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Optimization, Monitoring, and Control for Smart Grid Consumers

Honeywell

New Brunswick, NJ, 27 October 2010

Acknowledgements

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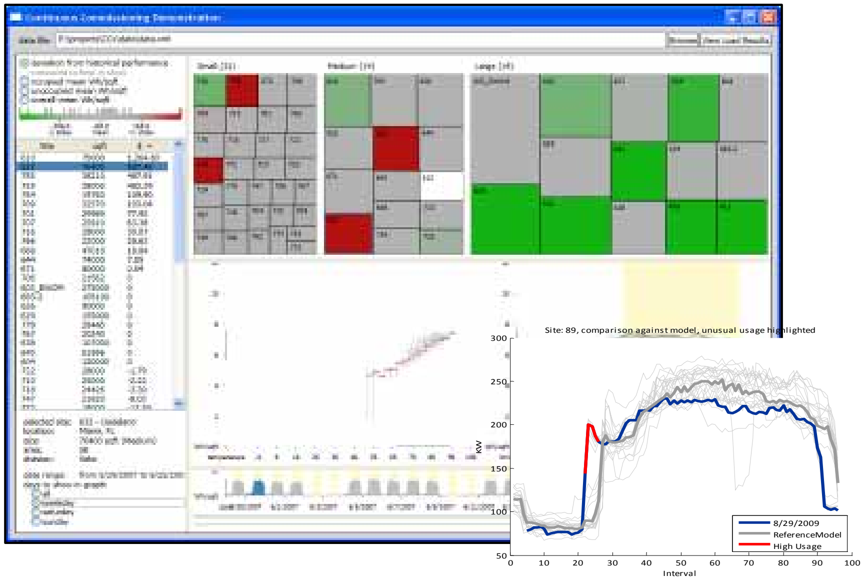
- Honeywell colleagues who have contributed: Datta Godbole, Wendy Foslien, Kevin Staggs, Petr Stluka

Outline

- Energy efficiency example: Honeywell Novar
- Smart grid and commercial buildings
- Smart grid and industrial facilities
- Research underway: microgrid optimization

Novar Remote Energy Management Service

- Honeywell Novar keeps energy consumption and costs low for multi-site businesses and reduces peak loads for utilities
  - 6 gigawatts of load in customer sites under management in U.S.
- Novar multi-site customers include:
  - Walmart, Office Depot, Home Depot, Lowes
- Internet and standard protocols used for communication
- Typical results
  - 20-40% improvement in energy efficiency and maintenance costs
  - 10-20% reduction in peak use
- Analysis & Feedback
  - comparison between buildings
  - comparison to baseline and model
  - root cause analysis
  - specific suggestions



Secure cloud-based energy management

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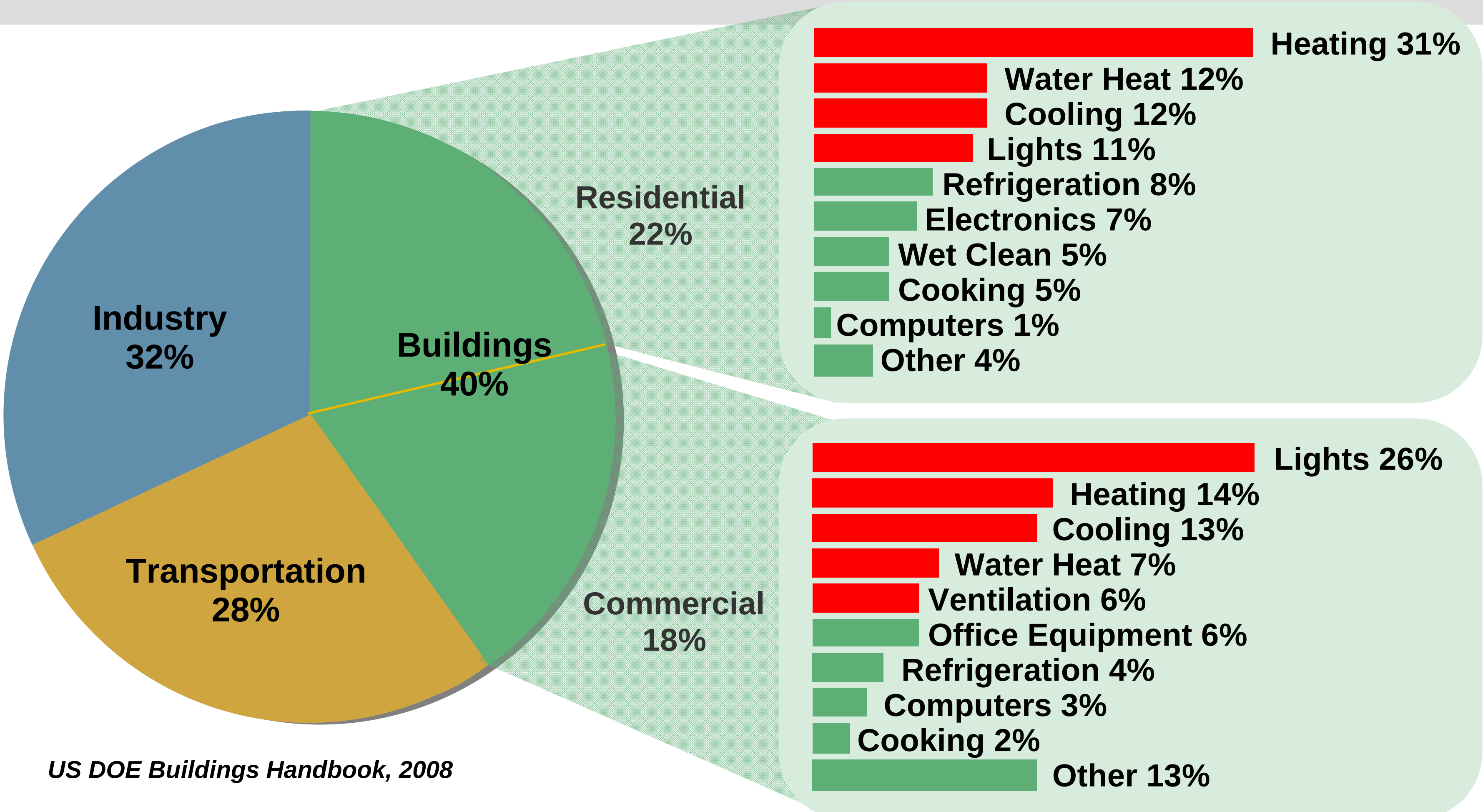
U.S. energy consumption (all sources)



US DOE Buildings Handbook, 2008

Building automation controls 66% of energy use in homes and buildings today—the smart grid will enable more

About 70% of the nation's <u>electricity</u> consumption is in homes and buildings

Wide range of building energy costs

2003 Energy Expenditures per Sq. Ft. of Commercial Floorspace and per Building, by Building Type ($2006) (1)

	Per Square Foot	Per Building (thousand)		Per Square Foot	Per Building (thousand)
Food Service	4.54	25.3	Mercantile	2.08	35.5
Food Sales	4.36	24.2	Education	1.34	34.1
Health Care	2.57	63.3	Service	1.29	8.4
Public Order and Safety	1.93	29.8	Warehouse and Storage	0.74	12.6
Office	1.87	27.7	Religious Worship	0.71	7.2
Public Assembly	1.61	22.9	Vacant	0.32	4.5
Lodging	1.60	57.3	Other	2.78	61.0

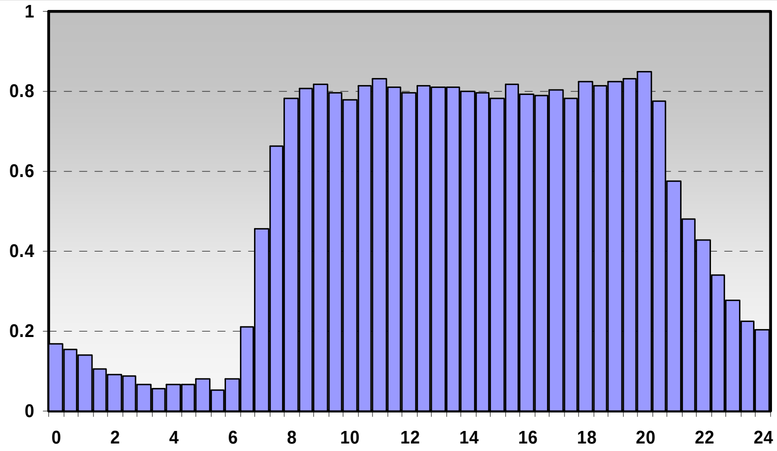
http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.3.9

- Over an order-of-magnitude spread in energy costs, both on per-sq-foot and per-building bases, across types of commercial buildings

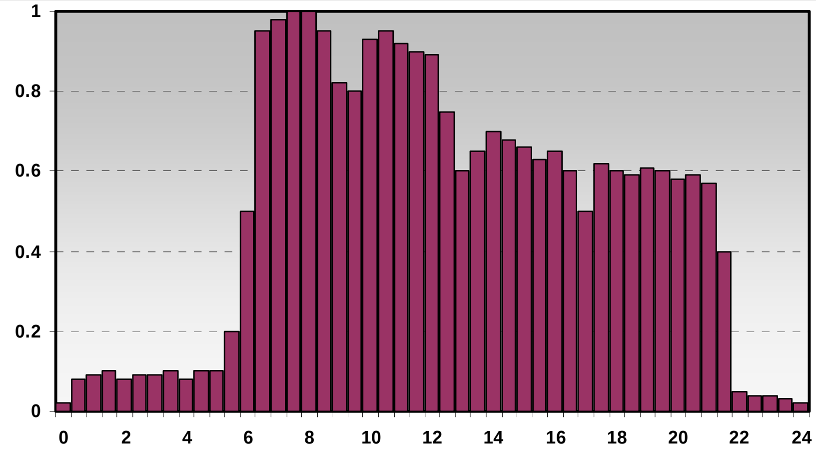
High diversity in construction and use of buildings

Various Daily Profiles …

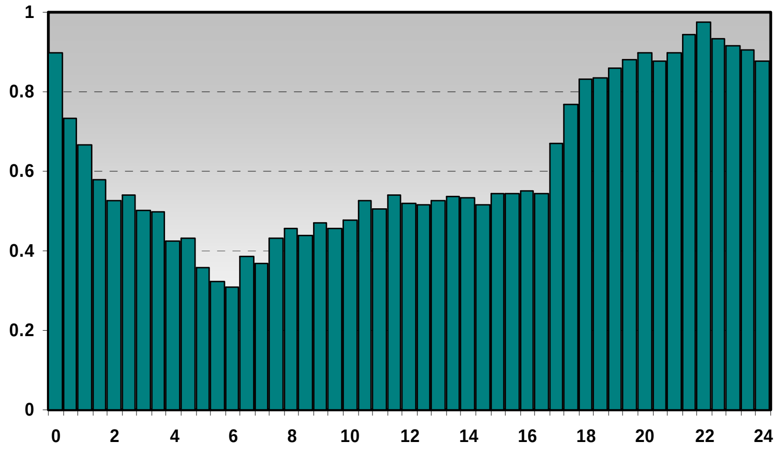
Daily Consumption Profiles



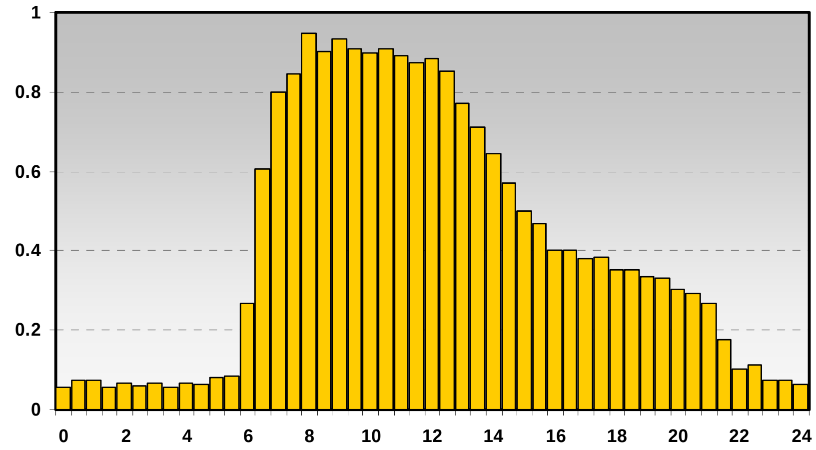
… commerce



… two-shift manufacturing



… casino



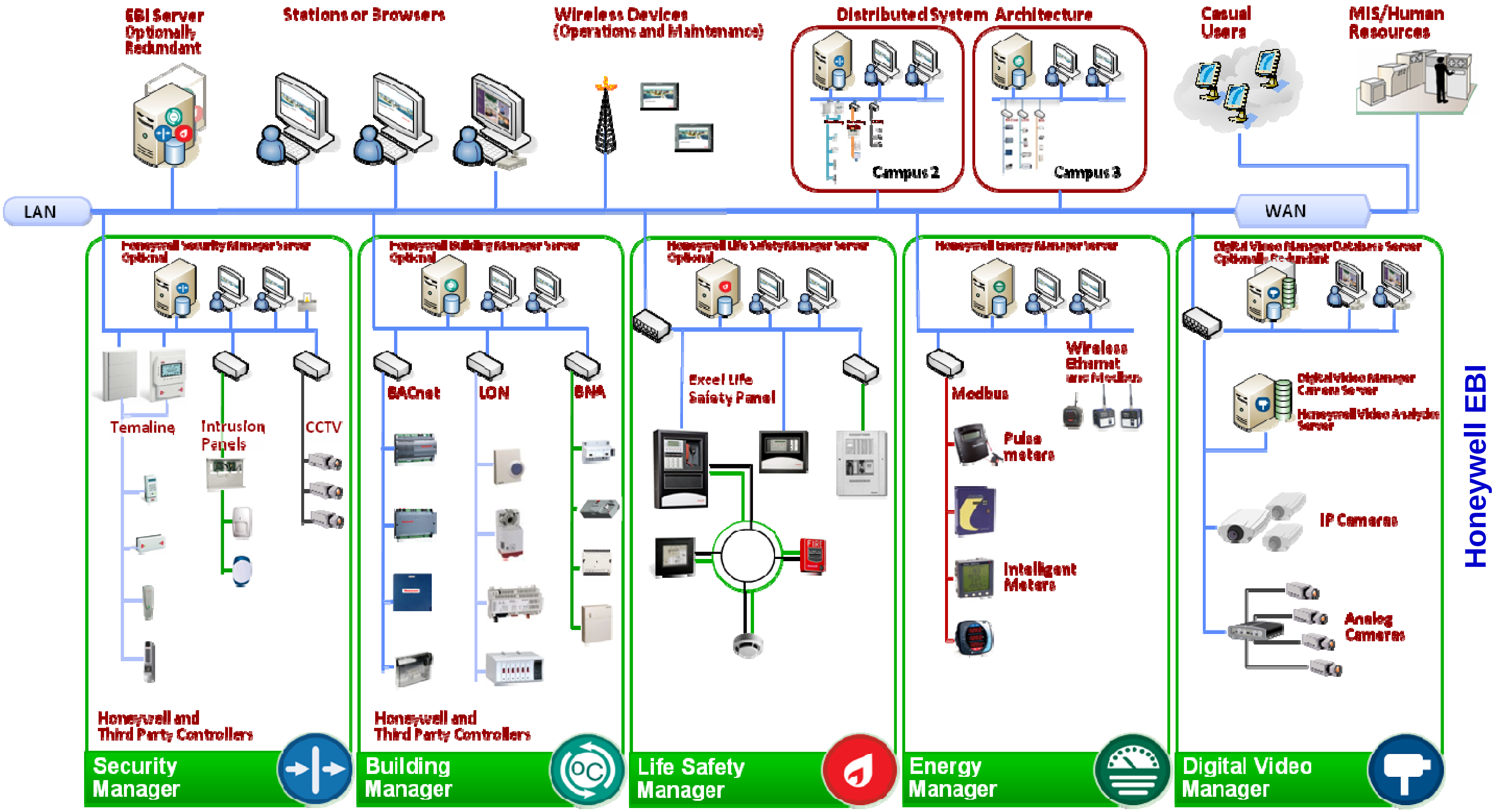
… administration

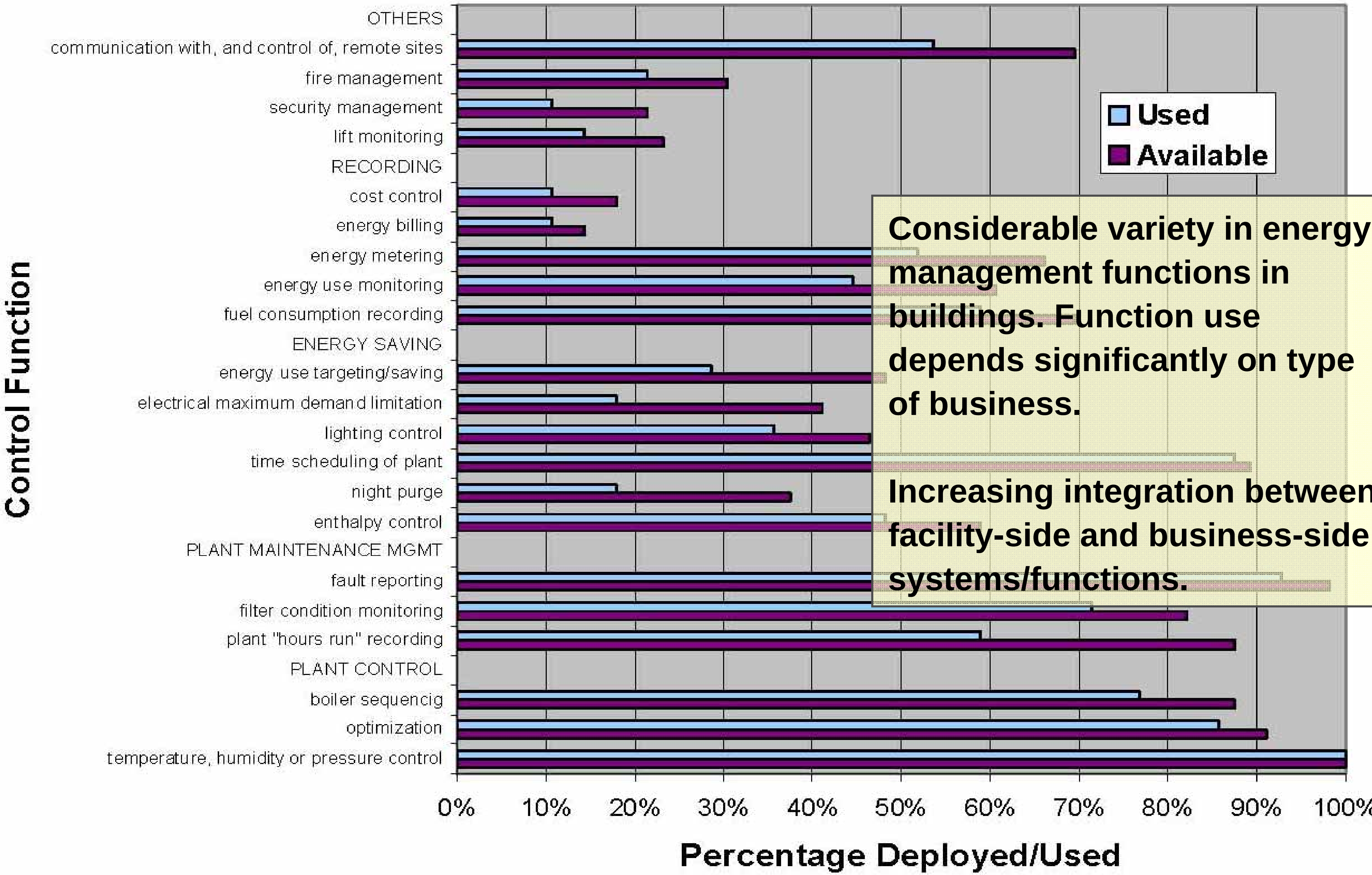
Commercial buildings—smart grid complexities

- The energy used for "overhead" (HVAC / lighting / etc.) must be balanced with the energy used for "production," or meaningful work in a facility
  - requires detailed knowledge of overhead and production loads
- Building codes must be followed (indoor air quality, energy efficiency, etc.)
  - specific operating conditions must be maintained
- Control schedules for commercial buildings must be designed with knowledge of weather, indoor conditions, expected occupancy, etc.
  - building should be "comfortable" just in time for first occupants but not any earlier
- Startup of loads (in occupied mode or after power failure) must be managed
  - e.g., electrical spikes cannot be tolerated
- Complete replacement of existing control systems typically not feasible
  - gateways used to interface with newer technologies
- Thermal / ice storage increasingly common for load shifting
  - requires knowledge of current and future cost of energy, weather information, current and future demand, existing storage capacity, etc.

Domain knowledge essential for load management

Building automation system example





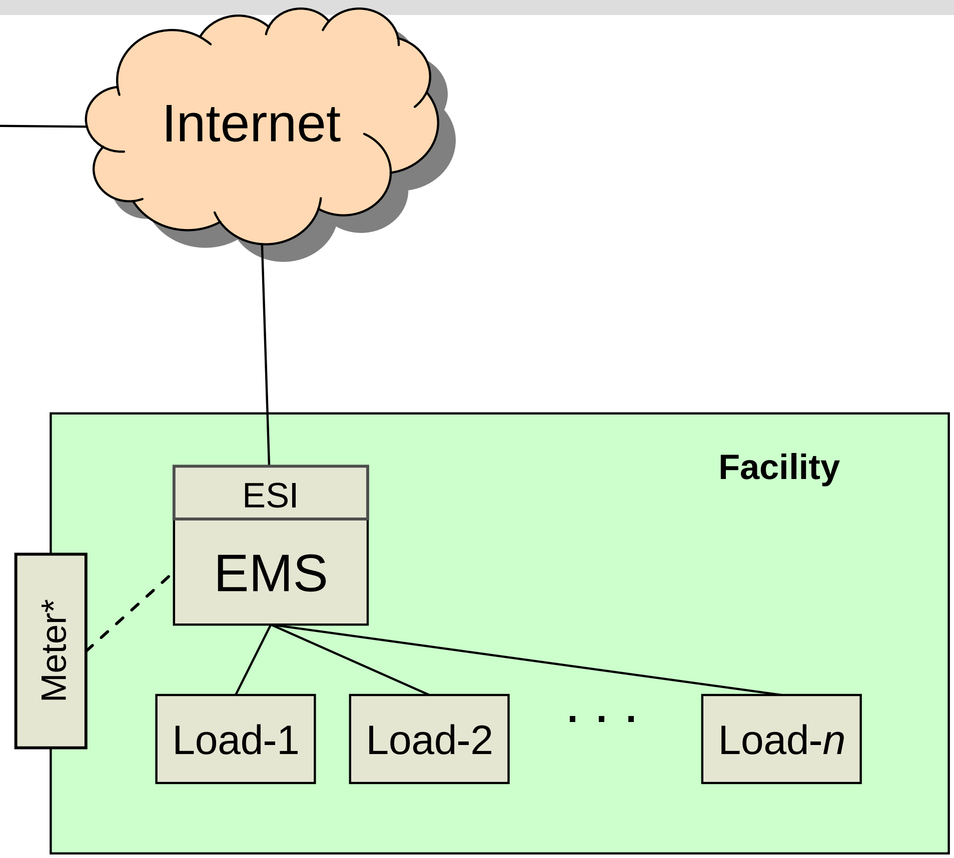
Considerable variety in energy management functions in buildings. Function use depends significantly on type of business.

Increasing integration between facility-side and business-side systems/functions.

Figure 2.1. Surveyed Prevalence and Usage Rates for Selected EMCS Functions (from Lowry 2002)

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15149.pdf

Commercial smart grid information architecture (1)

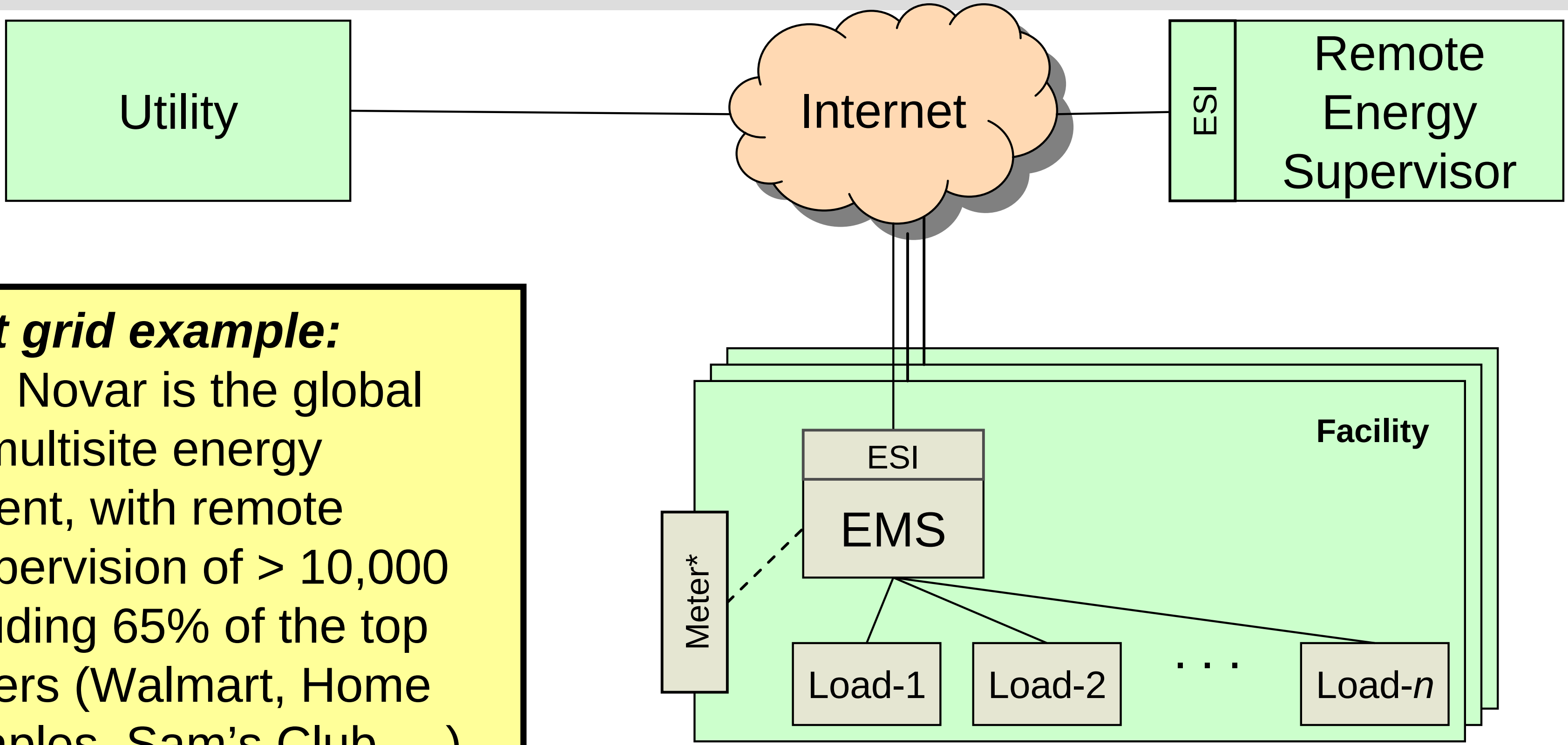


*may be shadow/interval meter

C&I smart grid example:
Johnson Controls (JCI) worked with Georgia Tech to implement a real-time-pricing controller for the campus. The BACnet-based JCI building automation system receives hour-ahead prices from Southern Company and adjusts temperature set points and boiler fuel source. Annual savings are estimated at $650K – $1M.

Courtesy of D. Alexander, Georgia Tech
For more information: http://www.fire.nist.gov/bfrlpubs/build07/PDF/b07028.pdf

Commercial smart grid information architecture (2)

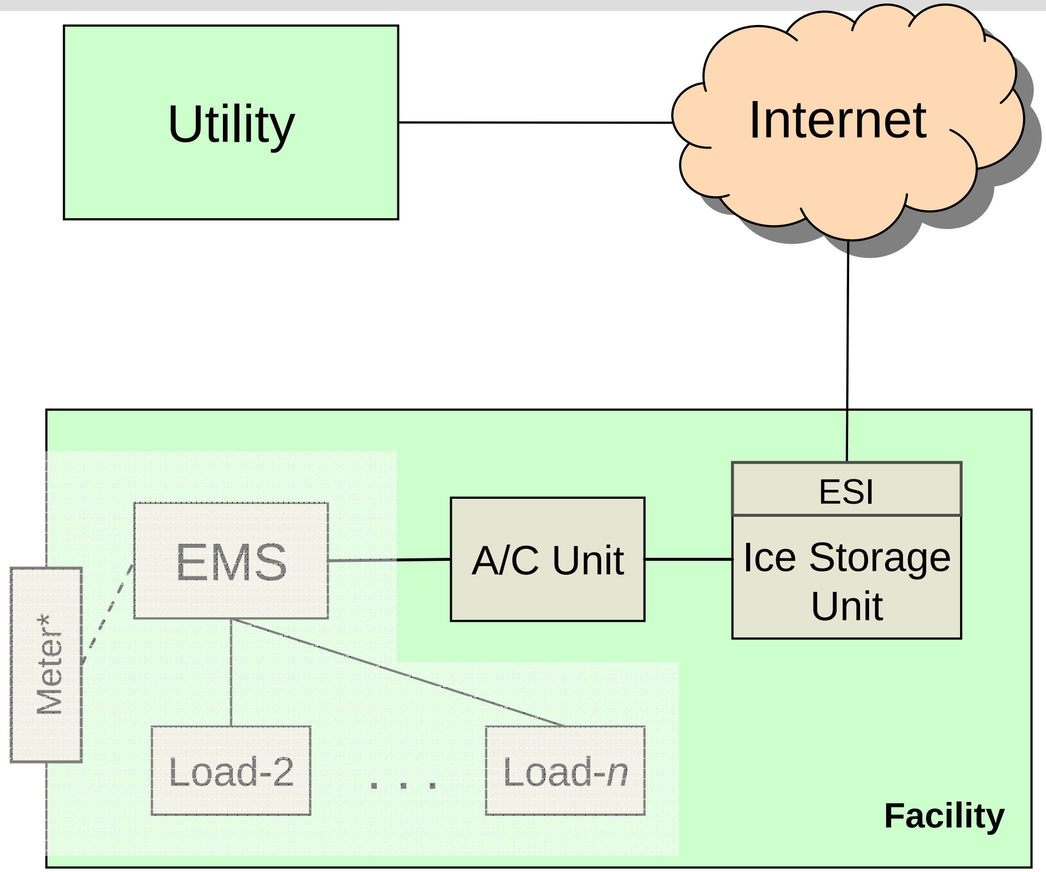


C&I smart grid example:
Honeywell Novar is the global leader in multisite energy management, with remote energy supervision of > 10,000 sites, including 65% of the top U.S. retailers (Walmart, Home Depot, Staples, Sam's Club, ...). In the U.S., Novar manages over 6 GW of loads in commercial buildings.

For more information: http://www.novar.com/

Commercial smart grid information architecture (3)

C&I smart grid example:
Ice Energy's storage solution (Ice Bear) enables peak load reduction in commercial buildings through the generation of ice during off-peak times and the use of the ice for cooling during peak load. A controller and ESI are part of the Ice Bear product, which determines the energy source (the EMS controls the cooling demand). Condensing unit peak reduction of 94 – 98 per cent is routinely realized in commercial installations.



Courtesy of B. Parsonnet, Ice Energy
For more information: http://www.ice-energy.com/

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Industrial sector—electricity use (U.S.)

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

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

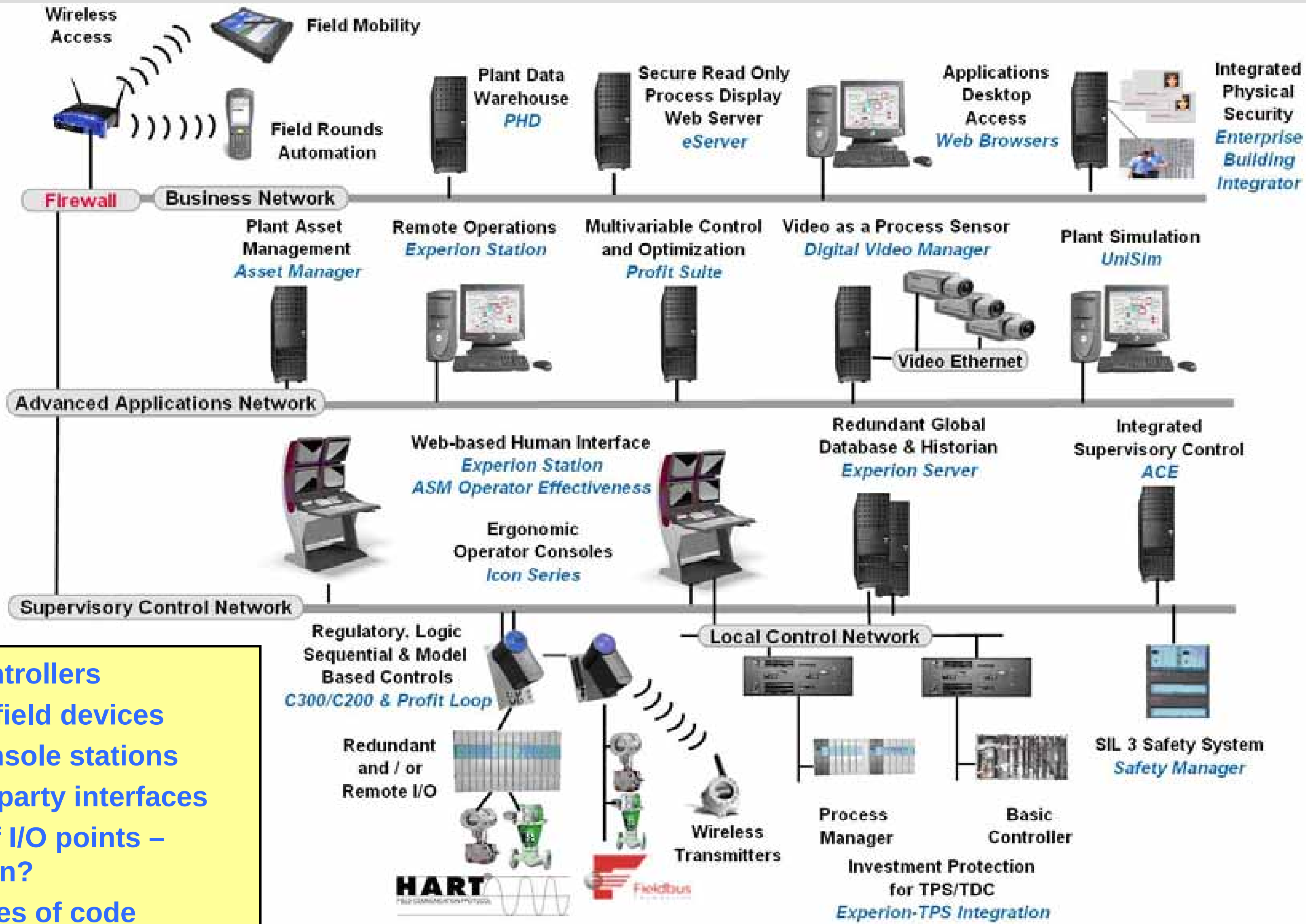
(plus smaller contributors)

Industry—smart grid complexities

- Industrial plants can be high consumers of electricity
  - up to 100s of MW at peak load and 100Ms of kWh annual consumption
  - Direct connection to transmission and distribution grids
- Large manufacturing facilities can have substantial on-site generation
  - U.S. industrial generation: 142 B kWh, about 15% of net electricity demand
  - sales and transfers offsite: 19 B kWh
- Automatic generation control (AGC) and ancillary services
  - large plants can play important roles for grid reliability and frequency regulation
- Industrial users have high interest in 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

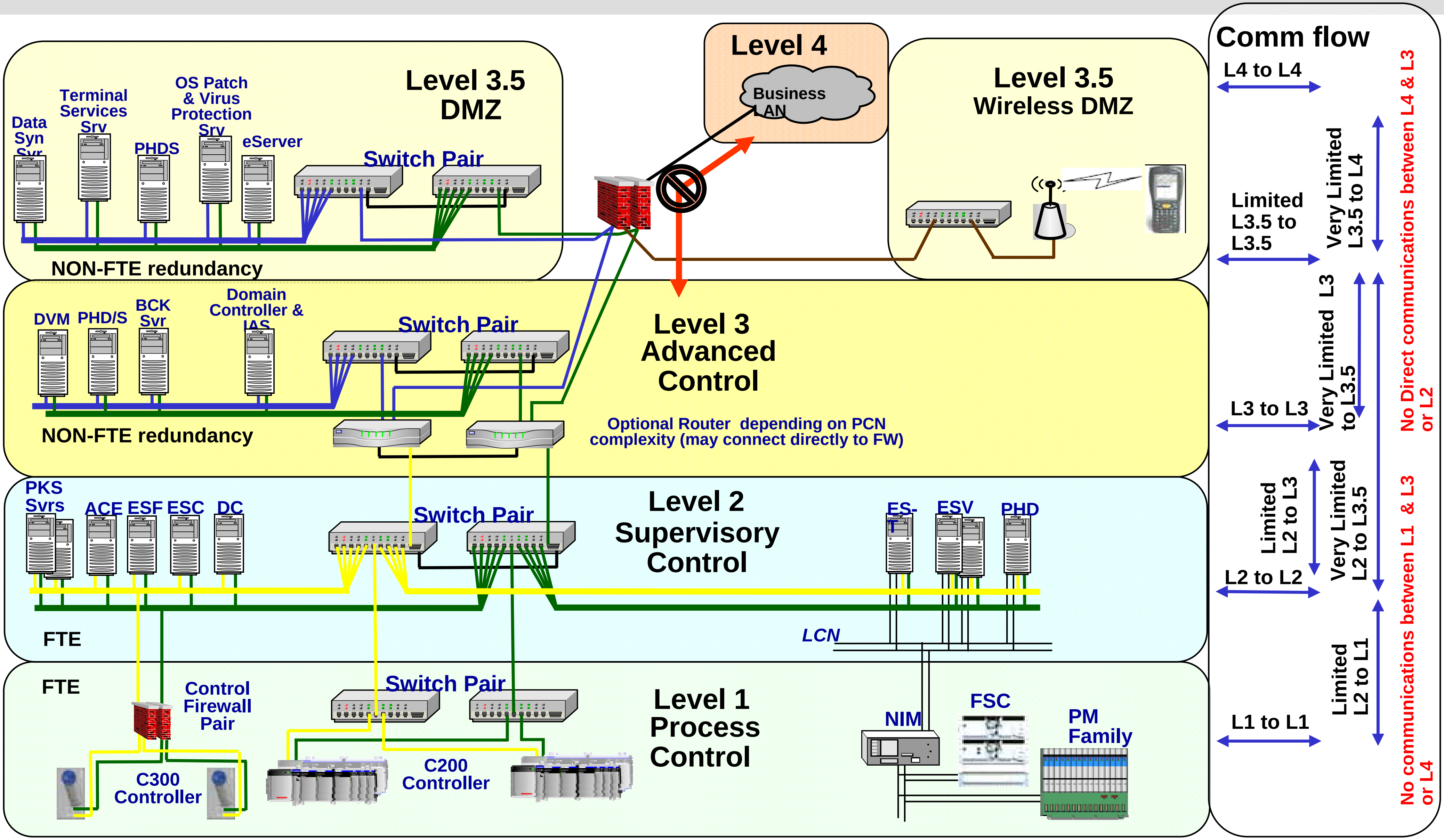
Distributed control system (DCS) example



Honeywell ExperionPKS

- 100s of controllers
- 10,000s of field devices
- 100s of console stations
- 100s of 3rd party interfaces
- 100,000s of I/O points – million soon?
- 10Ms of lines of code
- 100,000s of processors
- Cyber and physical security

High-security network architecture

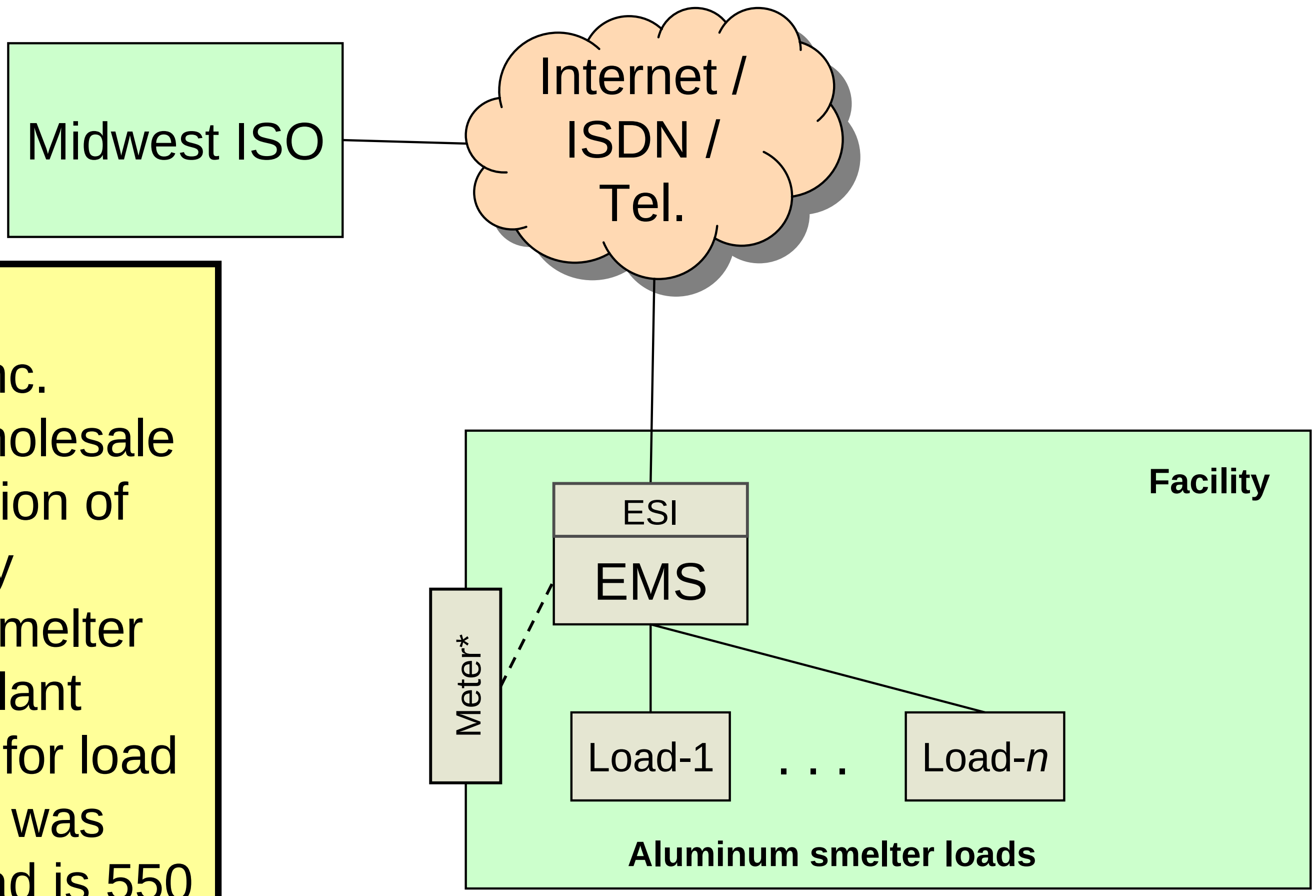


New DOE smart grid cybersecurity award

- *Role-Based Access Control (RBAC)-Driven Least Privilege Architecture for Control Systems*
- Building upon previous DOE research, Honeywell will research, develop and commercialize an architecture for critical systems that limits each operator's access and control privileges to the appropriate level for their job function.
- Partners: Univ. of Illinois, Idaho National Laboratory

See http://www.energy.gov/news/documents/Cybersecurity-Selections.pdf for details on this and other awards in this program (23 Sept., 2010).

Industrial smart grid information architecture (1)

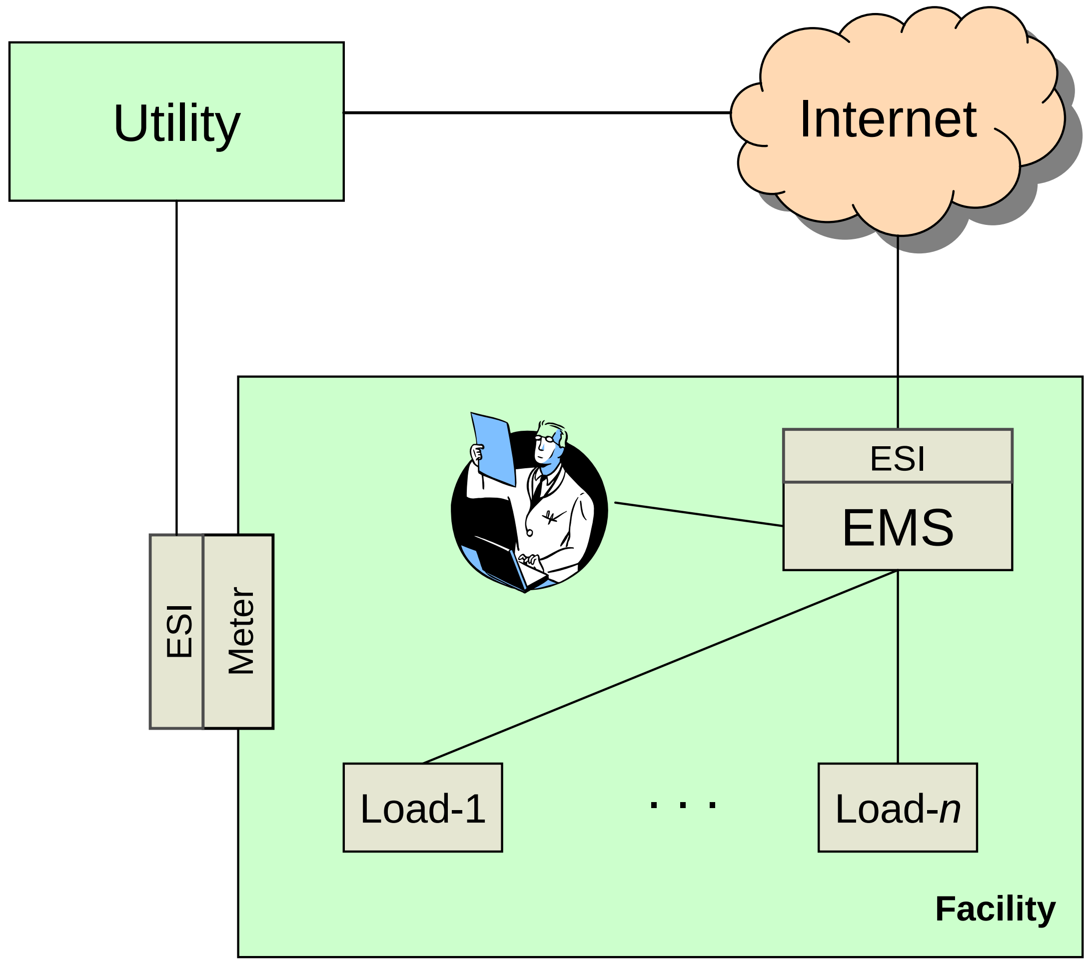


C&I smart grid example:
Alcoa Power Generation, Inc. participates in the MISO wholesale market by providing regulation of up to 25 MW as an ancillary service through control of smelter loads at Alcoa's Warwick Plant (Ind.). APGI is reimbursed for load modulation as if the energy was generated. Total facility load is 550 MW. More than15 GW of regulation capability is available in U.S. industry. Additional capability exists for other ancillary services.

Courtesy of D. Brandt, Rockwell Automation
For more information:
http://info.ornl.gov/sites/publications/files/Pub13833.pdf

Industrial smart grid information architecture (2)

C&I smart grid example:
A food manufacturer participates in a CAISO demand response program. Proposed day-ahead events are received from the utility. A person examines the production schedule to decide which (if any) manufacturing loads can be shed. The load shedding is enabled in the EMS for automatic execution based on further events the following day. The site receives utility compensation for participation based on actual meter readings compared to a baseline.



Courtesy of D. Brandt, Rockwell Automation

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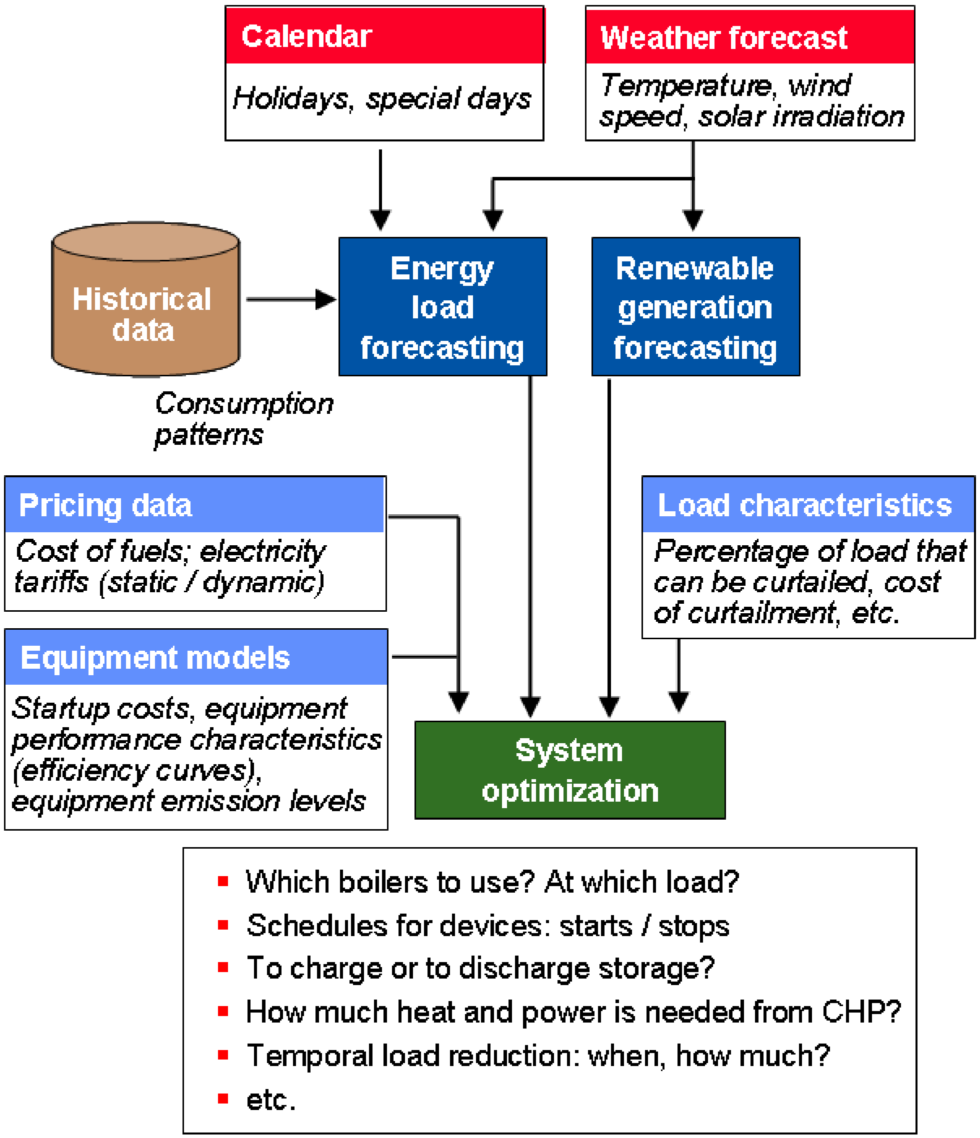
Microgrid optimization schematic



- Supply-side and demand-side aspects
- Not limited to electric power—microgrid can include cogeneration units
- Key challenges include:
  - optimization formulation
  - load forecasting
- Versatile Energy Resource Allocation (VERA) tool (Honeywell Prague Lab)

Supply-side microgrid problem (partial)

Indicator for *i*-th generator in operation

Startup operating cost for *i*-th generator

Minimize

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

Cost for importing grid power at time *t*

s.t.

Fixed operating cost for *i*-th generator

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

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

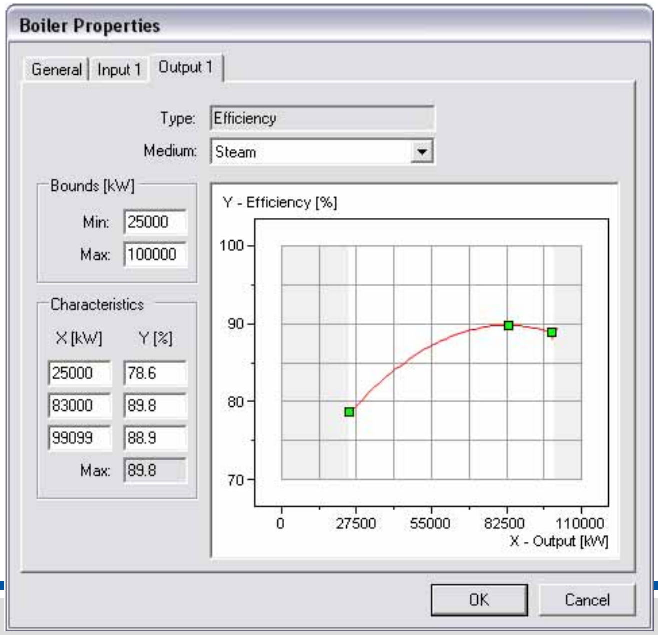
$$P_{i,\min}X_{t,i}\le P_{t,i}\le P_{i,\max}X_{t,i}$$

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

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

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

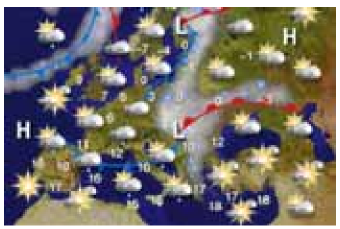
MINLP problem, solved with a solution step ranging from 15 minutes to 1 hour.



Forecasting for Effective Energy Management

Inputs

Time of day
Holiday
Ambient temperature
Wind velocity
Humidity



Demand Model

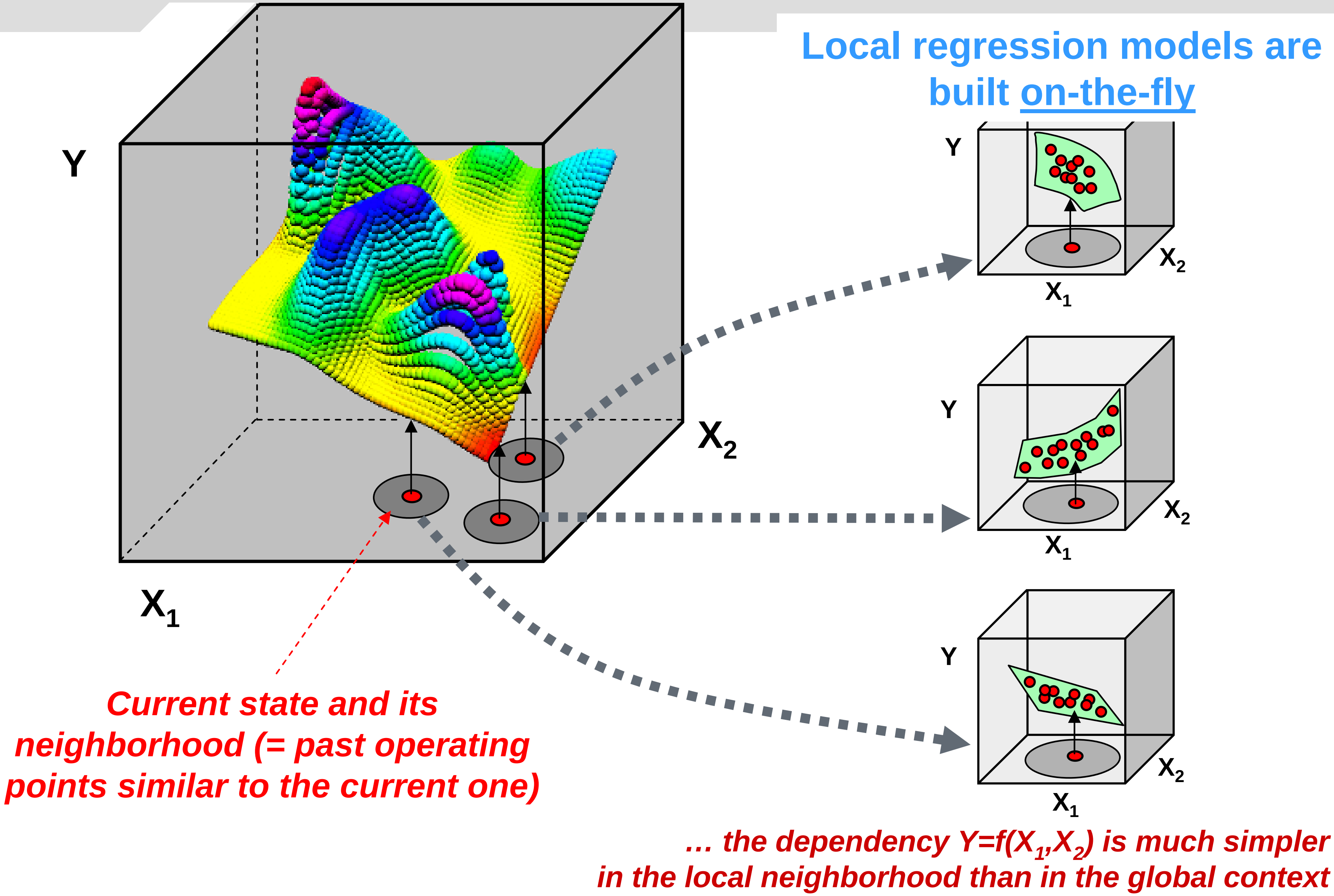
Predictions

Heating demand
Cooling demand
Electricity demand
Steam demand
…

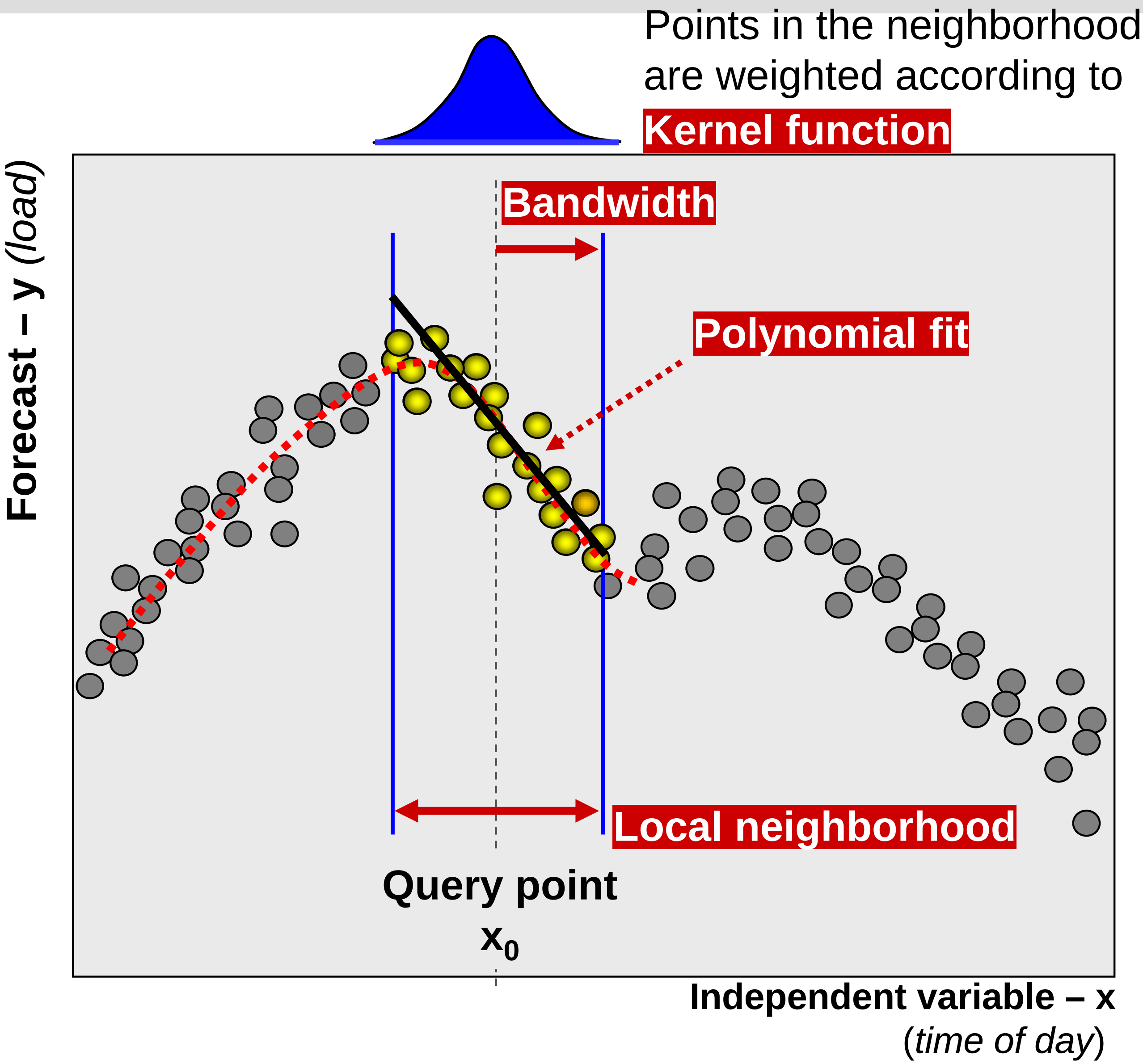
- Little first-principles understanding → statistical modes required
- Model form/structure varies with situation
- Need to take advantage of operational data as obtained

→ Data-centric local models

Data-centric modeling



Local Regression

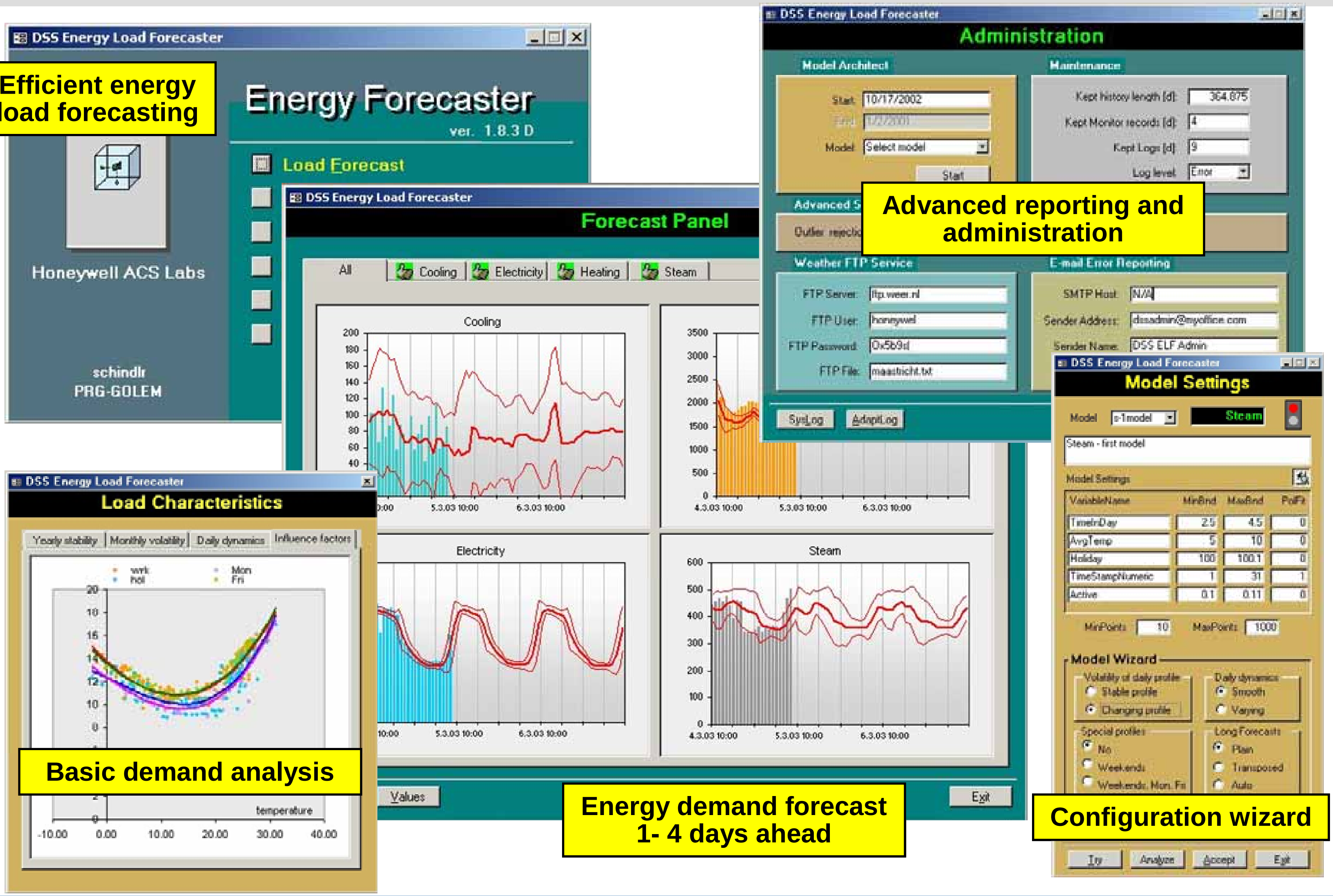


$$w = \exp\left(\frac{-3\sigma d^2}{2}\right)$$

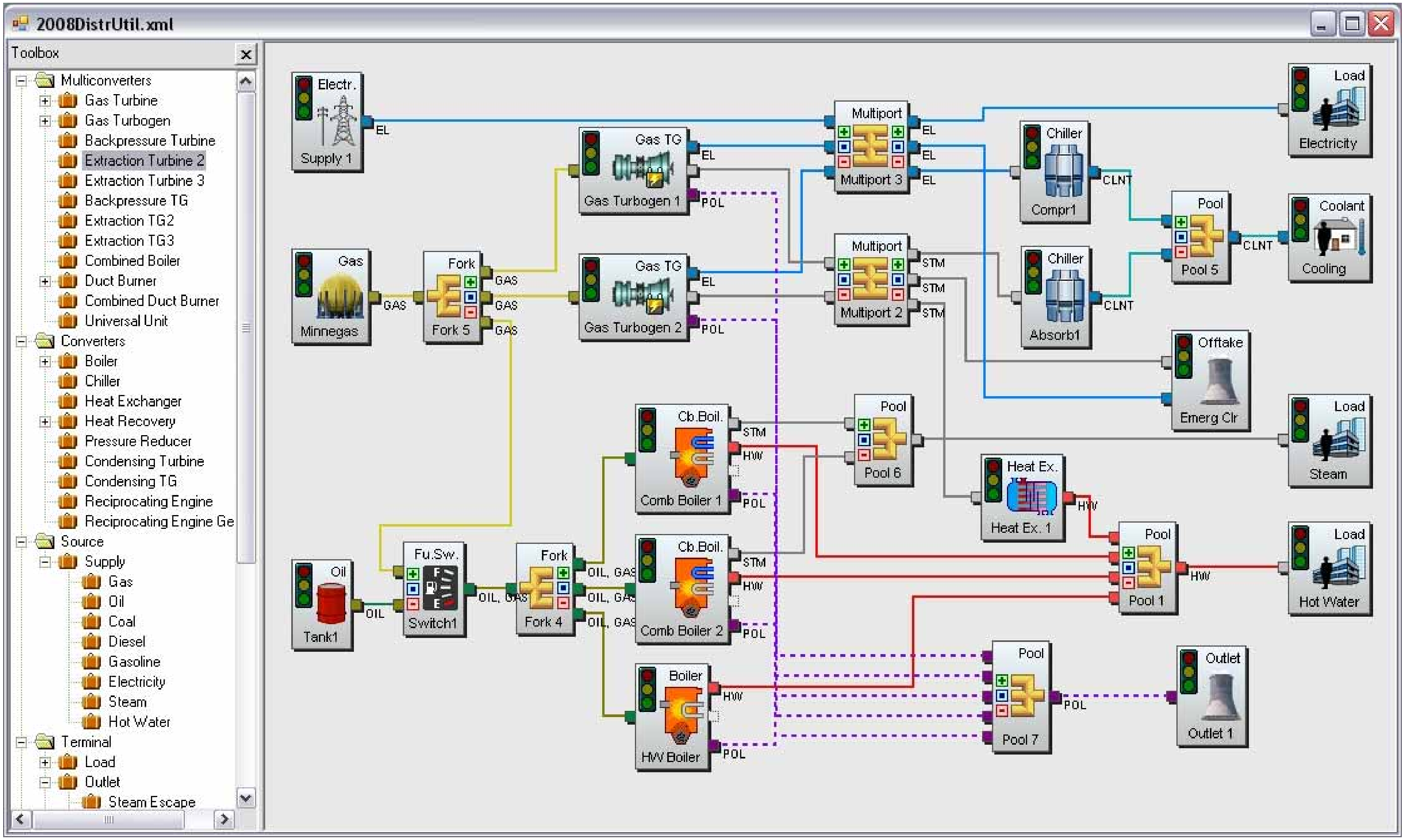
Distance function

$$d^2 = \sum_{i=1}^{N}\left(\frac{X_i^* - X_i}{h_i}\right)^2$$

Energy Forecaster



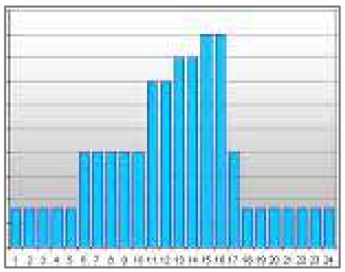
VERA interface



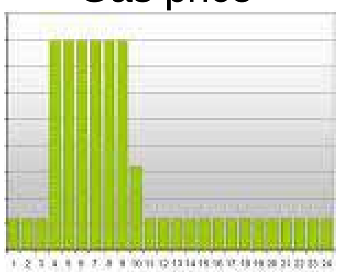
Optimization Results (Combined Heat & Power)

Real-time prices

Power price

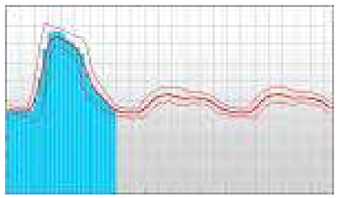


Gas price



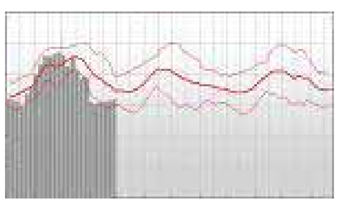
Forecasted demand

Power demand



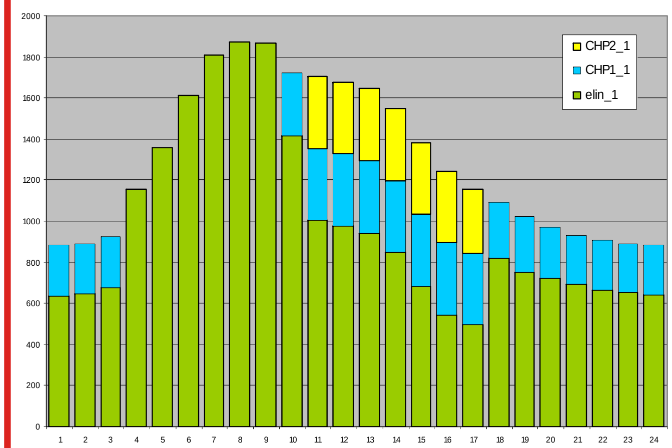
Heat demand

Steam demand



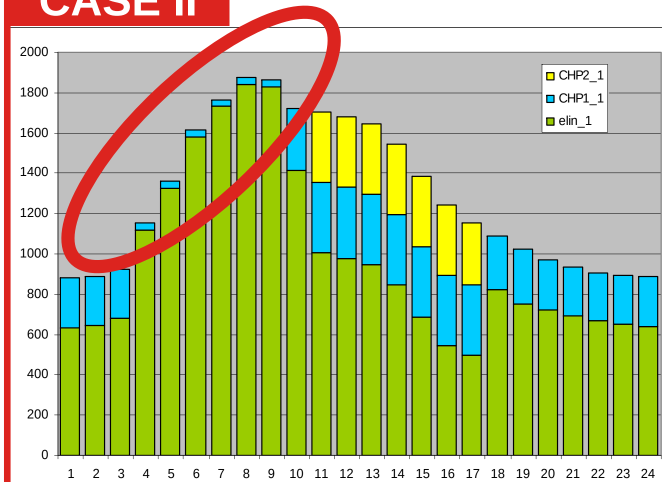
Optimal resource allocation

CASE I



Zero GT1 startup costs

CASE II



Non-zero GT1 startup costs

Gas turbine GT1 keeps running all day due to high start-up costs

Purchased power | Gas Turbine 1 generation | Gas Turbine 2 generation

5 – 20% reduction in energy consumption realized

VERA technology implementation

750-bed hospital in the Netherlands

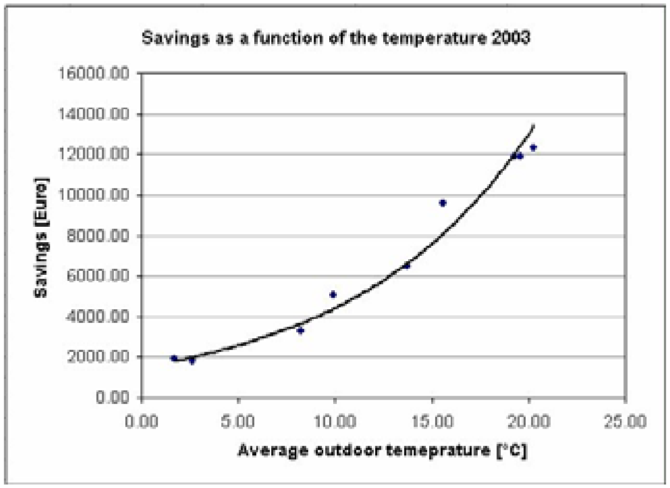
Approximate energy costs: € 1,200,000 per year

- hot water boiler
- 2 steam boilers
- Compressor and absorption chillers
- 2 gas combined heat and power units

Energy Forecaster + Optimizer installed in 2002, still in operation

Cost savings:

2003	€ 75 000 (6 %)
2004	€ 90 000
2005	€151 000



Savings improve over time …
more data ⇒ better forecasting model

Demand-side formulation (partial)

$$\text{Minimize} \sum_{t=1}^{T} \left(R_t^{sell} P_{t,u} - R_t^{buy} P_{t,LG}^{excess} - R_t^{buy} P_{t,s}^{grid} \right)$$

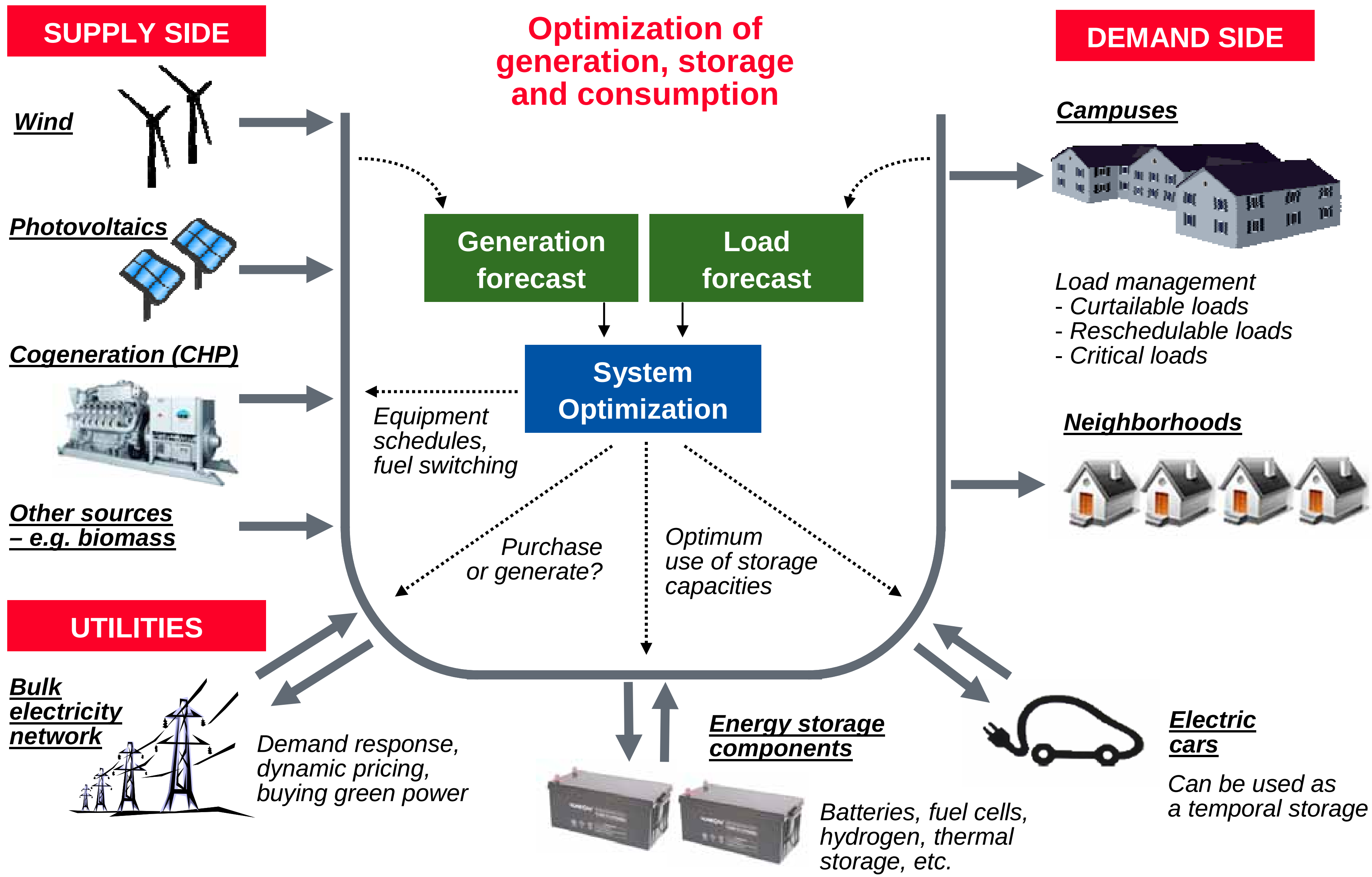
$$\text{subject to } P_{t,u} + P_{t,LG}^{cons} + P_{t,s}^{cons} = L_t$$

$$S_t = \max\left\{ \min\left[S_{t-1} + P_{t,LG}^{stored} + P_{t,u}^{stored} - P_{t,s}^{cons} - P_{t,s}^{grid}, S_{\max} \right], 0 \right\}$$

$$\left(P_{t,LG}^{stored} + P_{t,u}^{stored} = 0 \right) \vee \left(P_{t,s}^{cons} + P_{t,s}^{grid} = 0 \right)$$

- R_t^{sell}, R_t^{buy}: utility sell and buy rates at time *t*
- $P_{t,u}$: utility-supplied power at time *t*
- $P_{t,LG}^{cons}$, $P_{t,s}^{cons}$: locally generated and stored power consumed at time *t*
- $P_{t,s}^{grid}$: stored power supplied to grid at time *t*
- $P_{t,LG}^{stored}$, $P_{t,\,u}^{stored}$: locally generated and utility-supplied power used for storage at time *t*
- $P_{t.LG}^{excess}$: excess production at time t
- L_t: total load at time *t*
- S_t: state of charge for storage at time *t*

Integrated Microgrid Optimization Problem



Concluding remarks...

- 90+% of electricity generated is consumed in end-use facilities (in developed economies)
- Many successful applications today in commercial and industrial sectors
  - without smart meters
  - with available infrastructure (Internet, cellular, etc.)
  - ... but much more can be done
- Many common principles across all customer sectors, *including residential*
- Rich research opportunities for algorithmic research
  - microgrid optimization
  - integration of renewables, storage, PHEVs
  - cybersecurity, and integrated cyber/physical security
  - ...