Process Energy Systems: Control, Economic, And Sustainability Objectives

Thomas F. Edgar
University of Texas-Austin

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Outline

- U.S. energy/environment overview
- Energy efficiency and power production alternatives
- Smart manufacturing to reduce energy usage
- Next generation power systems(smart grids)
- Thermal energy storage and process control

The U.S. Industrial Sector

- Industrial energy usage = 35 quads; (total = 100 quads)
- This sector accounts for about one-third of total U.S. GHG emissions
- By 2030, 16% growth in U.S. energy consumption, which will require additional 200 GW of electrical capacity (EIA)
- Energy efficiency goals of 25% reduction in energy use by 2030 (McKinsey and National Academies Press reports)

Perspective of this Paper

- Focuses on process operation and control (not design)
- Assumes use of existing infrastructure to maximize thermal efficiency
- Maximize efficiency ≡ minimize carbon footprint
- Most carbon dioxide currently comes from fossil fuel combustion
- Progress will require a systems approach

CO_2 Policy Alternatives

- Cap and Trade
  - Establishes firm limit on CO_2 emissions
  - Auctioning/trading of emissions permits
- Carbon Tax
  - Price Predictability
  - Favored by large chemical companies
  - Apply to all Carbon Sources
- Regulated CO_2
  - Recent EPA announcement on reporting requirements
  - Proposed coal plant regulations

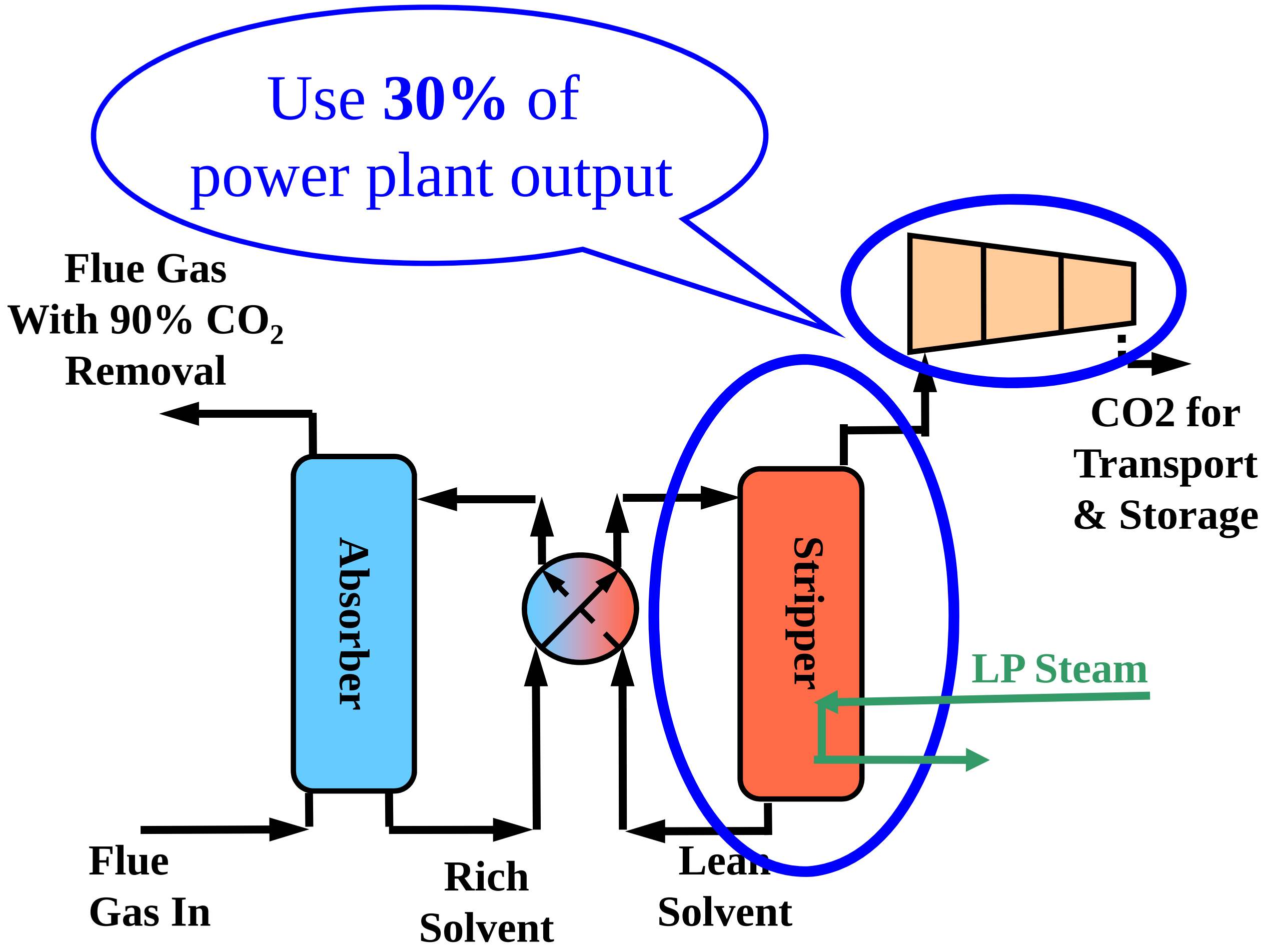
Reducing Carbon Footprint in Process Plants

- Reduce energy requirements
  - Use less energy-intensive chemistry/unit operations
  - Increase heat integration/cogeneration
  - Change the process to alter thermal vs. electro-mechanical energy
- Reduce carbon emissions (no major process changes)

Power Generation Strategies to Manage Carbon Emissions

- Use higher efficiency power cycles (e.g., combined cycle, solid oxide fuel cells)
- Fuel swapping (natural gas for coal)
- Conversion to non-fossil sources (e.g., nuclear or renewables)
- Nuclear thermal process energy
- Capture/disposal of CO_2 emissions

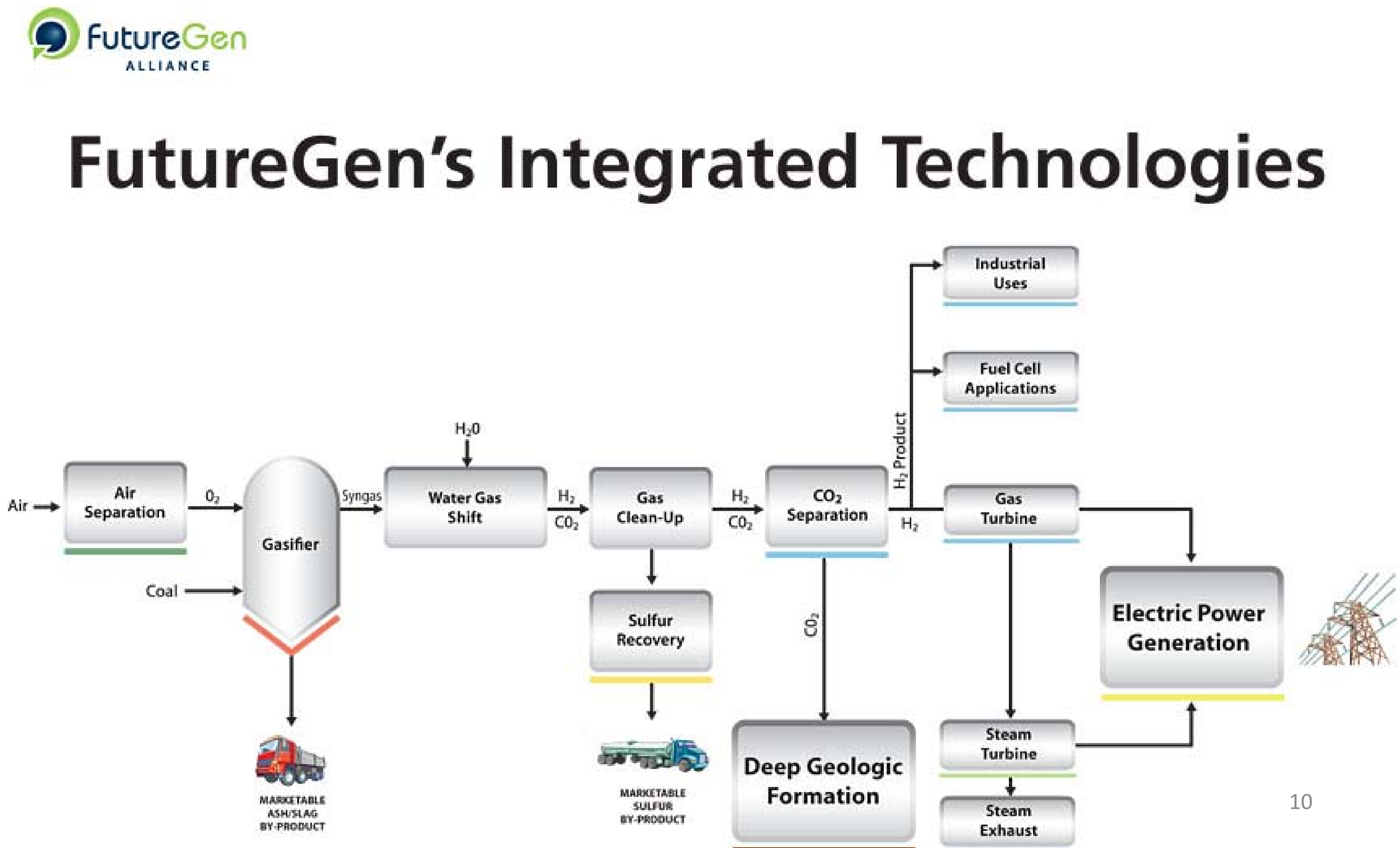
CO_2 Absorption/Stripping of Power Plant Flue Gas



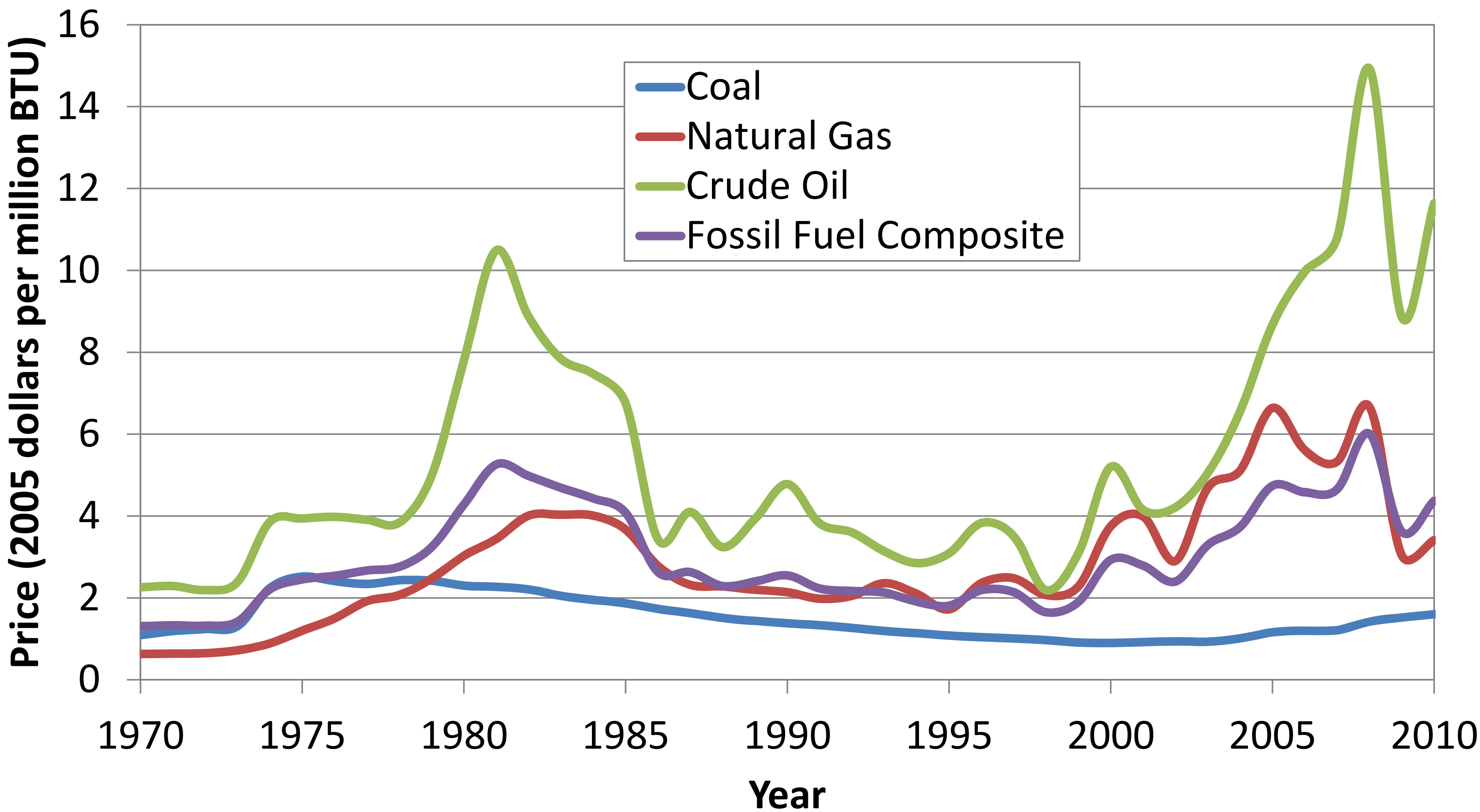
Biomass Gasification for Power Production

- Carbon-neutral alternative to use of coal
- Insensitive to nature of biomass
- Technology well-established, including combined cycle
- Supply chain limitations, but useful where biomass can be easily collected or as a byproduct (but not a broad U.S. strategy)

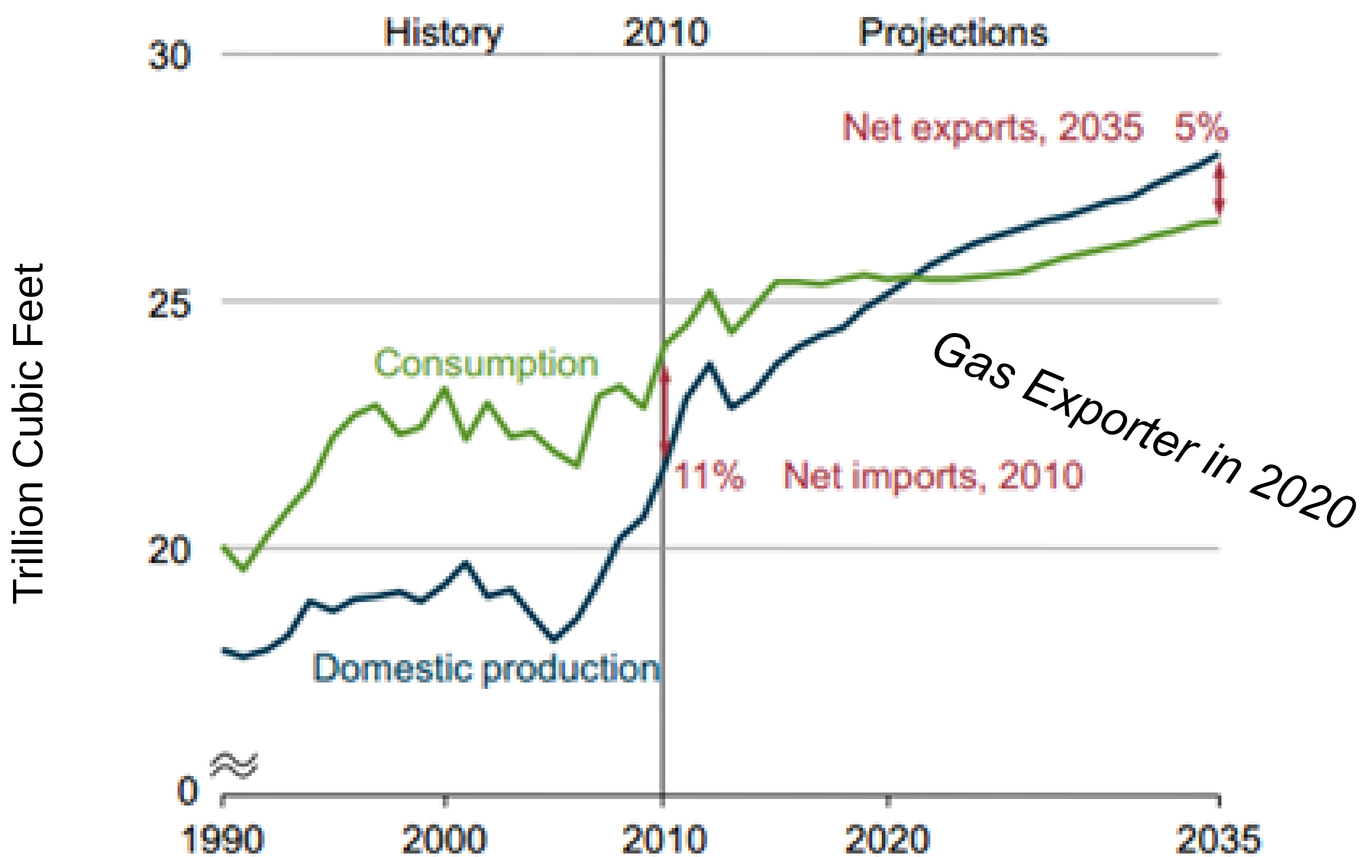
IGCC PROCESS



U.S. Energy Prices vs. Time

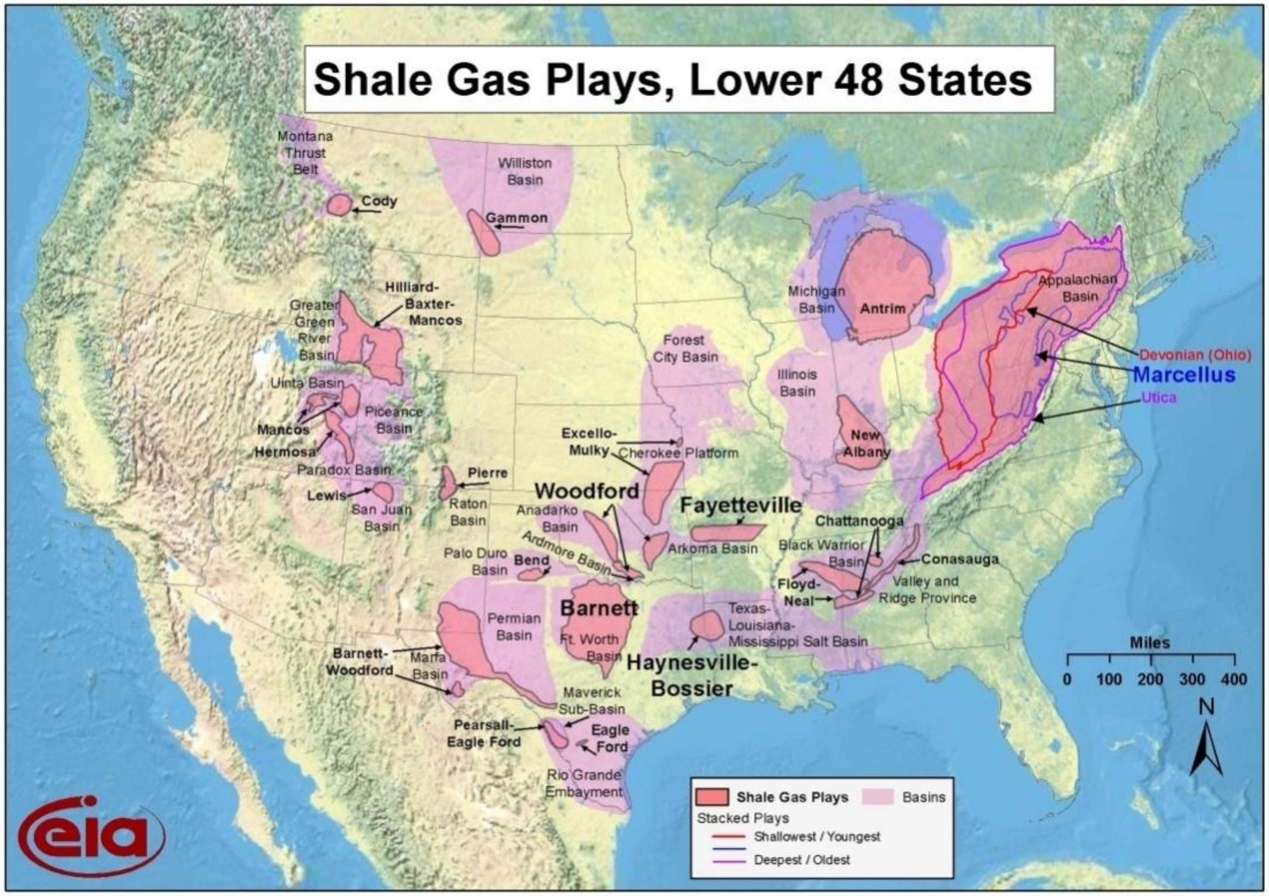


U.S. Production, Consumption, Net Imports



Energy Information Administration

U.S. Shale Gas Occurrence



Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

Source: U.S. Energy Information Agency

Impact of Shale (Natural) Gas in the U.S.

- Increasing supplies of domestic natural gas (+20%), $4/MSCF
- Increased usage in power generation(lower GHG)
- Makes U.S. industrial locations more globally competitive (feedstock, power)
- Changes regional industrial development options (e.g., NY-PA), subject to local environmental pressures

What is SMART Manufacturing?

The ability to take action, in real time, to OPTIMIZE your assets in the context of your business strategies and imperatives

SMLC

SMART MANUFACTURING LEADERSHIP COALITION

The infusion of intelligence that transforms the way Industries conceptualize, design, and operate the manufacturing enterprise.

https://smartmanufacturingcoalition.org

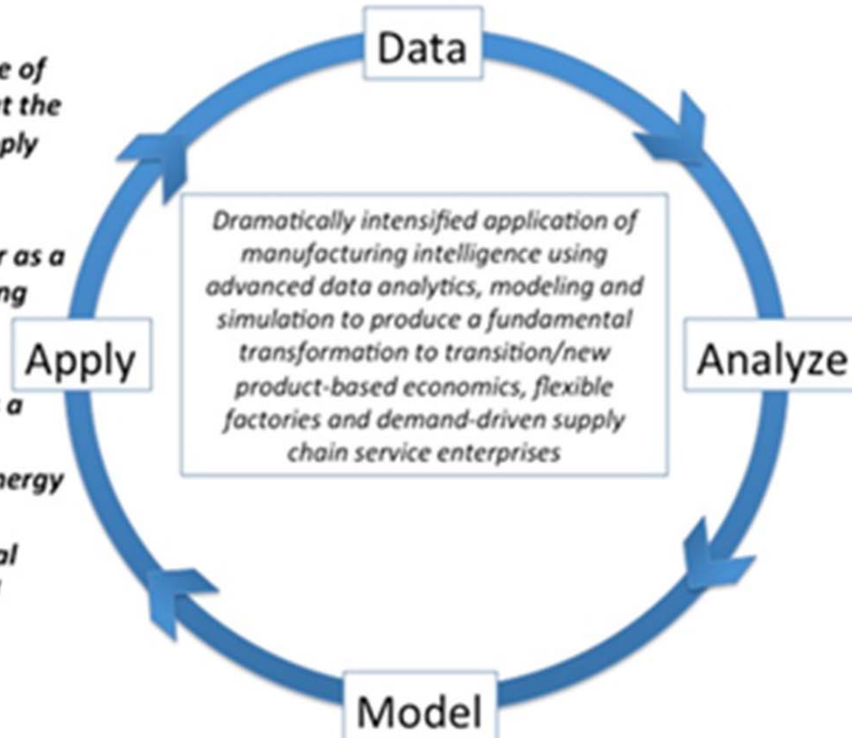
http://smartmanufacturing.com

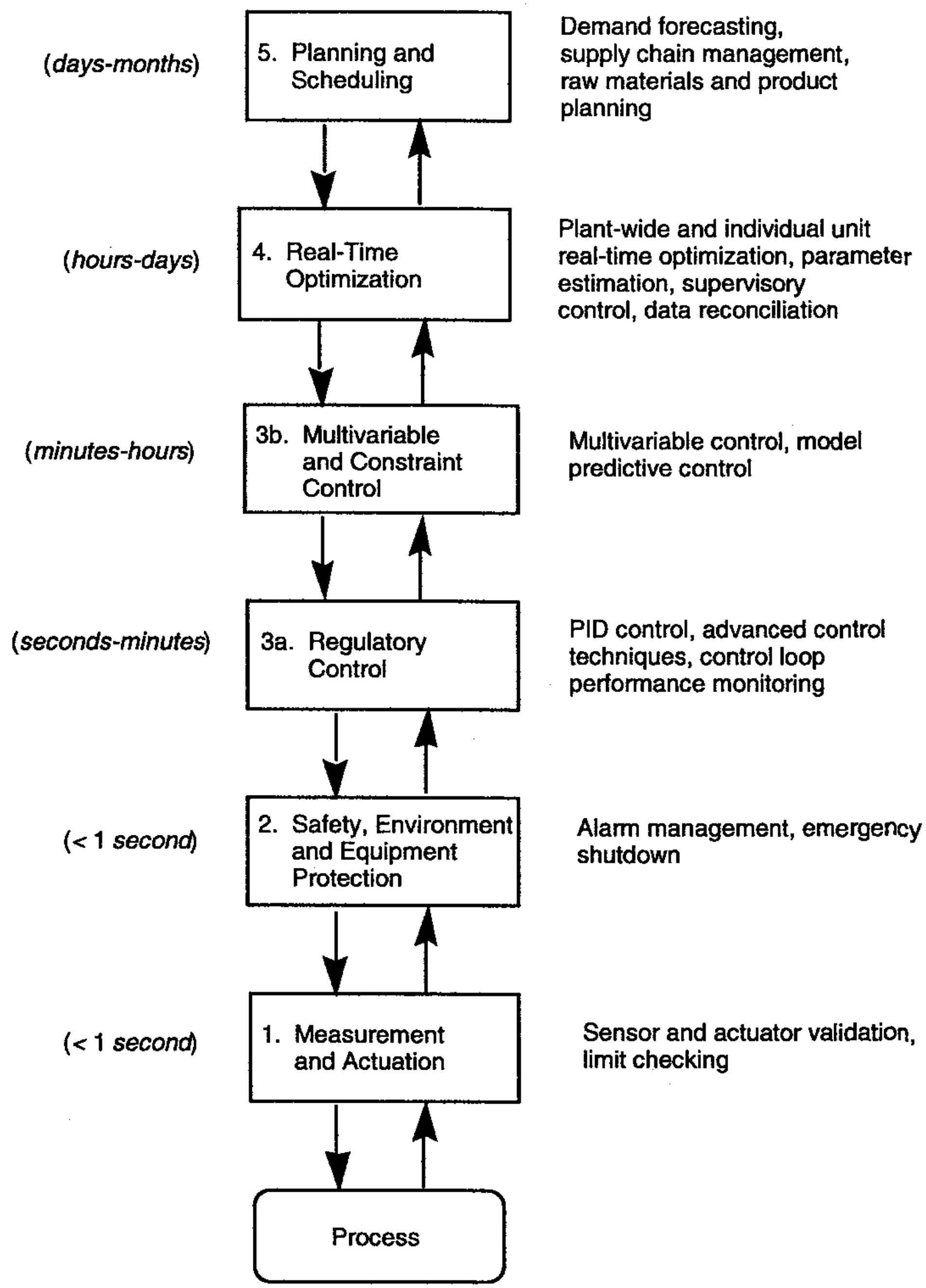
“Internet of Things” Deception

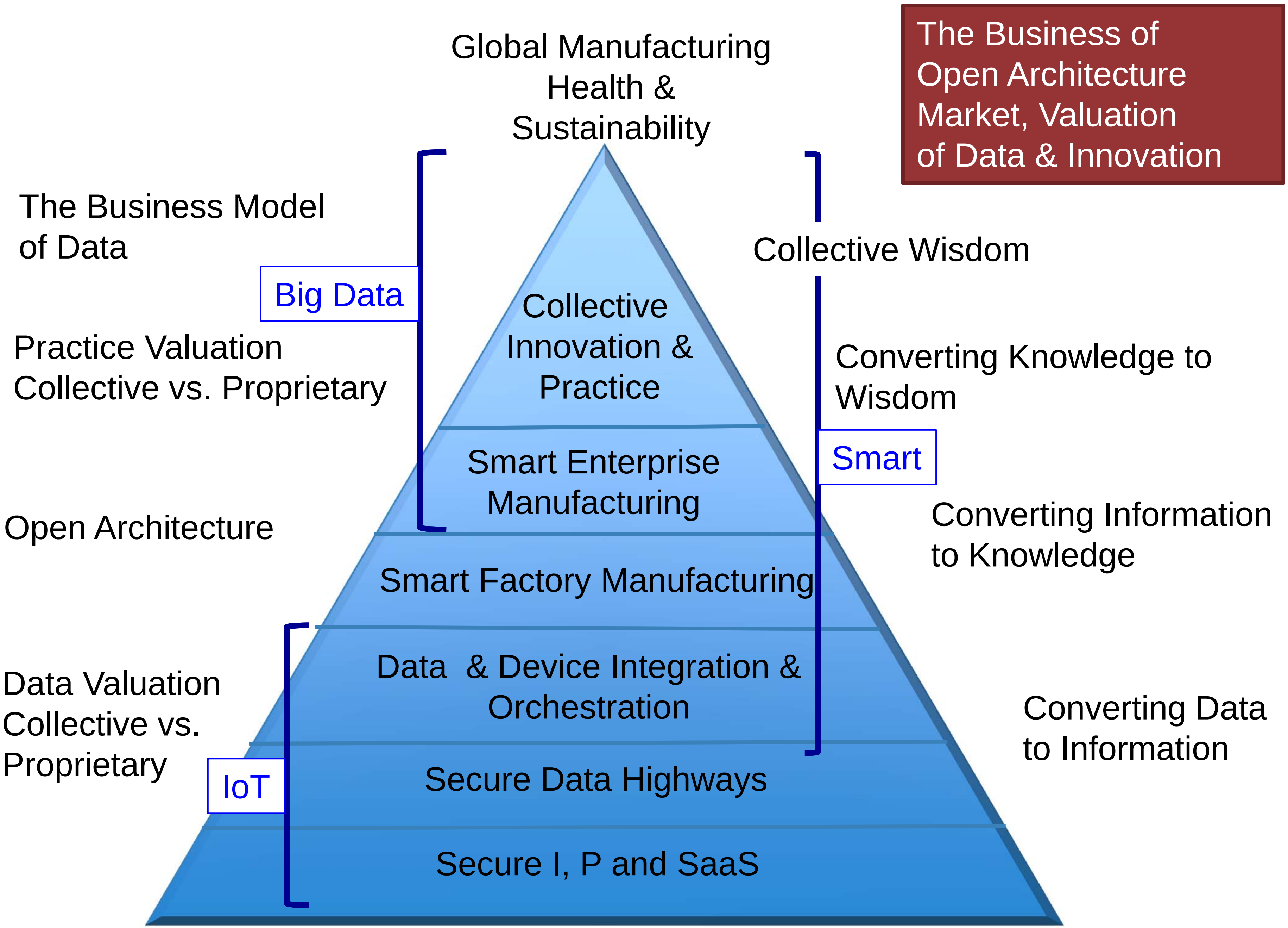
- Connect your smartphone to your digital scale
- Then you will lose weight
- You have to do something else?

21st Century Smart Manufacturing

- *Integrates the intelligence of the 'customer' throughout the entire manufacturing supply chain*
- *Responds to the customer as a coordinated manufacturing enterprise*
- *Responds to the public as a performance-oriented enterprise, minimizing energy and material usage and maximizing environmental sustainability, health and safety and economic competitiveness.*




(days-months)
5. Planning and Scheduling
Demand forecasting, supply chain management, raw materials and product planning
(hours-days)
4. Real-Time Optimization
Plant-wide and individual unit real-time optimization, parameter estimation, supervisory control, data reconciliation
(minutes-hours)
3b. Multivariable and Constraint Control
Multivariable control, model predictive control
(seconds-minutes)
3a. Regulatory Control
PID control, advanced control techniques, control loop performance monitoring
(< 1 second)
2. Safety, Environment and Equipment Protection
Alarm management, emergency shutdown
(< 1 second)
1. Measurement and Actuation
Sensor and actuator validation, limit checking
Process



Global Manufacturing Health & Sustainability
The Business of Open Architecture Market, Valuation of Data & Innovation
The Business Model of Data
Big Data
Practice Valuation Collective vs. Proprietary
Open Architecture
Data Valuation Collective vs. Proprietary
IoT
Collective Innovation & Practice
Smart Enterprise Manufacturing
Smart Factory Manufacturing
Data & Device Integration & Orchestration
Secure Data Highways
Secure I, P and SaaS
Collective Wisdom
Converting Knowledge to Wisdom
Smart
Converting Information to Knowledge
Converting Data to Information

Sustainability Drivers

- Health and safety
- New material minimization
- Energy efficiency
- Environmental protection
- Waste minimization
- Water management
- Climate mitigation
- Biological feedstocks

Control of Energy Usage – Some Observations

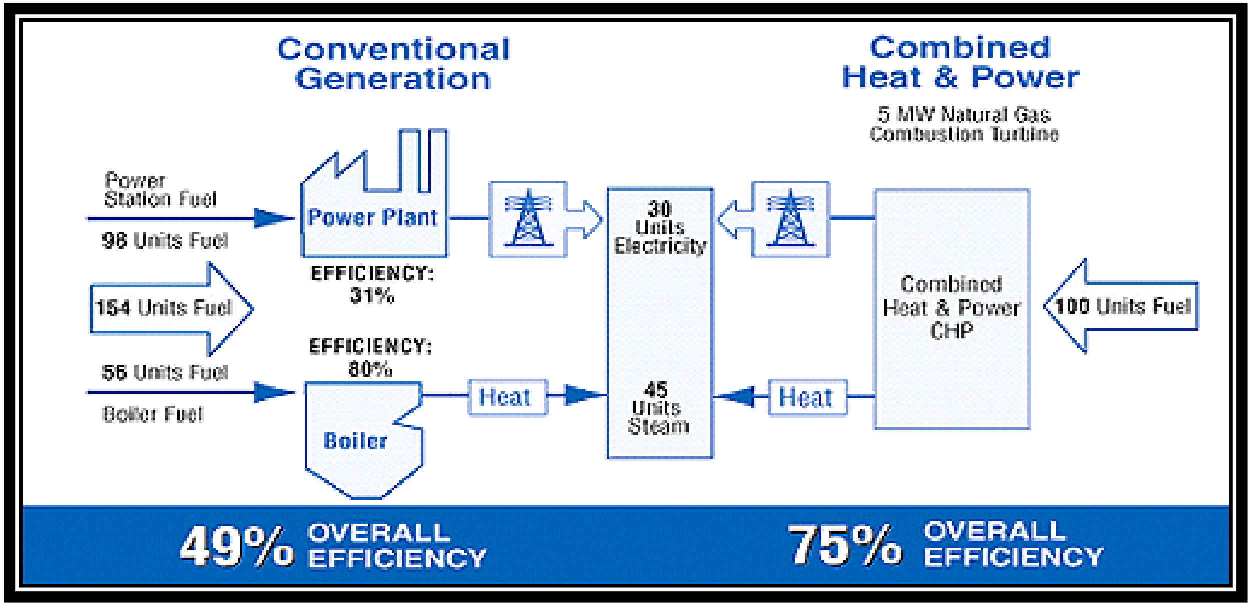
- Most plants do not control energy on a unit operations basis. Rather they monitor total plant usage on a daily or even monthly accounting basis.
- Plants are designed for energy efficiency, but do not include manipulated variables as degrees of freedom to minimize energy utilization.
- Individual users of utilities (e.g., steam to individual reboilers or exchangers) are not recorded although valve positions for energy flows usually are known.
- Plants control for throughput or fitness for use attributes (purity, molecular weight, etc.), but adjust utilities to achieve these goals.

More Observations

- Most multivariable control algorithms (like MPC) do not assign an economic value to the manipulated variable moves, although some research efforts have been oriented towards "economic" MPC.
- Energy reuse adding heat and power integration will create unit and control loop interactions and new disturbance patterns, making control strategies more complex. Integer (on-off) variables for equipment such as chillers will need to be optimized.
- Swapping thermal and electrical forms of energy can have unexpected utilities systems impacts (dynamics and control).
- Attempting to control carbon emissions as well as energy usage will require new research investigations in PSE.

Increased Generation Efficiency

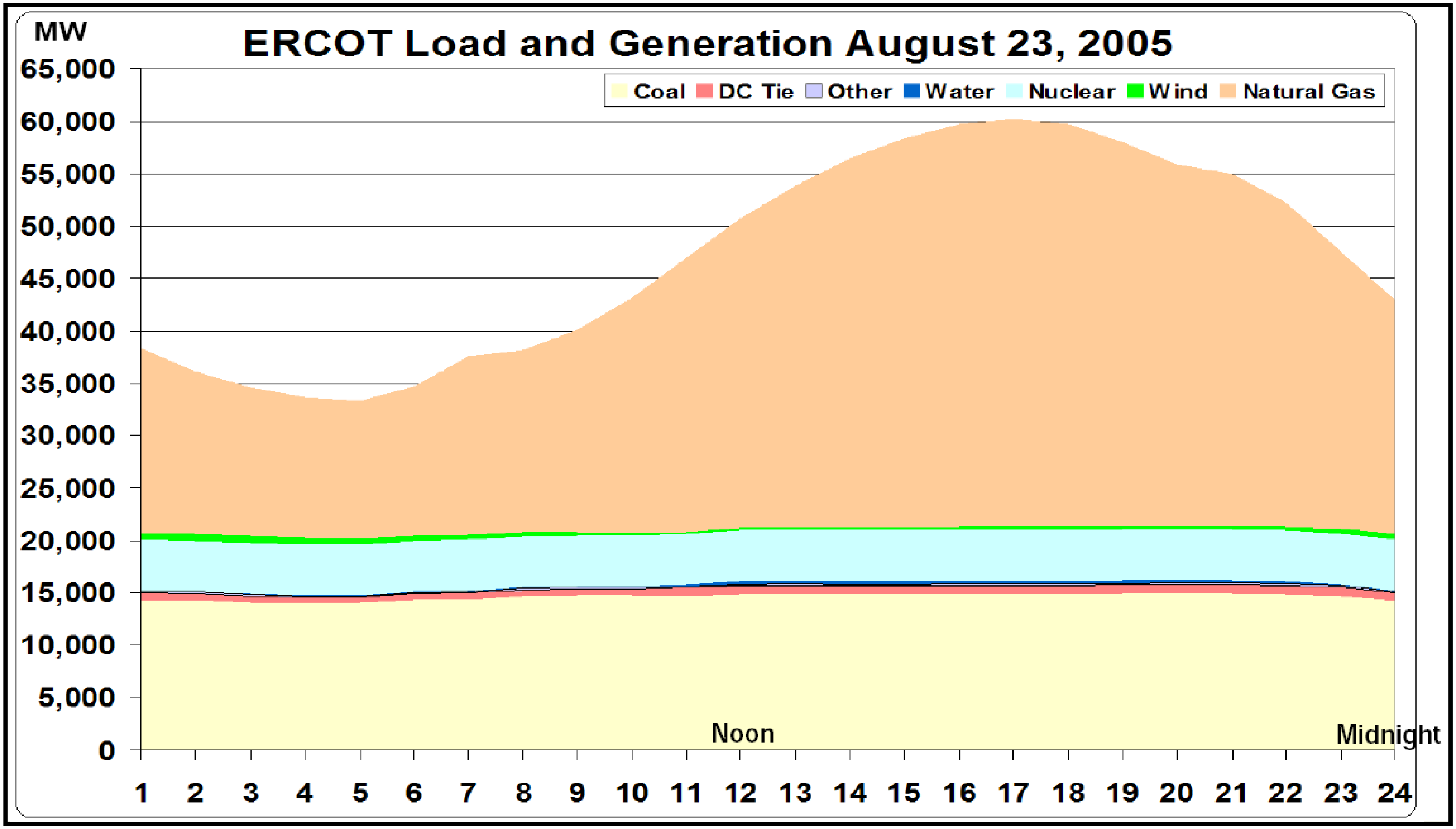
- Conventional efficiency: 40-55%
- Cogeneration efficiencies: 75-85%



Smart Power Grids

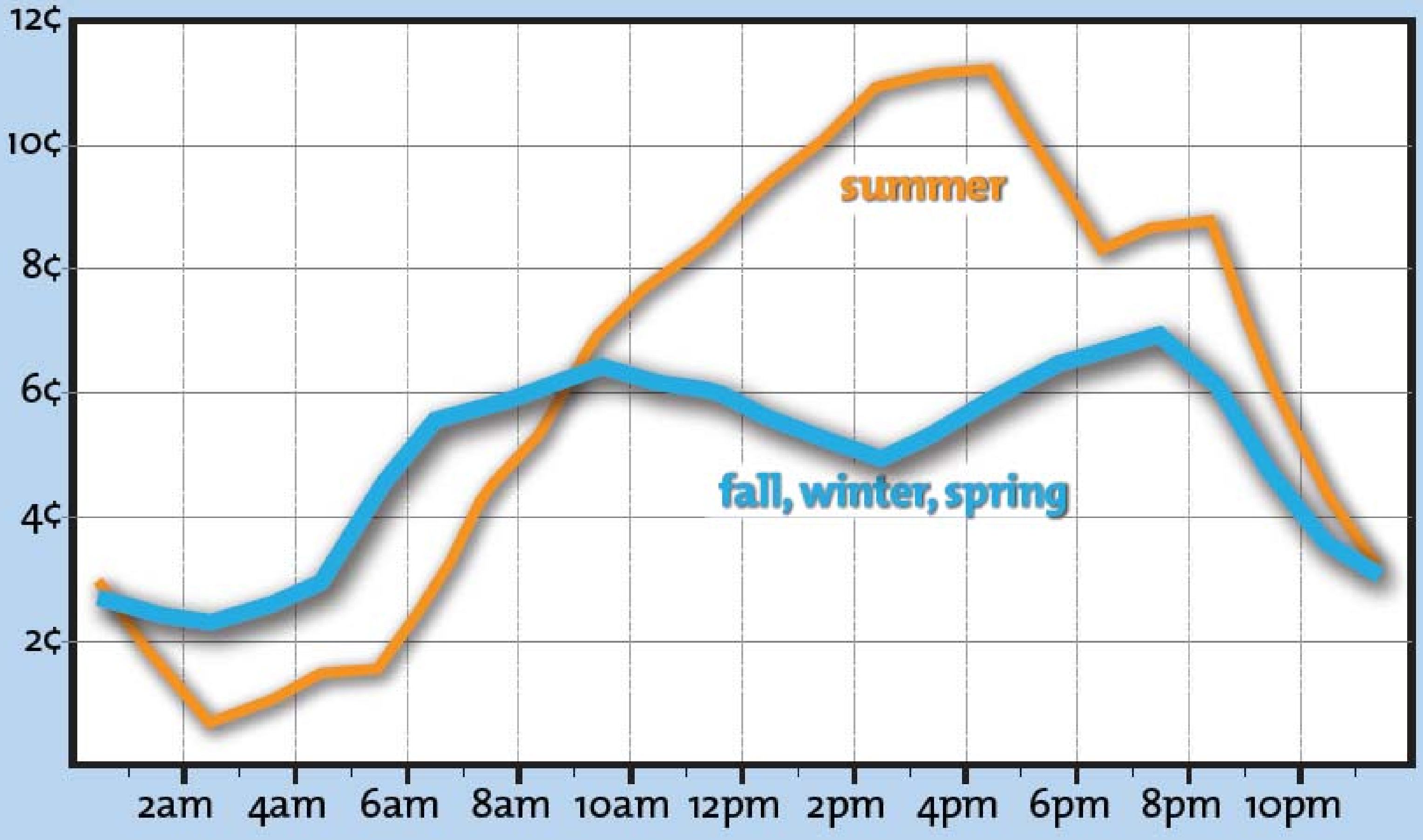
- Delivery of electric power using two-way digital technology and automation with a goal to save energy, reduce cost, and increase reliability.
- Power generated and distributed optimally for a wide range of conditions either centrally or at the customer site, with variable energy pricing based on time of day and power supply/demand.
- Increased use of intermittent renewable power sources such as solar or wind energy but increased need for energy storage.

Electricity Demand Varies throughout the Day



Source: ERCOT Reliability/Resource Update 2006

Average Real-Time Pricing Patterns for 2008*



*Summer prices are for June - August. Depending on market conditions, prices can vary signficantly from this typical pattern. Savings cannot be guaranteed.

Future Industrial Environment

- Stronger focus on energy use(corporate energy czars?)
- Increased energy efficiency and decreased carbon footprint
- Energy use measured and optimized for each unit operation
- Increased use of renewable energy(e.g., solar thermal and biomass) and energy storage
- Interface with smart grids and energy storage

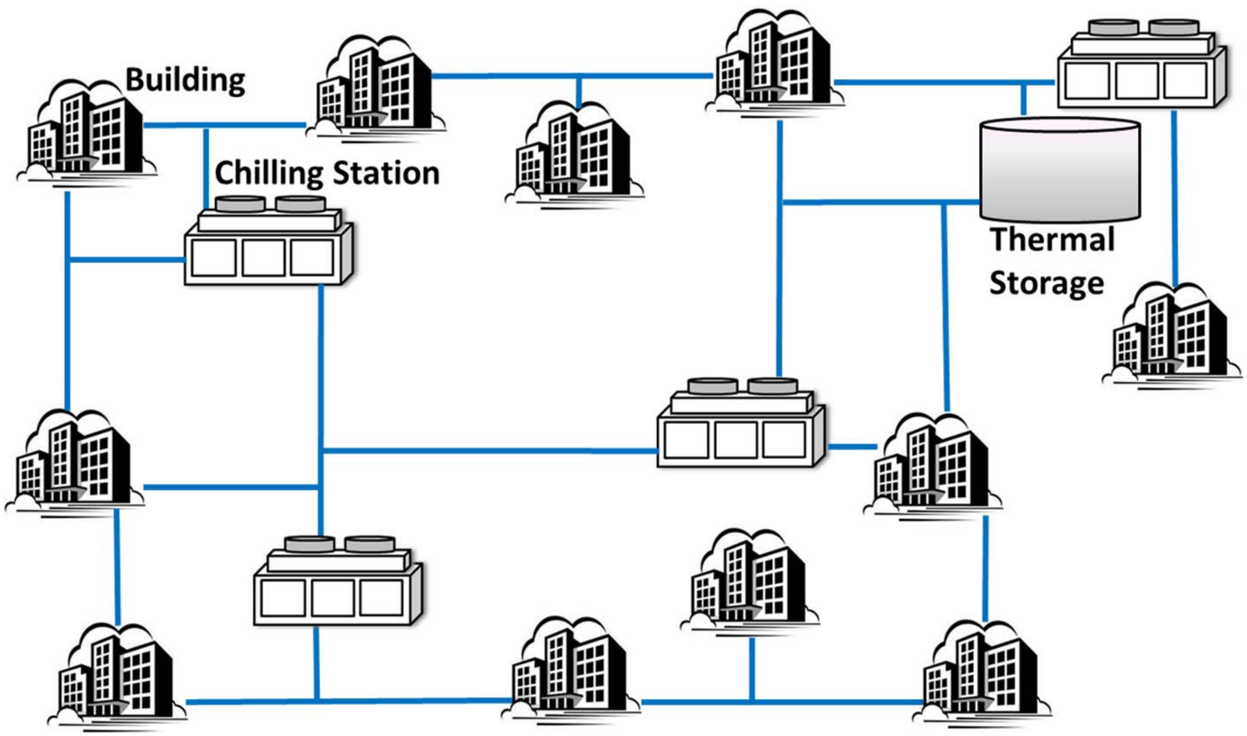
"FIRST, THE GOOD NEWS: WE'VE SHUT DOWN THE COAL-FIRED ELECTRIC POWER PLANT IN YOUR BACKYARD..."

Thermal Energy Storage

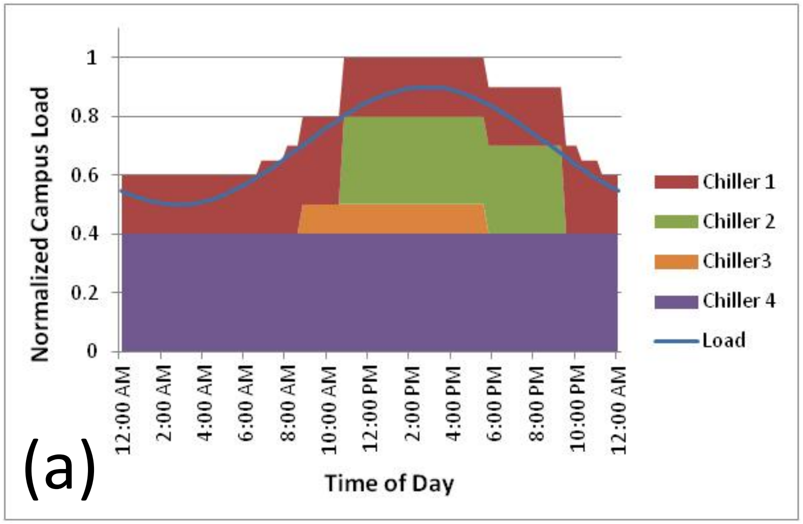
- Thermal energy storage (TES) systems heat or cool a storage medium and then use that hot or cold medium for heat transfer at a later point in time (steam, water, ice).
- Using thermal storage can reduce the size and initial cost of heating/cooling systems, lower energy costs, and reduce maintenance costs. If electricity costs more during the day than at night, thermal storage systems can reduce utility bills further.
- Incentive for thermal storage (NY Con Edison) for building or industrial users: $2,600/KW vs. $2,100/KW for battery storage

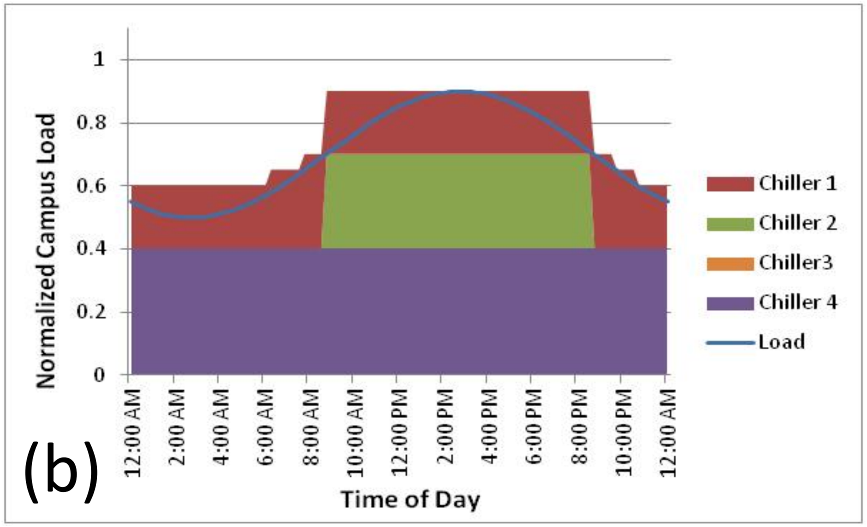
District Cooling

- Chilled water network
- Economy of scale
  - Centralized chillers
  - Thermal energy storage
- Opportunity for optimal chiller loading



Thermal Energy Storage Operating Strategy with Four Chillers





-Chillers 1& 4 are most efficient, 3 is least efficient

-Chiller 1 is variable frequency

(a) Experience-based (operator-initiated)

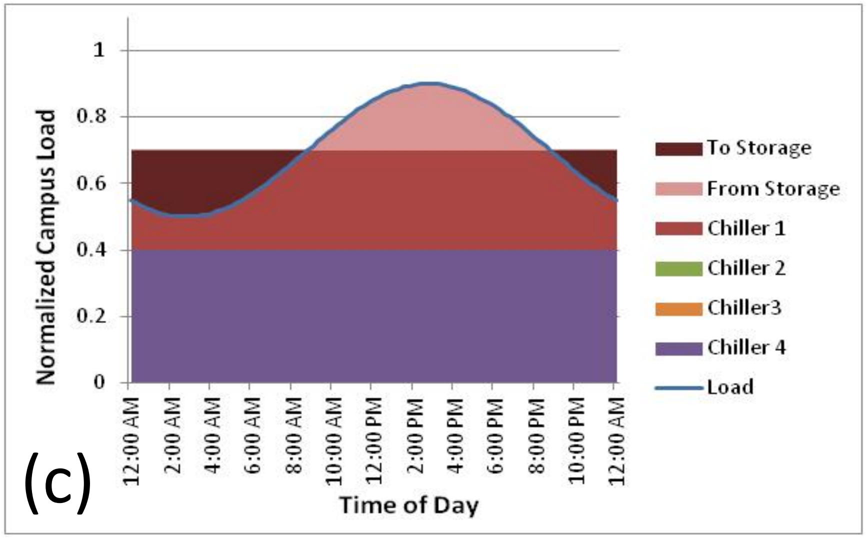
- -No load forecasting
- -Uses least efficient chiller (Chiller 3)

(b) Load forecasting + optimization

- -Uses most efficient chillers (avoids Chiller 3)

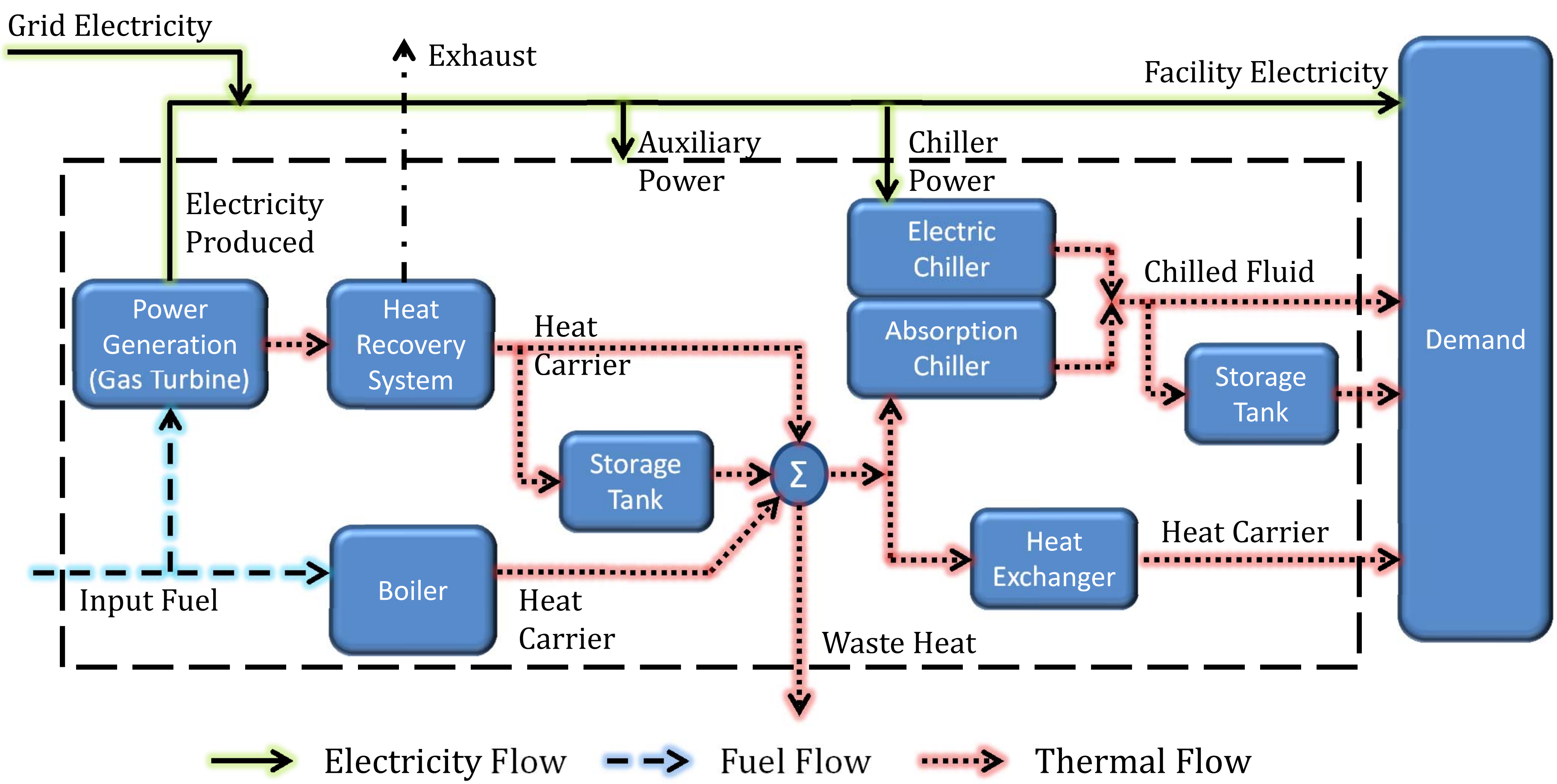
(c) Load forecasting + TES + optimization

- -Uses only two most efficient chillers



CHP Energy and CO_2 Savings Potential (10 MW)

	10 MW CHP	10 MW PV	10 MW Wind	Combined Cycle (10 MW Portion)
Annual Capacity Factor	85%	22%	34%	70%
Annual Electricity	74,446 MWh	19,272 MWh	29,784 MWh	61,320 MWh
Annual Energy Savings	308,100 MMBtu	196,462 MMBtu	303,623 MMBtu	154,649 MMBtu
Annual CO_2 Savings	42,751 Tons	17,887 Tons	27,644 Tons	28,172 Tons
Annual NOx Savings	59.4 Tons	16.2 Tons	24.9 Tons	39.3 Tons

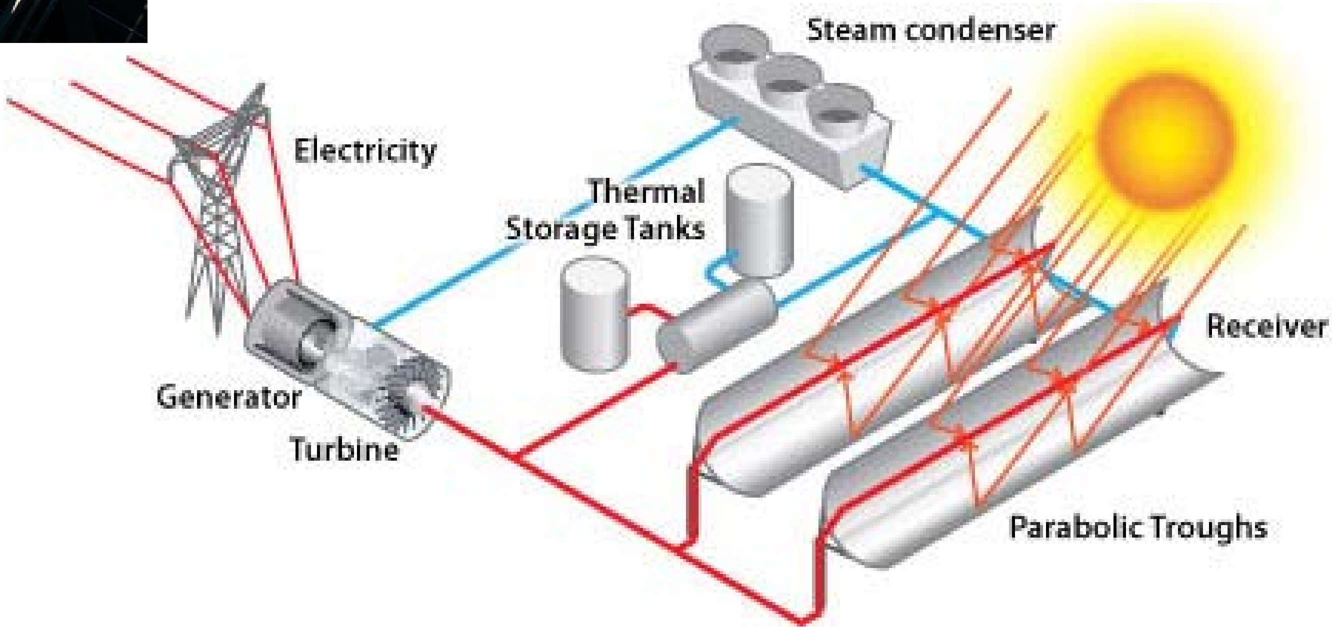


Energy flows in a combined heat and power system with thermal storage

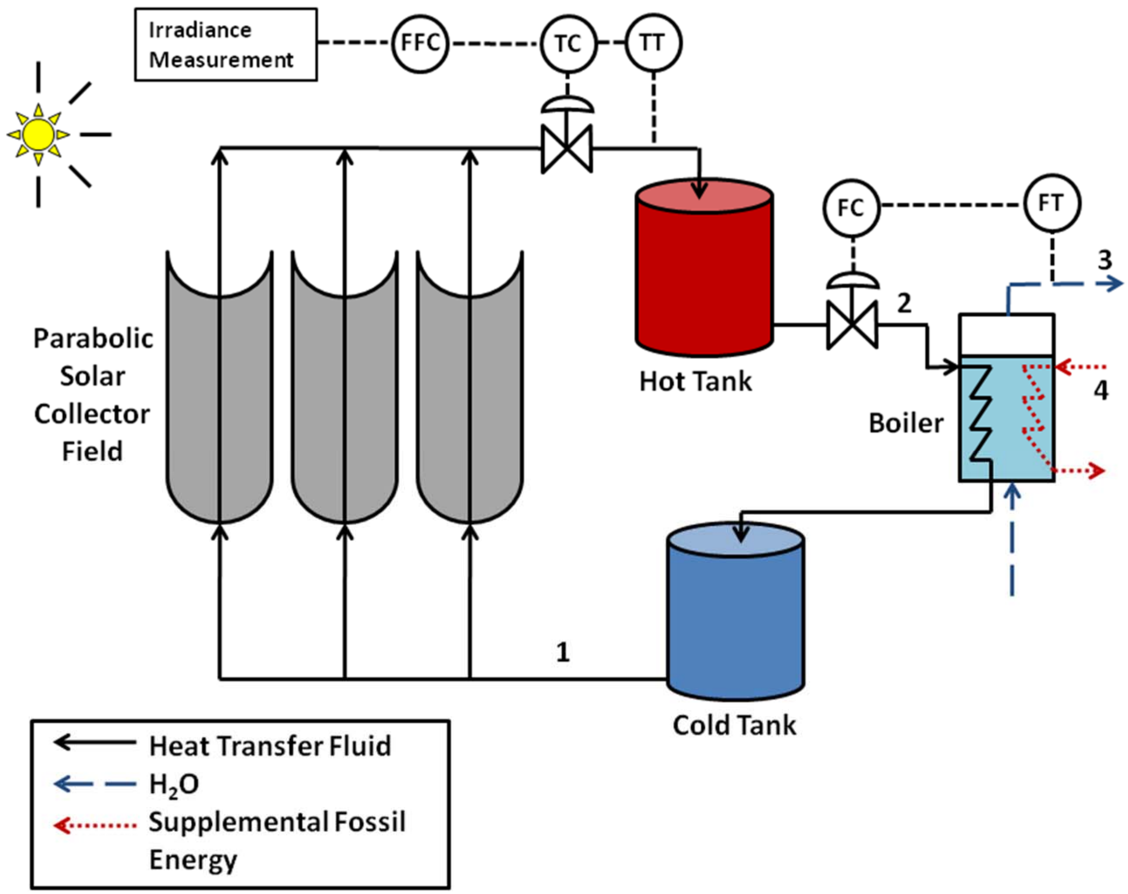
TES with Concentrated Solar Power (CSP)

- CSP technologies concentrate sunlight to heat a fluid and run a generator

- By coupling CSP with TES, we can better control when the electricity is produced

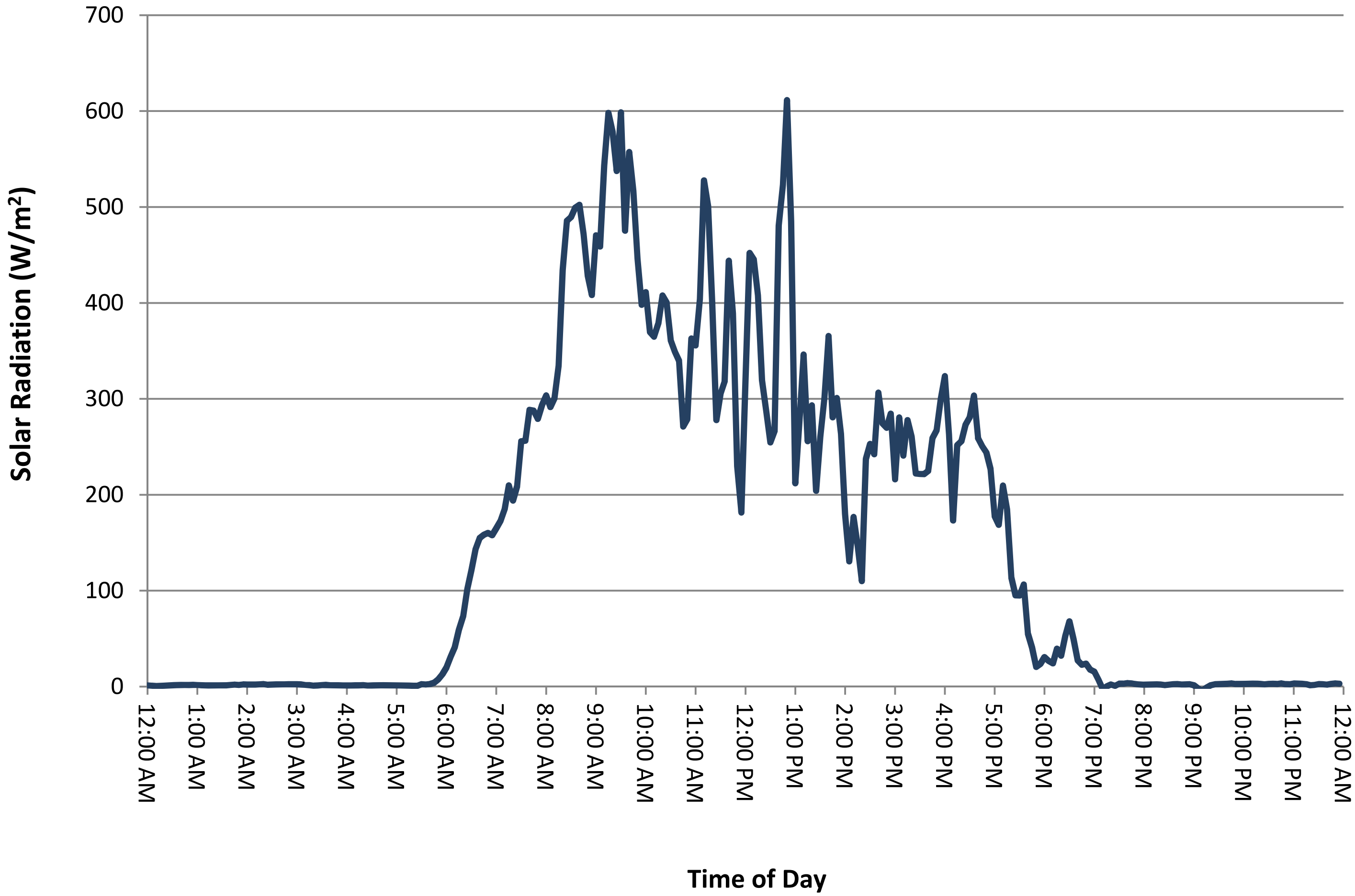


Control Strategy

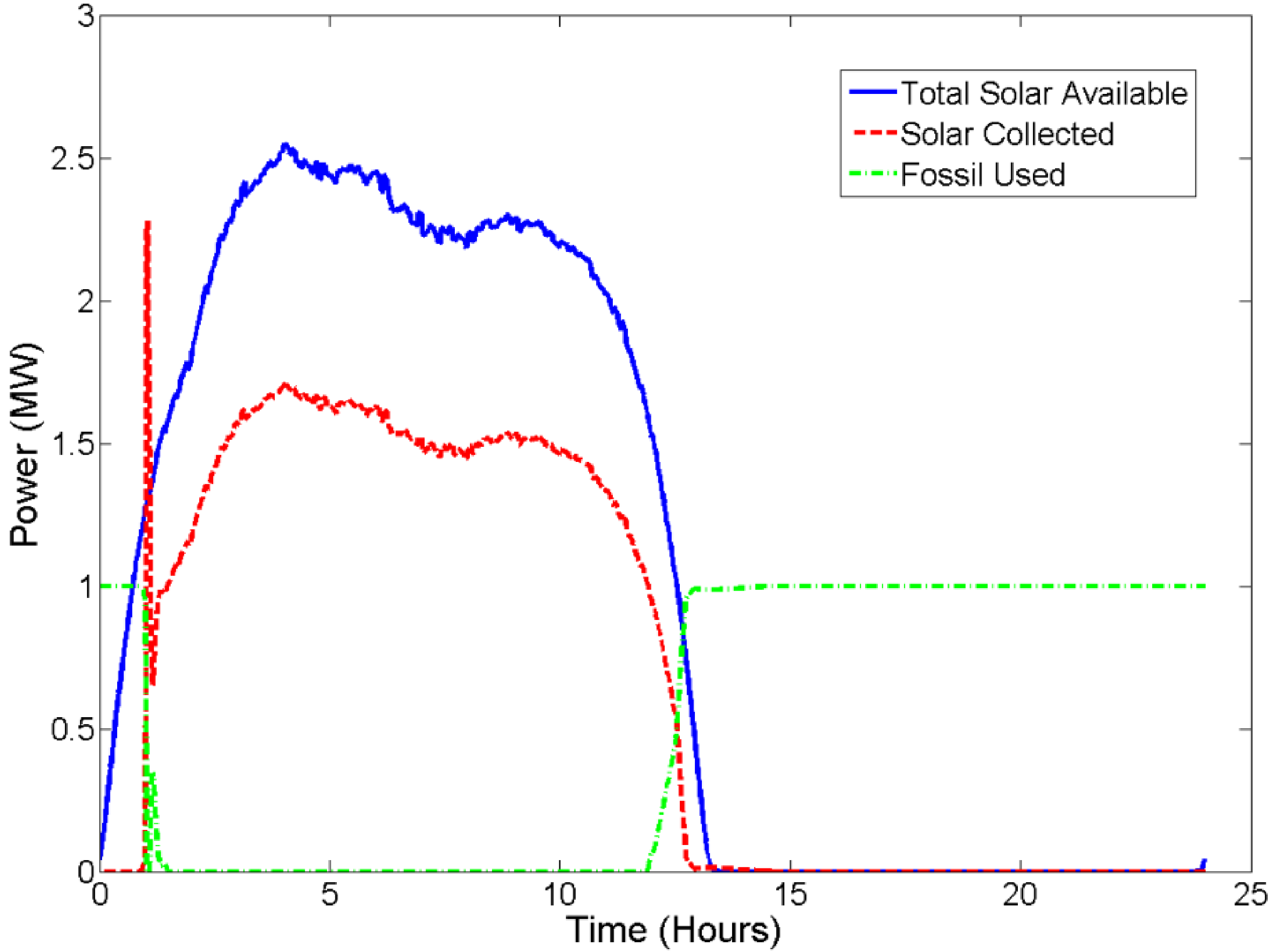


- Feedforward + Feedback (PID) temperature control
  - Uses FF measurements of solar irradiance
  - Flow rate of stream 1 is manipulated variable
- Feedback control (PID) used for steam flow (power) control
- Supplemental gas used when solar energy is not sufficient (stream 4)

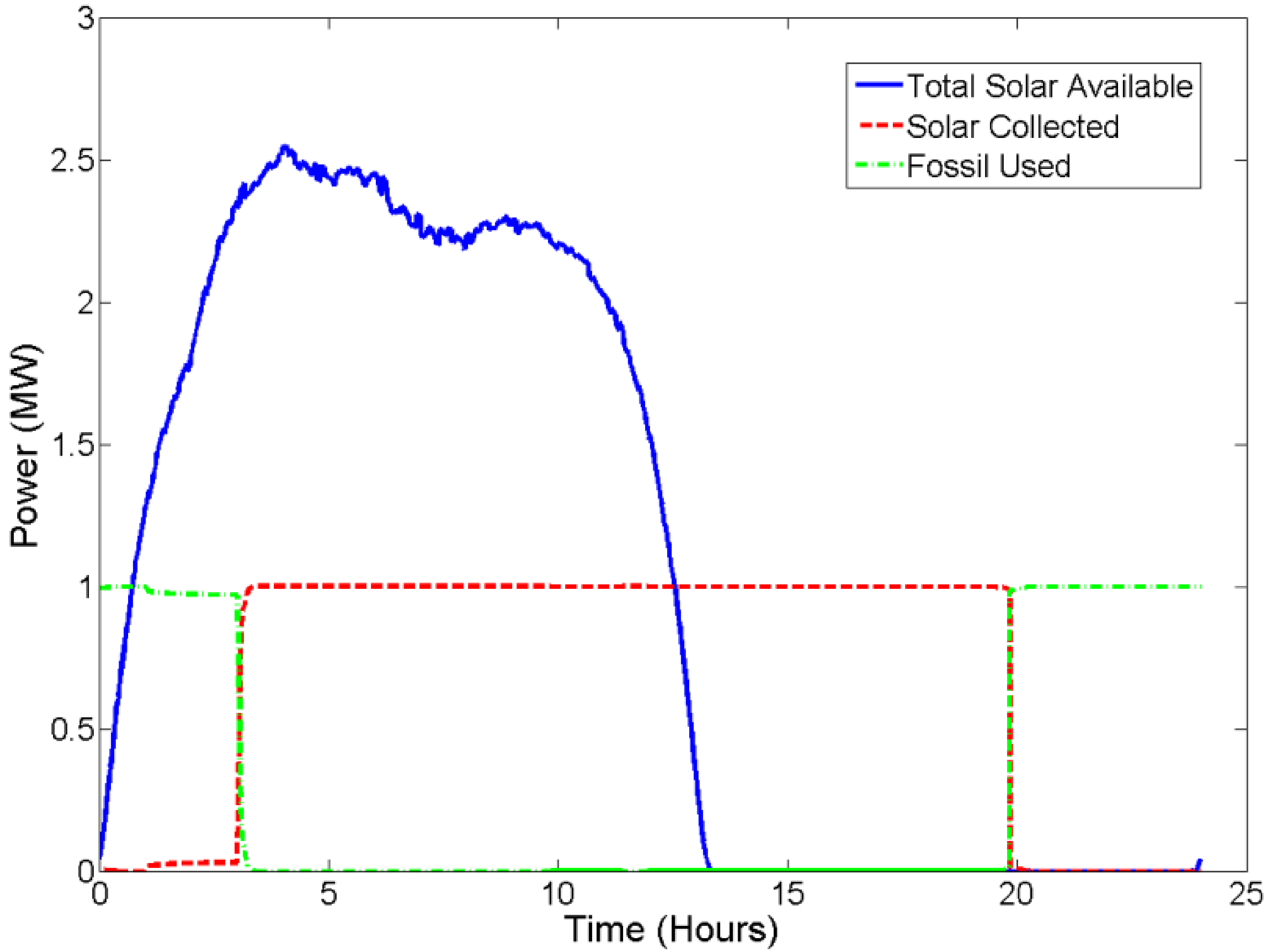
Solar Energy and the Need for Storage



Results: Sunny Day, System without Storage (No Power Control)



Results: Sunny Day, System with Storage and Power Control



Summary of Results

	Sunny Day: System without Storage	Sunny Day: System with Storage	Cloudy Day: System without Storage	Cloudy Day: System with Storage
Solar Energy Delivered to Load	16.48	16.82	8.40	8.49
Supplemental Fuel Required (MWh)	12.58	7.18	15.78	15.51
Solar Share	47.6%	70.1%	34.3%	35.4%

- Solar Share increased by 47% on sunny day, 3% on Cloudy day
- Power quality much better with storage
- Dynamic optimization with weather forecasts can further improve solar share

Minimization of the nonrenewable energy consumption in bioethanol production processes using a solar-assisted steam generation system

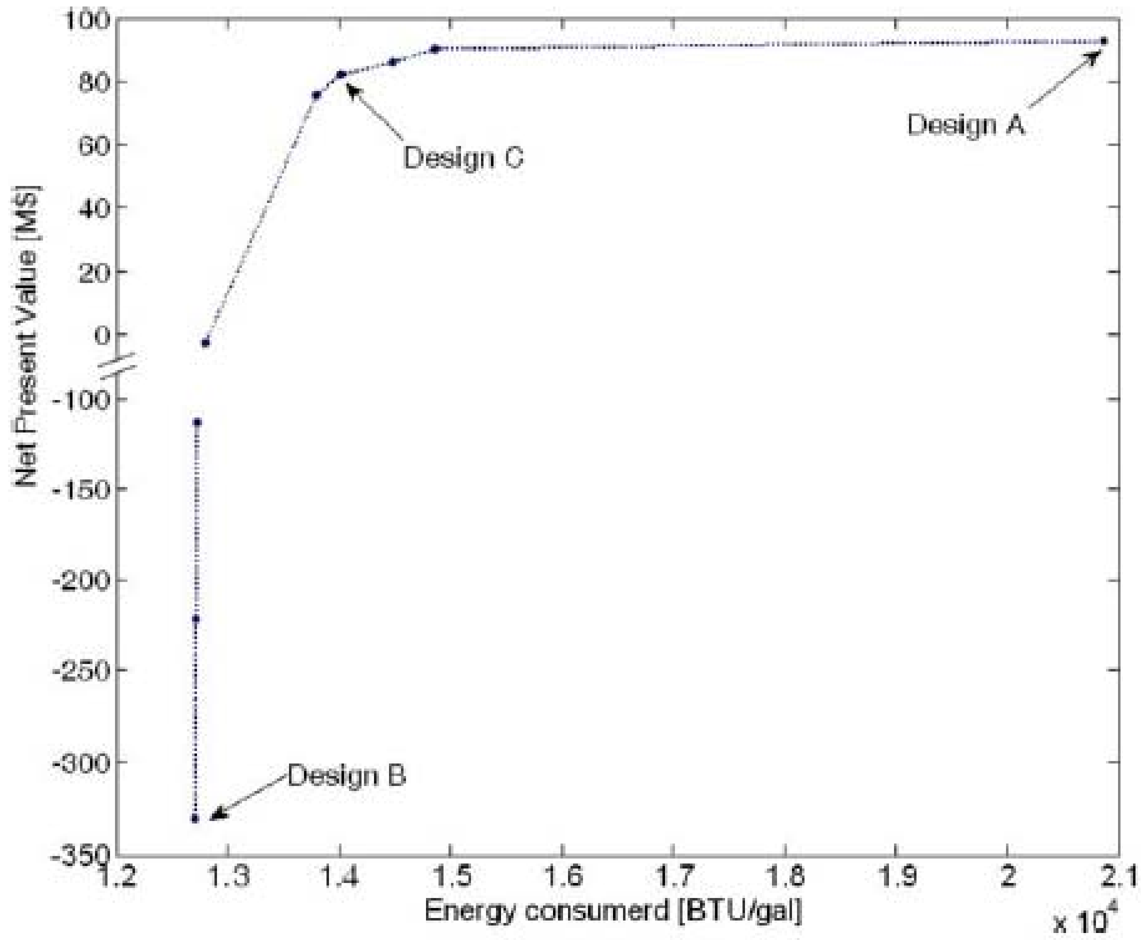


Figure 3. Pareto set of optimal solutions in the bioethanol production plant

AIChE Journal

Brunet, Robert, Gonzalo Guillén-Gosálbez, and Laureano Jiménez. "Minimization of the nonrenewable energy consumption in bioethanol production processes using a solar-assisted steam generation system." *AIChE Journal* 60.2 (2014): 500-506.

Table 5. Economic and Energetic Summary of the Bioethanol Process

Item	Design A	Design B	Design C
Net Present Value ($)	92,752,281	−328,817,003	75,610,887
Energy consumed (Btu/gal)	20,968	12,838	13,903
Total Capital Investment ($)	37,159,397	316,441,020	44,862,192
Operating Cost ($/yr)	63,021,995	79,893,062	62,606,124
Production Rate (kg/ yr)	119,171,463	119,171,463	119,171,463
Unit Production Cost ($/kg)	0.67	1.12	0.68
Unit Selling Price ($/kg)	0.69	0.69	0.69
Total revenues($)	81,826,000	81,826,000	81,826,000
Area solar panels (m^2)	0	5,430,794	71,053
Natural gas consumed (kg/yr)	22,066,980	10,570,180	12,102,040

AIChE Journal

Brunet, Robert, Gonzalo Guillén-Gosálbez, and Laureano Jiménez. "Minimization of the nonrenewable energy consumption in bioethanol production processes using a solar-assisted steam generation system." *AIChE Journal* 60.2 (2014): 500-506.

Conclusions

- Many opportunities to improve energy efficiency in the process industries
- Energy efficiency ≡ sustainability (carbon footprint)
- Smart grids, cogeneration will change the power environment for manufacturing
- Energy storage plus PSE tools will be critical technologies to deal with this dynamic environment
- A focus on energy comparable to the current emphasis on safety would yield significant improvements in energy efficiency.