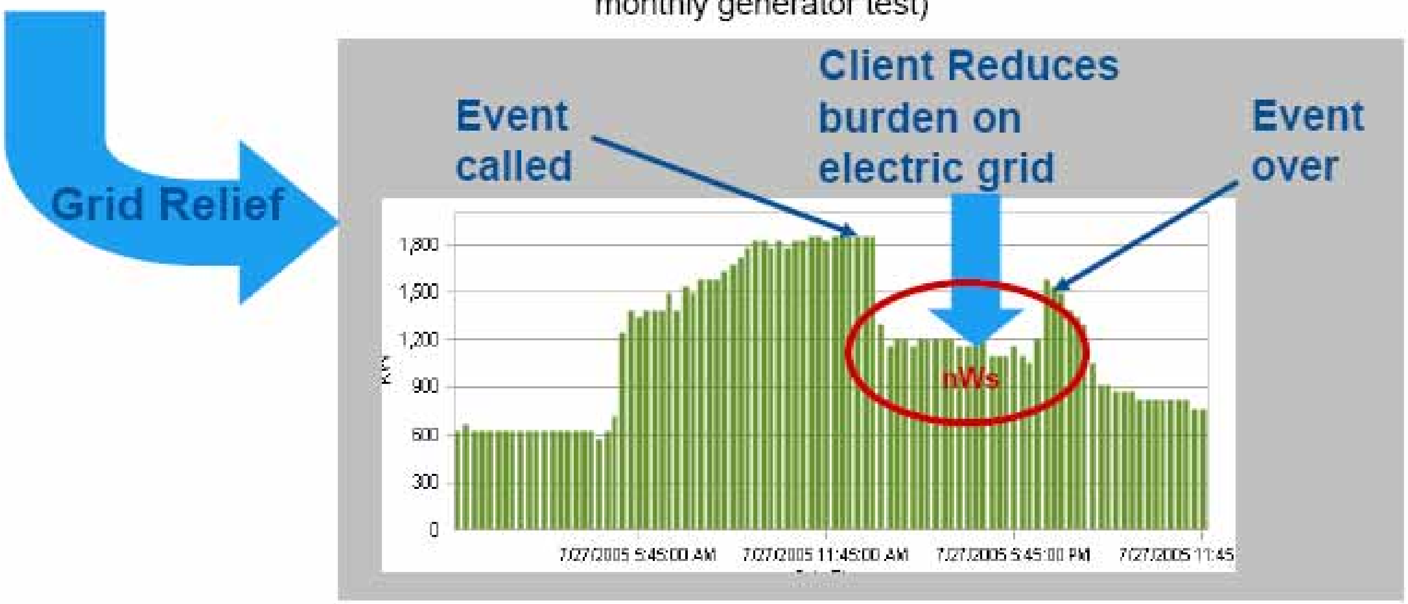


Turn off 1 of 4 elevators

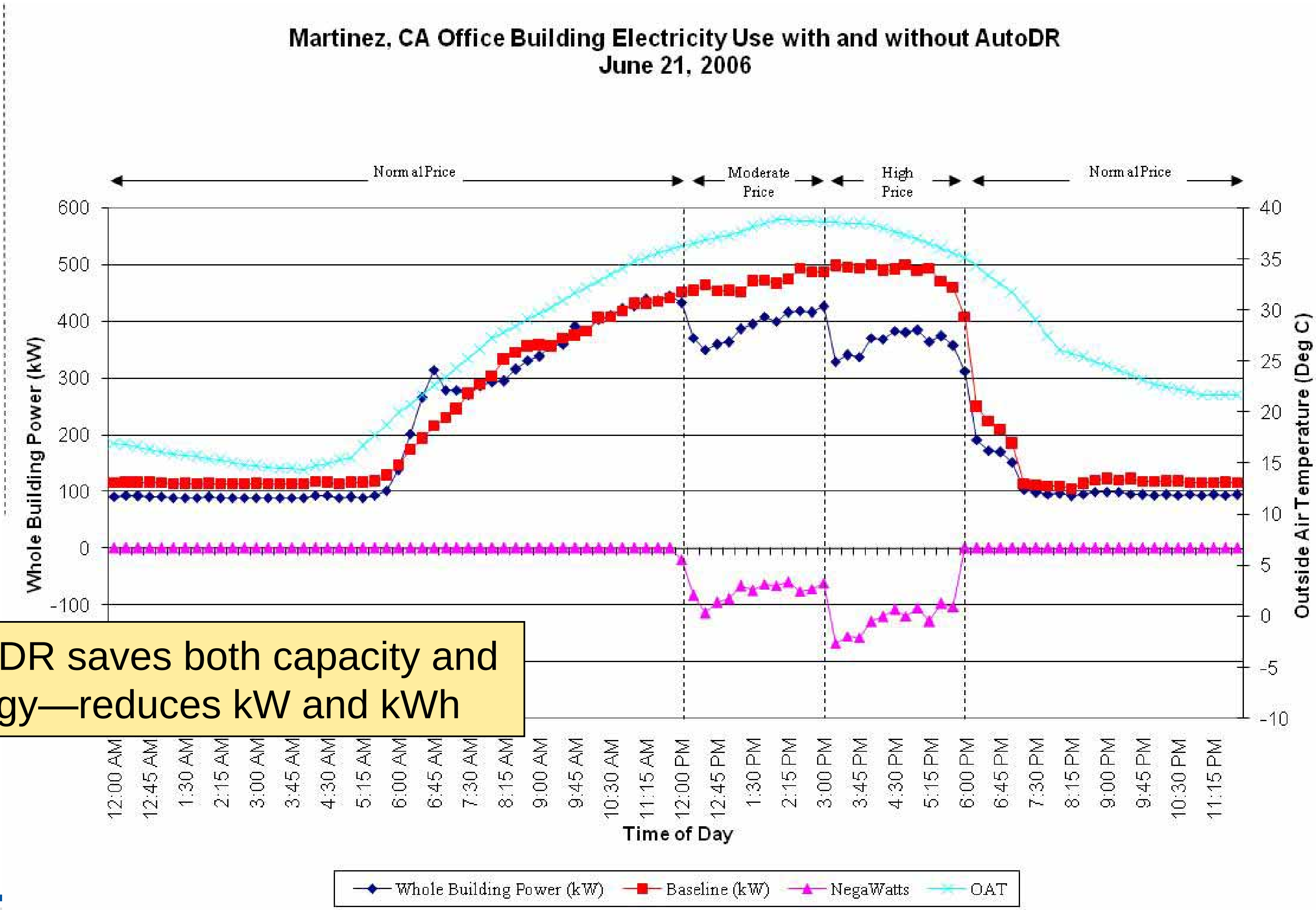
Pre-cool building in early morning hours

Turn on emergency generator (can use as monthly generator test)

Turn off non-essential lighting



Summer Time Shed In California



AutoDR saves both capacity and energy—reduces kW and kWh

Automated demand response for ancillary services

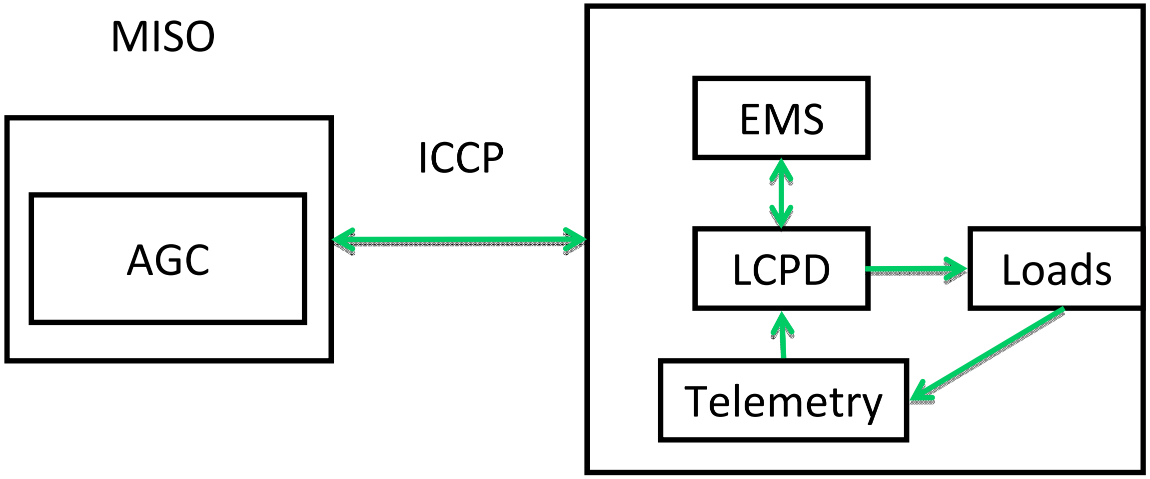
- Ancillary services that “support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.“ (FERC)
- Demand-side resources can now participate in ancillary services
  – some industrial plants capable of providing regulation services, the most challenging

Ancillary Services	Response Time	Duration	Telemetry
Regulation Up	Start in <1 min.; reach limit in <10 min.	15 – 60 min.	4 sec.
Regulation Down	Start in <1 min.; reach limit in <10 min.	15 – 60 min.	4 sec.
Non-Spinning Reserves	Output in < 10 min.	30 min.	4 sec.; every minute
Spinning Reserves	Instant start; full output in <10 min.	30 min.	4 sec.; every minute

(Products and requirements of ancillary services markets in California)

Application 1: Aluminum Processing

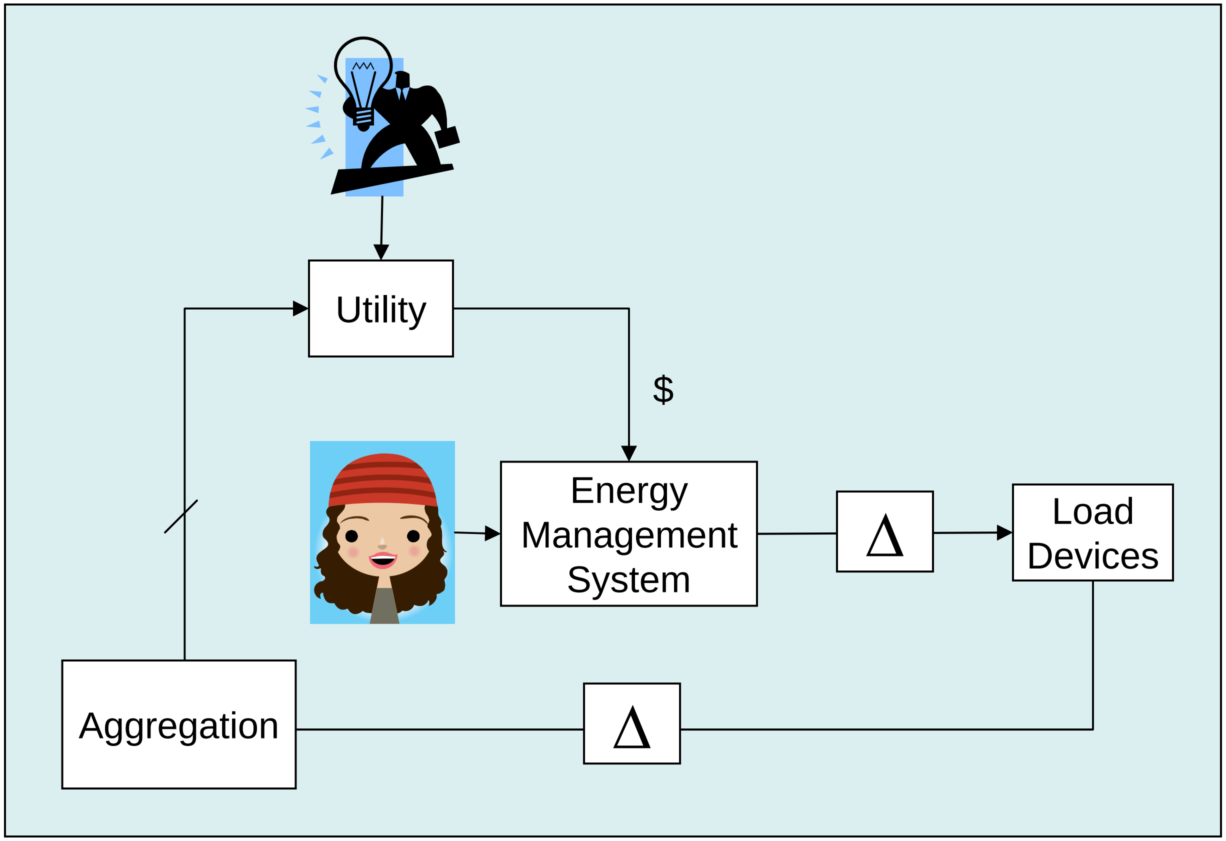
- Alcoa (Warrick, Ind.) participation in Midwest ISO ancillary services market—regulation through control of smelters
- Reimbursed for load modulation as if the energy was generated
- Up to 70 MW of regulation services provided
- Control strategies include cycling and voltage control of smelting potlines
- About $700K investment, ROI in 4 months



MISO – Midwest ISO
AGC – Automatic Generation Control
EMS – Energy Management System
LCPD – Smelter Potline Load Control System
ICCP – Inter-Control Center Communications Protocol

(Todd et al., 2009)

Demand response—markets and power



- *What are appropriate demand response signals?*
  - price signals? load reduction commands?
- *When and how should DR signals be issued?*
  - frequency, timing, variation
- *How can we model load flexibility and consumer response?*
  - delays, learning, fatigue, ...
- *What are the performance and stability implications of coupling markets and power systems?*
  - real-time automated DR
- *What is the minimum necessary direct load control component?*
  - utility control should be limited, but it removes uncertainty
- *How can automated DR be extended to storage and co-gen?*

Storage as a smart grid technology

- Storage can help decouple power consumption from operation
- Multiple types of storage
  - electrical storage (batteries, flywheels, pumped hydro)
  - thermal storage (precooling, preheating)
  - inventory storage (especially useful for industrial applications)
- Dual-purpose electric vehicles—mobility and plant power source
  - high charge rates of EVs must be managed
  - other constraints on battery charge/discharge

When is investment in new storage technologies justified?

How can storage be optimally operated?

Application 2: Process with Cooling Demand

- Industrial plant in NYC with significant process cooling demand
- High peak prices in NYC as a result of limited power import capacity
- Plant creates ice slurry at night with chillers and stores the slurry in insulated tanks
  - slurry used during the day to cool refrigerant without running electric chillers
  - 5,000 ton-hours of cooling capacity available
- Peak demand reduction of > 600 kW realized
- Similar ice storage technologies also being used in commercial facilities—e.g., see www.ice-energy.com

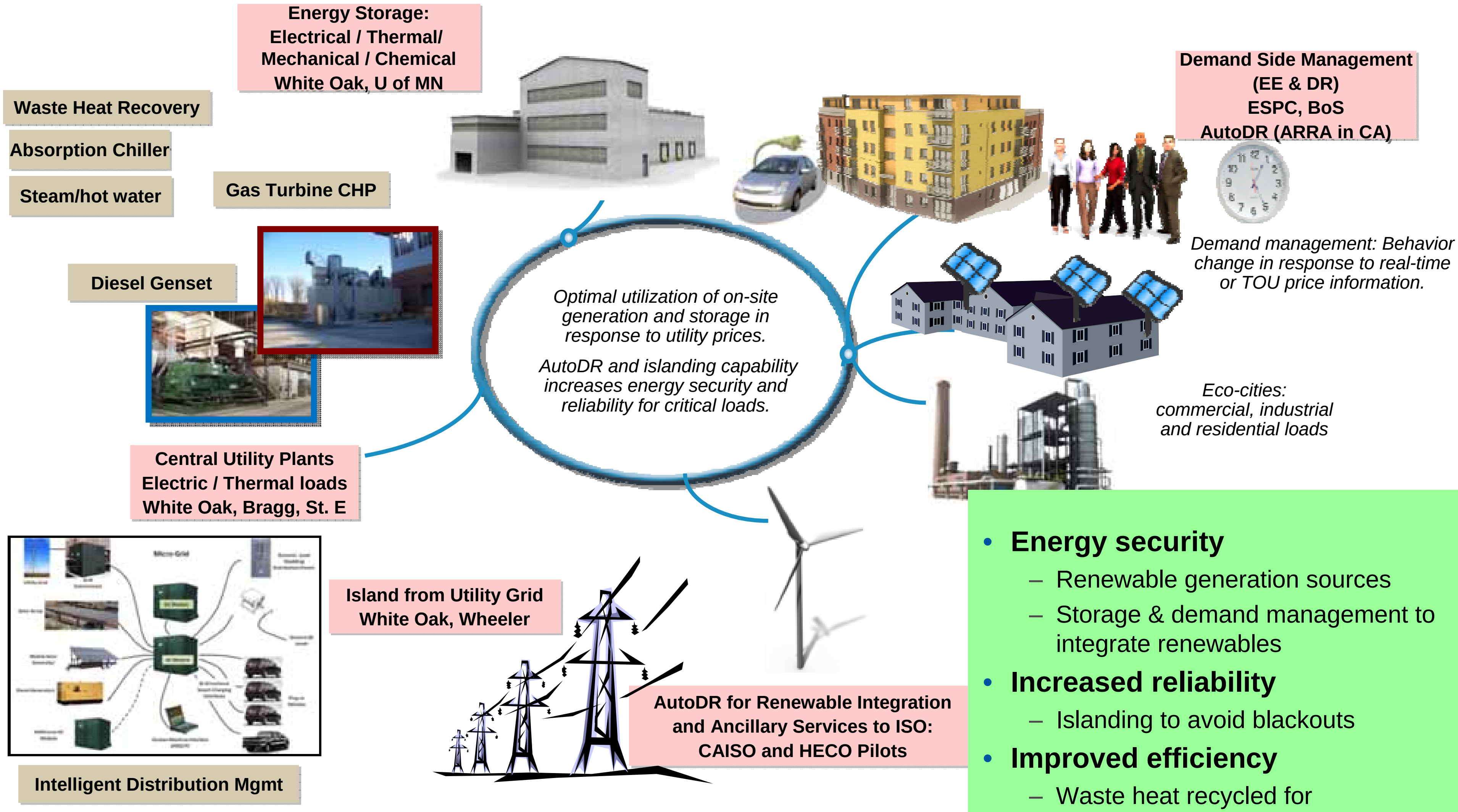
(Epstein et al., 2005)

Application 3: Cement Manufacture

- Lafarge Building Materials (NY) participation in NYSERDA and NYISO load reduction and demand response programs for industrial facilities
- On request from NYISO, Lafarge can shut down its rock crushers, shedding up to 22 MW of load
- Production unaffected; stockpiled crushed rock available
- As part of DR program, Lafarge can schedule equipment maintenance when grid prices are high—$2M revenues for DR
- Installation of fiber-optic Ethernet, Internet connectivity, EMS functionality required

(Epstein et al., 2005)

Microgrid: Comprehensive campus energy management



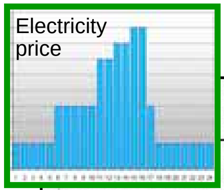
- **Energy security**
  - Renewable generation sources
  - Storage & demand management to integrate renewables
- **Increased reliability**
  - Islanding to avoid blackouts
- **Improved efficiency**
  - Waste heat recycled for heating/cooling of buildings
  - Reduced T&D losses

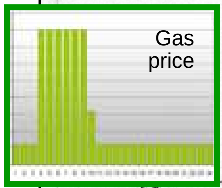
Microgrid Assets

- Supply side
  - cogeneration units (combined heat and power [CHP])
  - distributed renewable generation (wind, solar)
  - stand-alone diesel gensets
  - the electricity distribution network (power grid)
- Demand side
  - critical loads: must be met at all times
  - curtailable loads: can be temporarily lowered
  - reschedulable loads: can be flexibly shifted in time
- Energy storage
  - electricity storage
  - thermal storage
  - electric and plug-in-hybrid vehicles

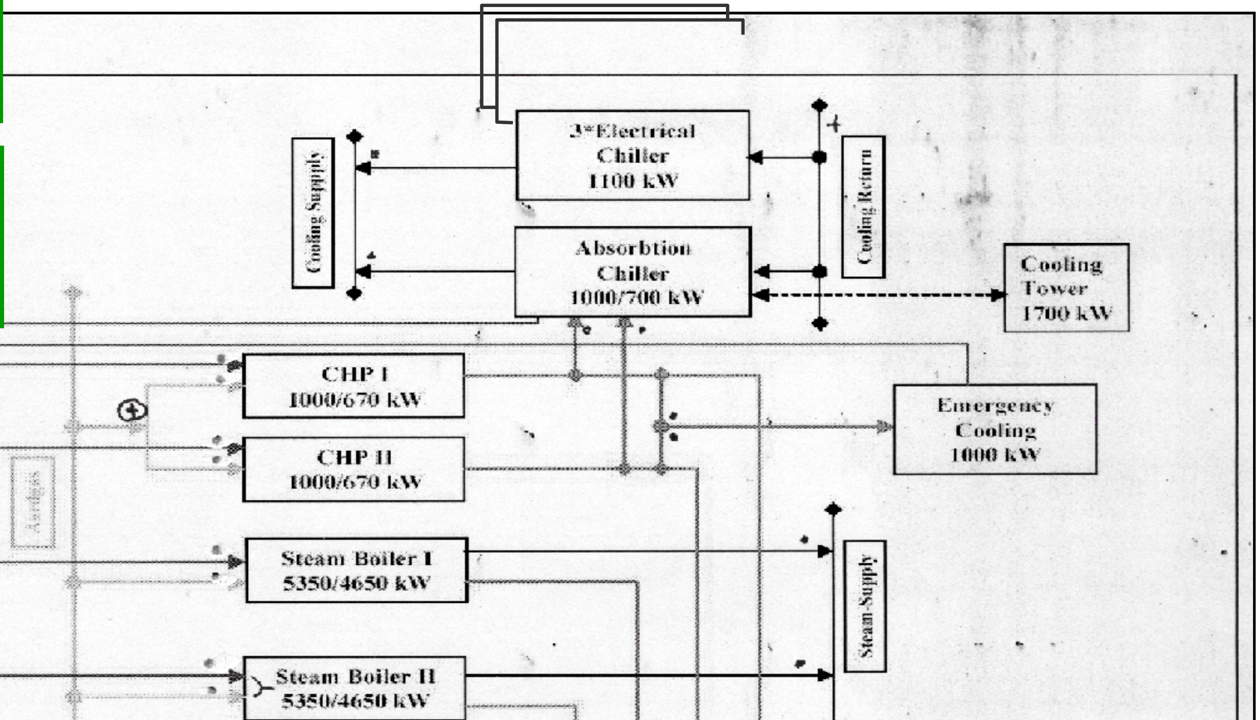
Application 4: Utility Plant

PRICES

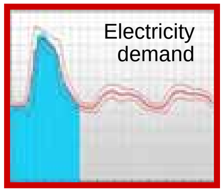


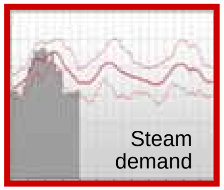


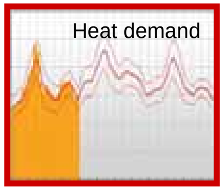
Utility plant – Atrium hospital, Heerlen

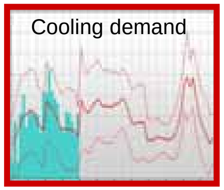


Gas engines, Chillers, Boilers, Cooling towers









LOADS

Stluka, Godbole, Samad (IEEE CDC, 2011)

A supply-side microgrid formulation

Minimize

$$\sum_{t=1}^{T}\left[\sum_{i=1}^{N}\left[\overline{X_{t,i}}\cdot\left(\underline{f_i\left(P_{t,i}\right)}+\underline{C_i^{fixed}}\right)+\overline{C_{t,i}^{start}}\max(X_{t,i}-X_{t-1,i},0)\right]+\underline{P_{t,u}R_t^{sell}}\right]$$

Indicator for *i*-th generator in operation

Startup operating cost for *i*-th generator

Cost for importing grid power at time *t*

Fixed operating cost for *i*-th generator

Variable cost for *i*-th generating asset at *t*

s.t.

$$\sum_{i=1}^{N}P_{t,i}+P_{t,u}=D_t$$

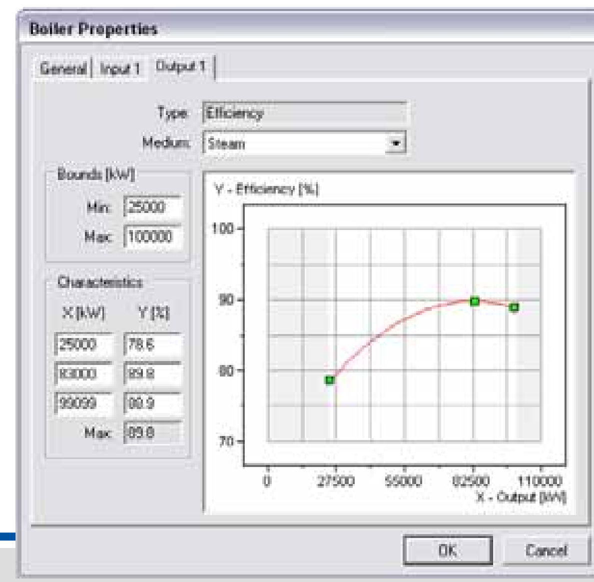
$$P_{i,\min}X_{t,i}\le P_{t,i}\le P_{i,\max}X_{t,i}$$

$$P_{u,\min}\le P_{t,u}\le D_t$$

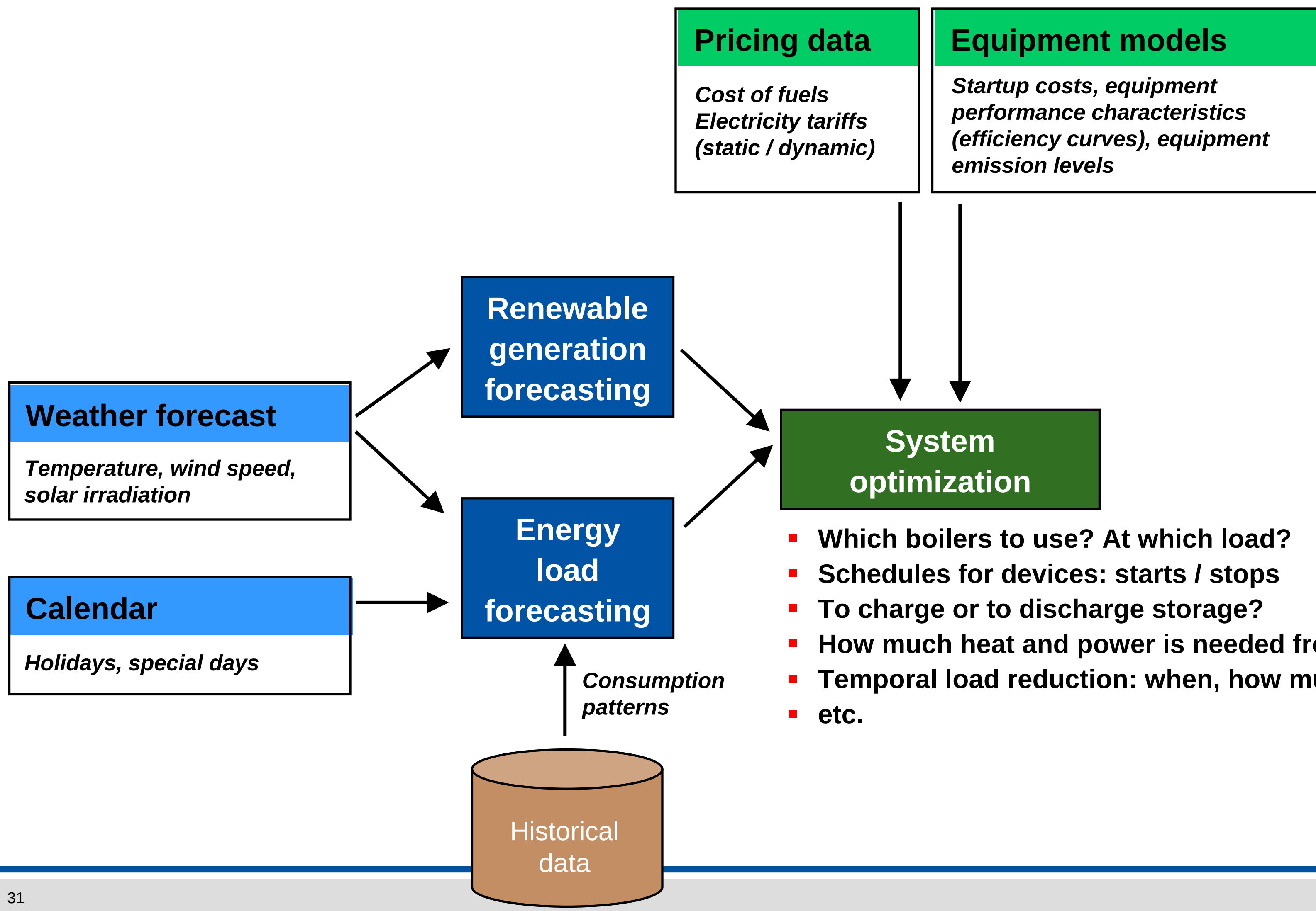
$$X_{t,i}\in\{0,1\}$$

$$X_{0,i}=\overline{X}_{0,i}$$

MINLP problem, solved with a solution step ranging from 15 minutes to 1 hour.



Solution Workflow

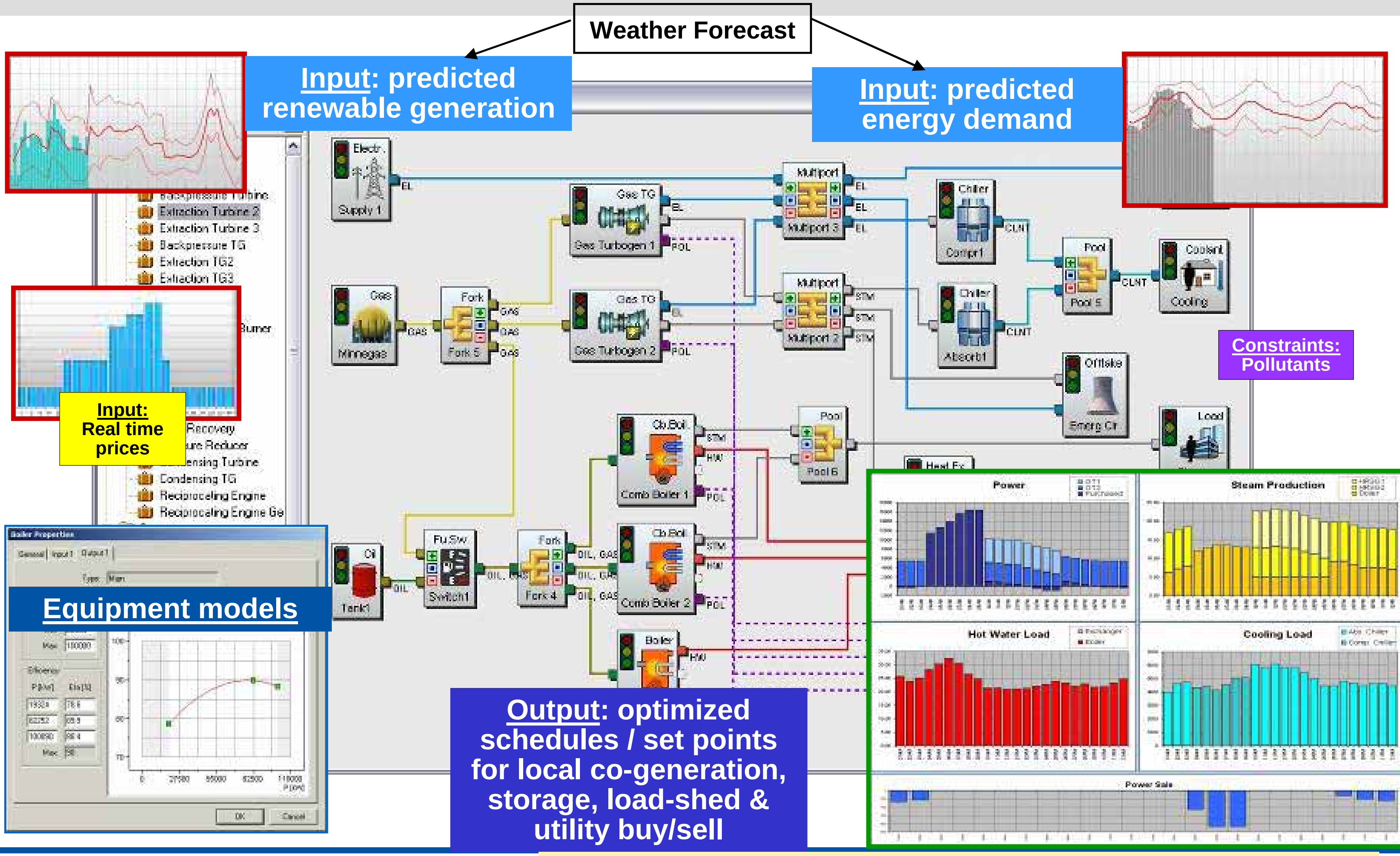


- Which boilers to use? At which load?
- Schedules for devices: starts / stops
- To charge or to discharge storage?
- How much heat and power is needed from CHP?
- Temporal load reduction: when, how much?
- etc.

Honeywell

Honeywell.com

VERA Micro-Grid Optimization



6 – 12 % energy savings annually for a decade; ROI < 1 year

Opportunities for Research

- Data mining for energy diagnostics
- Modeling power consumption and defining pricing schemes
- Closed-loop real-time demand response
- Forecasting for renewable generation and demand
- Optimal design and operation of storage
- Integrated supply-side and demand-side microgrid optimization
- *. . . and many other topics for modeling, control, forecasting, optimization, and others of your favorite tools!*

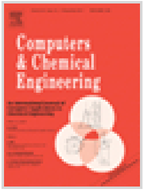
Hot off the press . . .

ELSEVIER

Computers & Chemical Engineering

Available online 26 October 2011

In Press, Corrected Proof — Note to users



Optimal production planning under time-sensitive electricity prices for continuous power-intensive processes

Sumit Mitra[a], Ignacio E. Grossmann[a], Jose M. Pinto[b], Nikhil Arora[c]

[a] Center for Advanced Process Decision-making, Department of Chemical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, United States

[b] Praxair Inc., Danbury, CT 06810, United States

[c] Praxair Inc., Tonawanda, NY 14150, United States

Received 2 July 2011. Accepted 29 September 2011. Available online 26 October 2011.

http://dx.doi.org/10.1016/j.compchemeng.2011.09.019, How to Cite or Link Using DOI

Permissions & Reprints

View full text

Modeling and optimization for industrial smart grid applications, with simulation case studies for air separation units and cement plants

Outline

- Smart grid background
- Electricity and the industrial sector
- Power markets
- Smart grid “technologies” and case studies
- Engaging the process operations research community in smart grids
- Conclusions

Industrial Engagement in Smart Grids

- Smart grids is a “hot topic,” but not in the process industries!
  - much more interest in residential and commercial sectors
- Yet benefits of smart grid technologies already demonstrated for industrial consumers
  - a few, one-of-a-kind implementations
  - distinct opportunities for industry
- Price volatility, renewables emphasis, potential CO_2 constraints . . .
  - importance of smart grids for industrial facilities likely to increase
  - research funding available!
- Exciting areas for research in modeling, optimization, control, . . .
  - automated demand response, microgrids, storage
- Technology development and *standardization* required
  - charter of NIST Smart Grid Interoperability Panel (SGIP)

Interested in Smart Grids?

- Join SGIP and its Industry-to-Grid (I2G) working group!
  - free to join—Observer or Participating Member categories
  - biweekly I2G conference calls
  - reviews of developments
  - preparation of white papers and presentations
  - opportunities to learn and contribute
  - I2G chair: Dave Hardin (EnerNOC)
- SGIP: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/WebHome
  - or Google “twiki SGIP”
- I2G: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/I2G
  - or Google “twiki I2G”

Questions?

Tariq Samad
Honeywell

+1 763 954 6349
tariq.samad@honeywell.com