

Decision Models for Bulk Energy Transportation Networks

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→ Computational modeling:

- integrated fuel, electricity networks
- environmental impacts
- electricity commodity markets
- behavior of market traders
- uncertainty in demand & fuel price
- participatory research and modeling

→ Link structure & decision-making

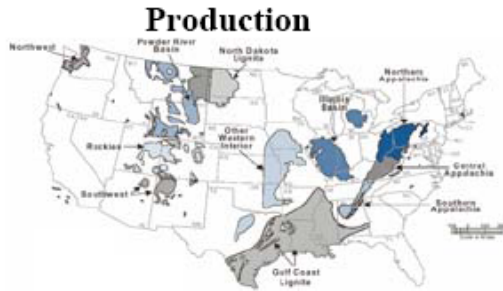
→ Bridge separate fields: Power Engineering, Sociology, Economics, Industrial Engineering

→ Answer energy-related questions
national, regional, local significance

www.econ.iastate.edu/tesfatsi/nsfenergy2005.htm

Aggregated Topologies

Coal Subsystem



Transportation & Storage



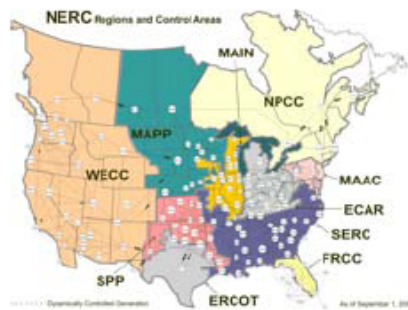
Aggregated Model



Gas Subsystem



Electric Subsystem



Overall Objectives of the Study

National Scale (federal government, NERC):

- (1) Possible improvements in energy flow patterns
- (2) Effects of catastrophic events and detection of infrastructure weaknesses
- (3) Infrastructure enhancements to improve performance
- (4) Effects of environmental regulations on energy system performance

Regional Scale (regional independent system operator):

- (1) Effects of market design on market performance
- (2) Sensitivity of market performance to system shocks
- (3) Potential improvements in market design

Local Scale (local electric utility company):

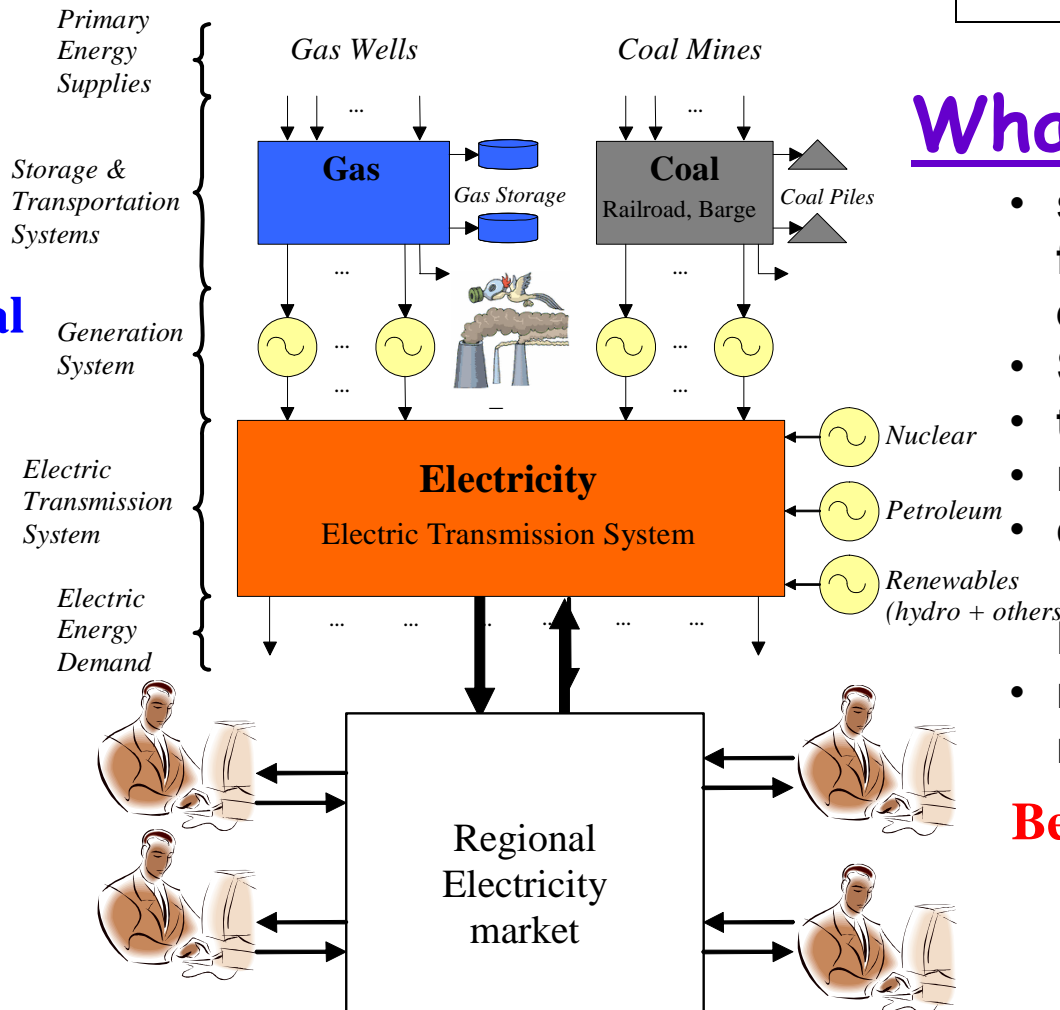
- (1) Effects of changes in raw fuel production and transportation on the returns from investing in specific types of plants at specific locations
- (2) Response of energy buyers and sellers to potential new policies designed to improve transparency and ease of trade

What is modeled

- Gas wells & pipelines
- Coal mines & rail/barges
- Storage
- Electricity market
- Electric gen & trans
- Costs, capacities
- SO2 constraints
- Market traders

Decision Models for Bulk Energy Transportation Networks

Structural Model

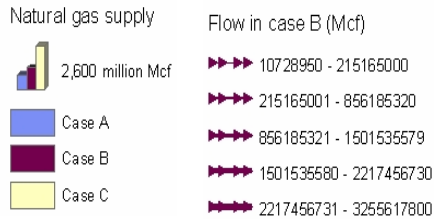
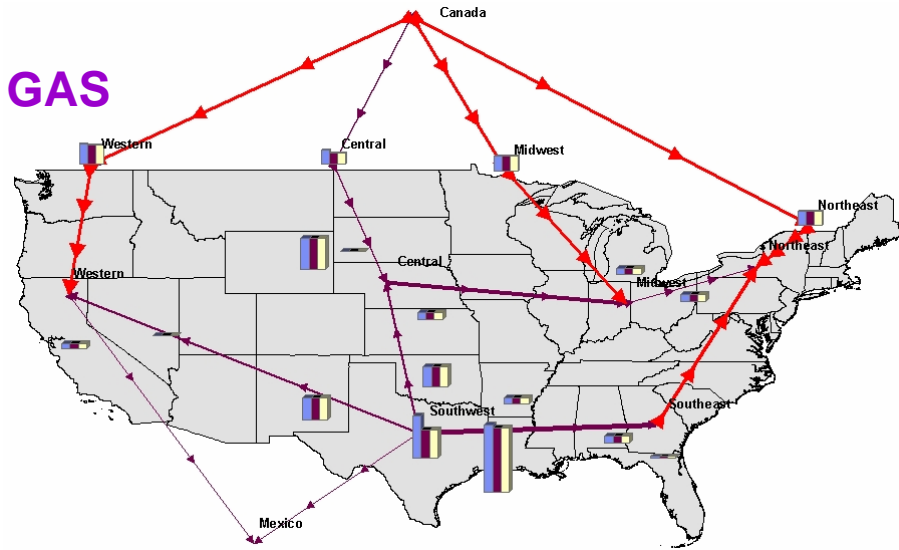


What is computed

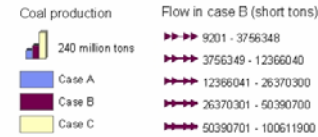
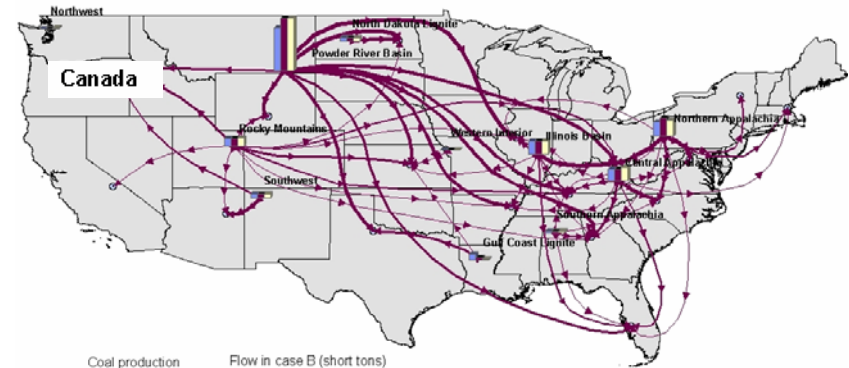
- spatial & temporal energy flows & nodal prices (fuel, electric)
- SO2, allowance price
- total costs
- network attributes
- decision-making of market traders with learning capabilities
- market efficiency and market power outcomes

Behavioral Model

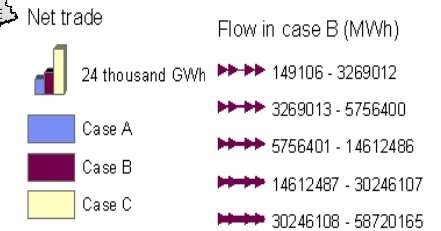
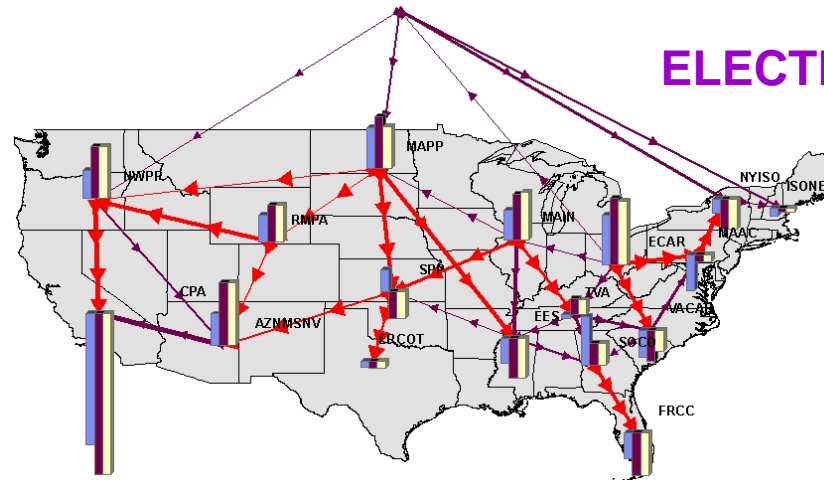
Structural Model: Energy Flows



COAL



ELECTRIC

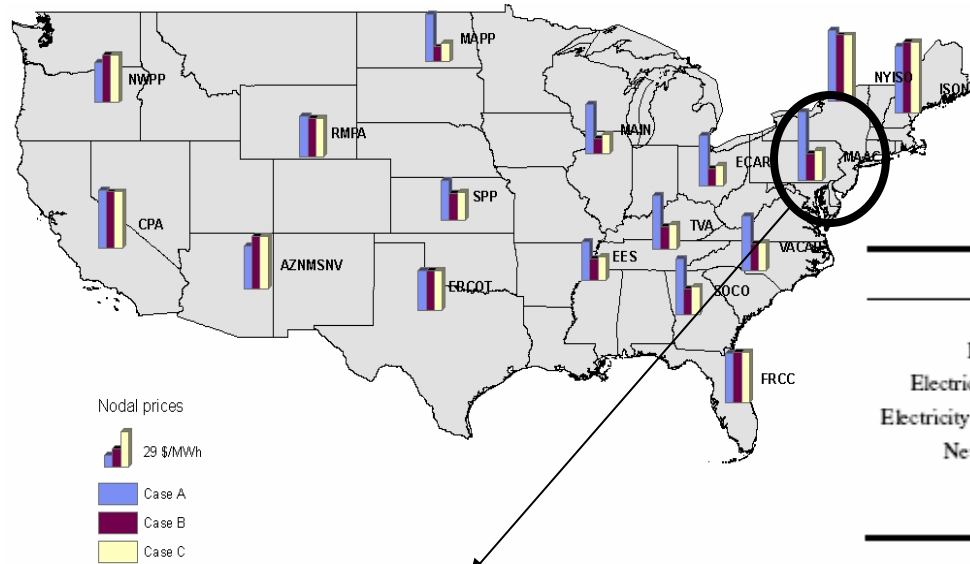


Case A: 2002 reference, actual generation

Case B: Optimized, no emissions constraint

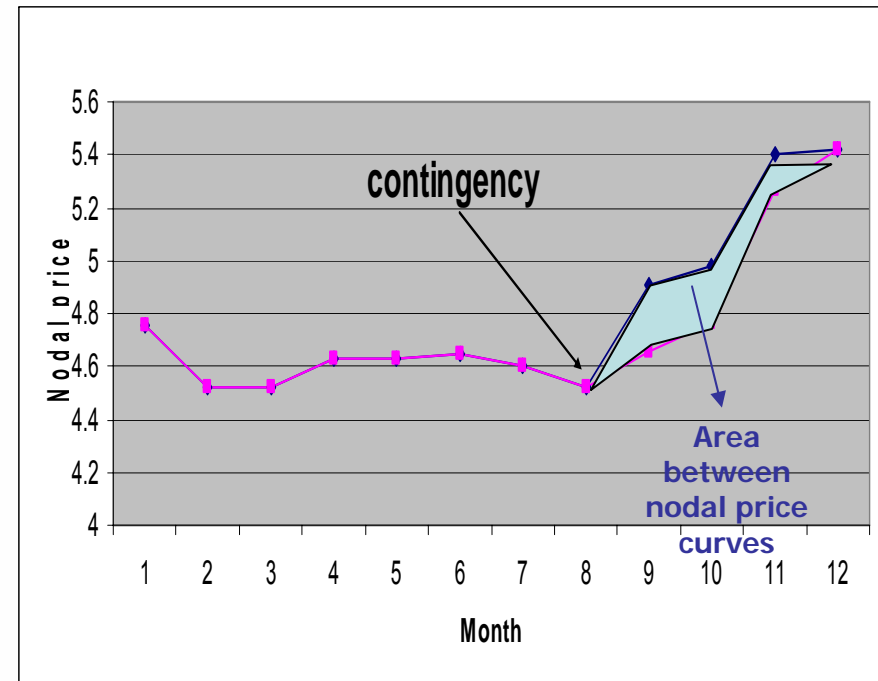
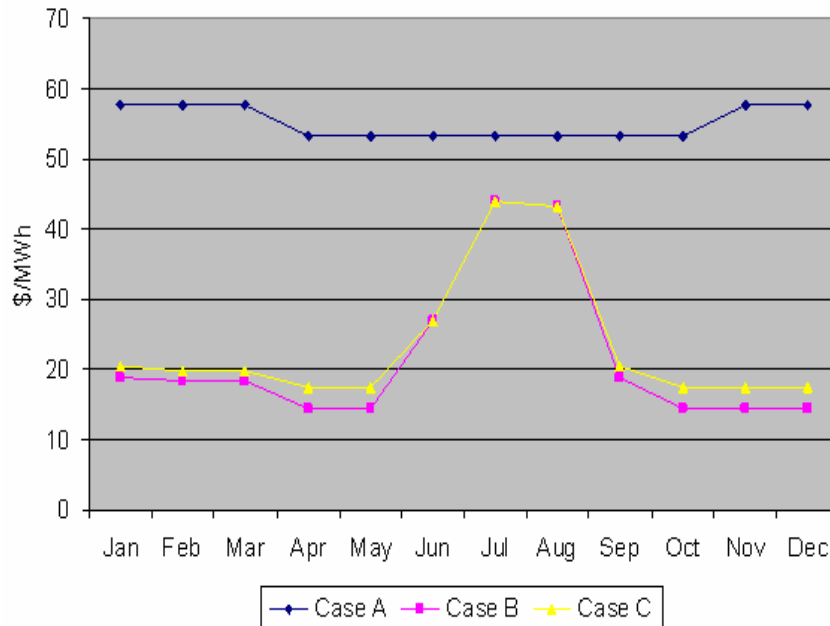
Case C: Optimized, with emissions constraint

Structural Model: Nodal Prices and Reliability

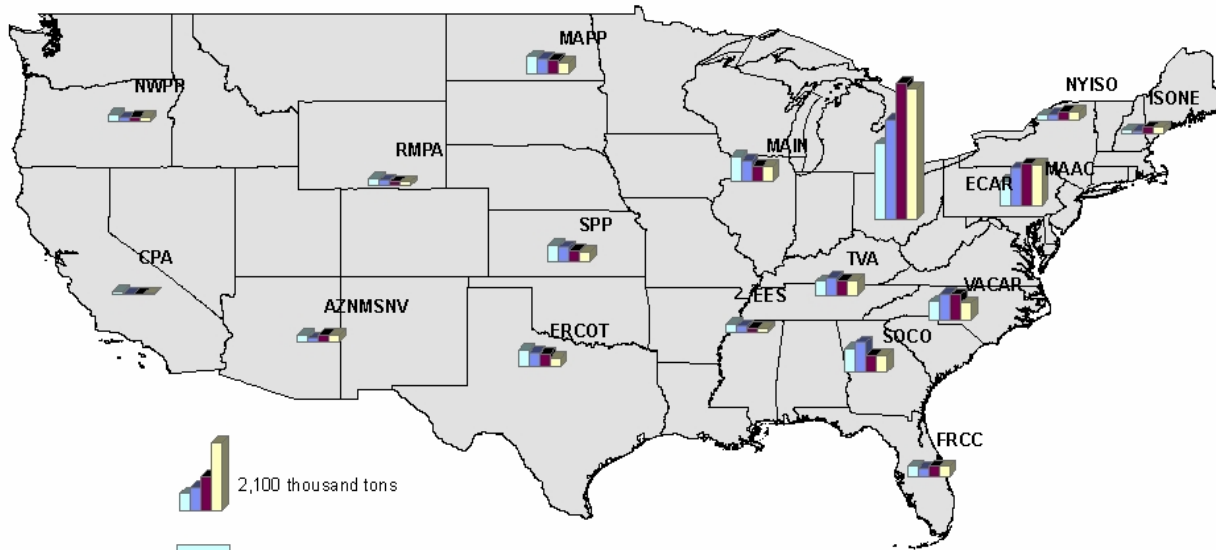


Result	Case A	Case B	Case C
Coal deliveries (million tons)	953	1,054	1,048
Natural gas deliveries (million Mcf)	5,125	3,615	3,615
Electricity generation from coal (thousand GWh)	1,910	2,117	2,116
Electricity generation from natural gas (thousand GWh)	607	414	414
Net electric power trade (thousand GWh)	205	382	367
Allowance price (\$)	98	-----	359
Total costs (billion \$)	101.42	96.89	96.96

MAAC



Structural Model: Environmental Studies

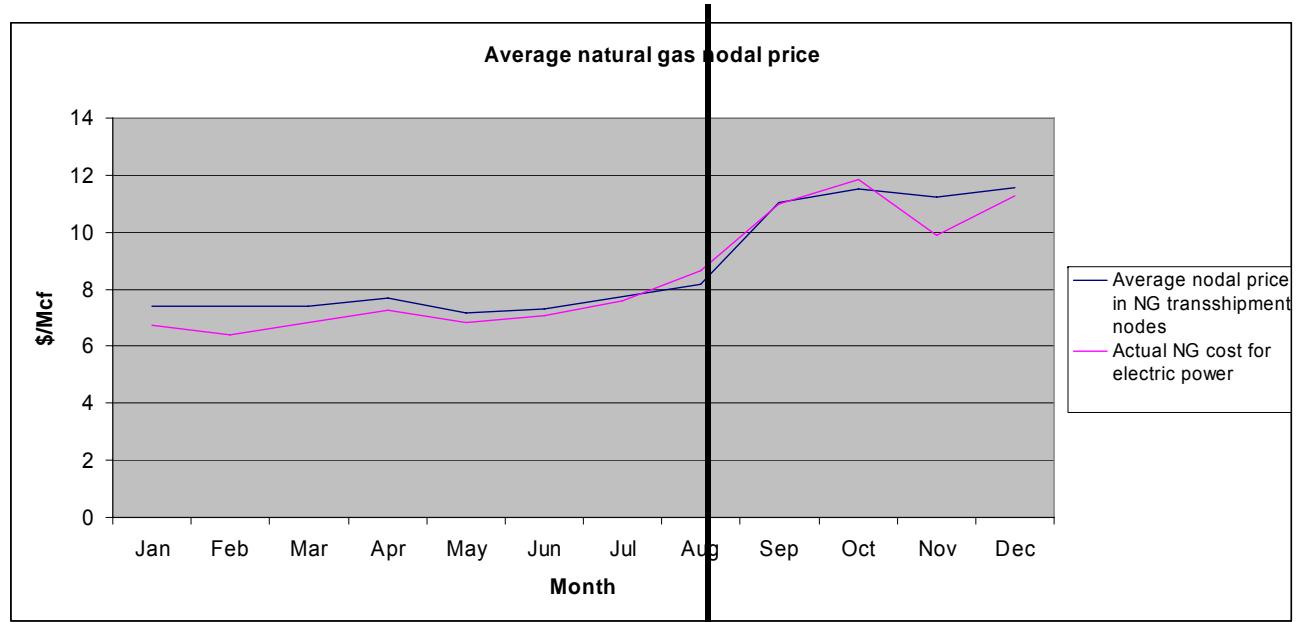


The national limit on emissions is determined by summing the 2002 vintage unit-level emissions allowances allocated in the CAAA and adjusted to account for net banking and trading activities

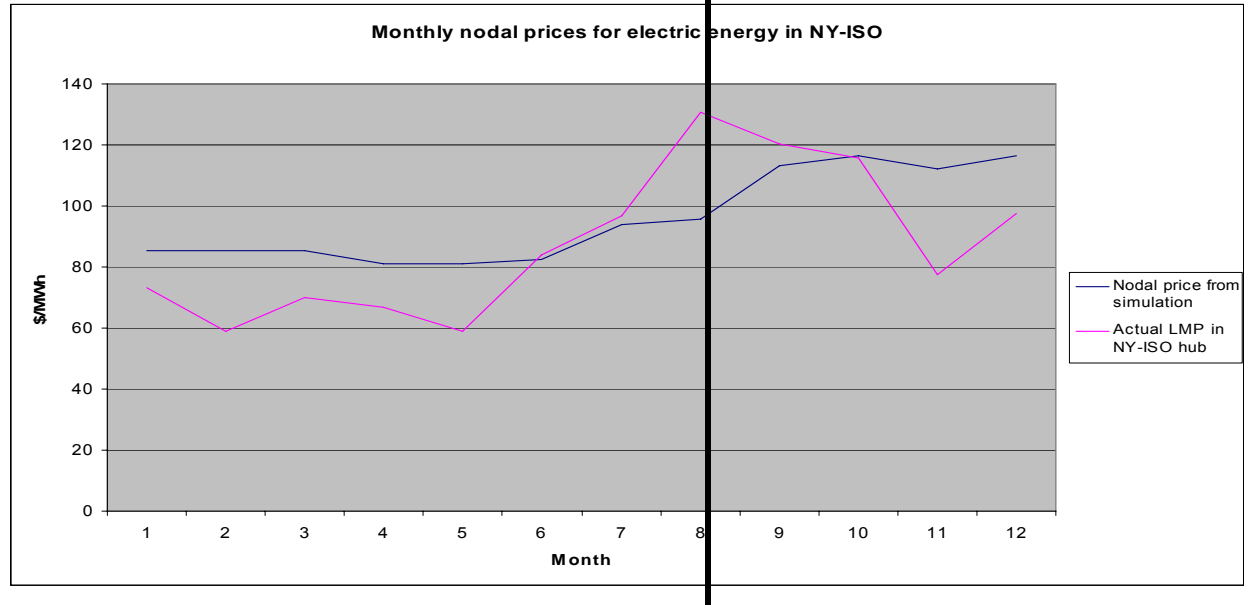
The level of emissions produced depends on the fuel used, pollution control devices installed, and the amount of electricity generated

Structural Model: Effects of Katrina

Comparison of average nodal gas prices from model with actual gas prices during 2005



Comparison of monthly electric prices at NY-ISO from model with actual NY-ISO prices during 2005

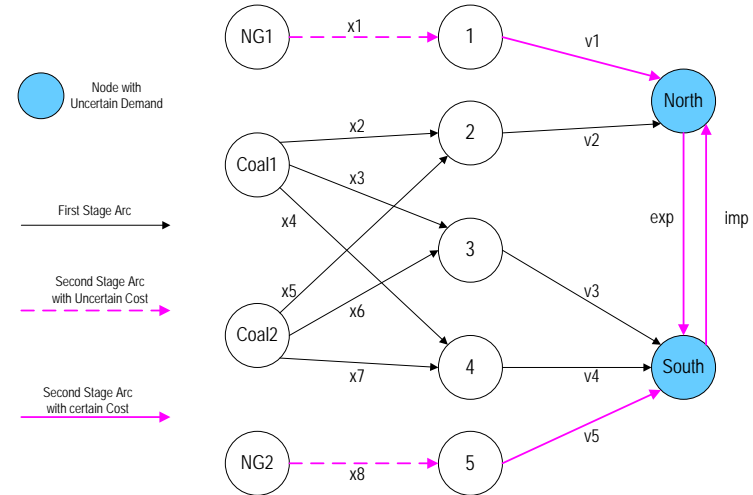


Structural Model: Stochastic generalized network flow

$$\begin{aligned} \min \quad & z = \sum_{t \in T} \sum_{(i,j) \in A} c_{ij}(t) x_{ij}(t) \\ \text{s.t.} \quad & \sum_{(j,k) \in A} x_{jk}(t) - \sum_{(i,j) \in A} r_{ij} x_{ij}(t) = b_j(t) \quad \forall j \in N, \forall t \in T \\ & x_{ij,\min} \leq x_{ij}(t) \leq x_{ij,\max} \quad \forall (i,j) \in A, \forall t \in T \end{aligned}$$

Fuel cost uncertainty: $c_{ij}(t)$ random variable for fuel acquisition arcs

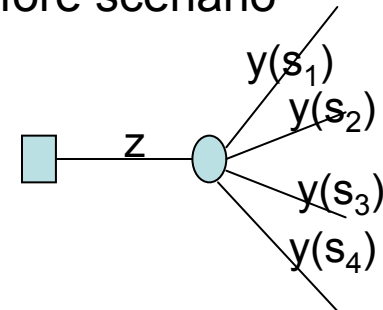
Discrete distributions: define a scenario s for each combination of values, with probability $\pi_s = P(c_{ij}(1) = c_{s1}, c_{ij}(2) = c_{s2}, \dots, c_{ij}(T) = c_{sT})$



Stage 1: Long term coal contracts
Stage 2: Natural gas purchases, generation, transmission

2-stage stochastic recourse model

- Stage 1 decisions z made with knowledge of distributions, before scenario realization:
- Stage 2 decisions y made after scenario realizations known
- Deterministic equivalent $x = (z, y)$ has $y(s)$ for each scenario

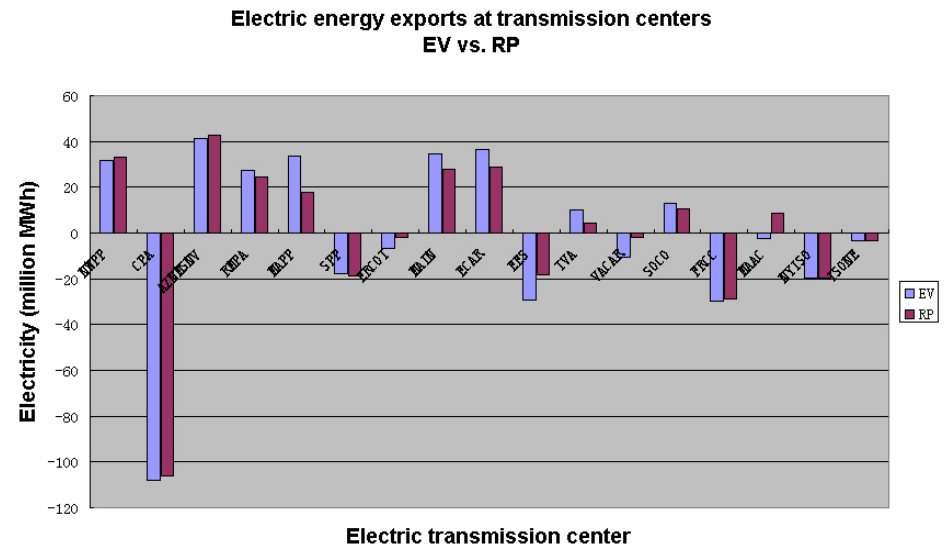
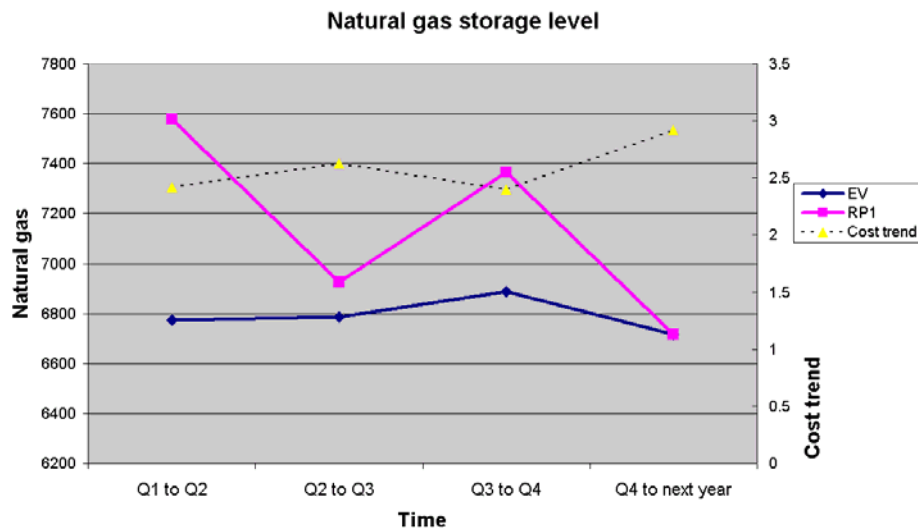


Structural Model: Stochastic Recourse Results

- Wait and See (WS): solve the deterministic problem with actual gas cost
- Expected Value (EV): solve the deterministic problem with expected value of gas costs
- Recourse Problem (RP): solve the stochastic problem with a rolling horizon

Result	Actual	EV	RP
Coal deliveries (million tons)	976	1,071	1,018
Natural gas deliveries (million Mcf)	5,398	3,861	5,011

Generation mix under stochastic costs is more like actual than deterministic optimum!



Behavioral Model: Key Objectives

* Research/teaching/training-grade electricity market test-bed permitting:

- Dynamic testing with learning traders
- Intensive sensitivity experiments
- Full access (free open-source Java code)
- Easy modification (extensible/modular architecture)
- **Integration with structural model**

* Targeted Users

- **Academic researchers** (qualitative understanding)
- **Industry stakeholders** (learn rules, test business strategies)
- **Policy makers** (efficient and reliable market design)

Behavioral Model: Background

- In April 2003, U.S. FERC proposed a **Wholesale Power Market Platform (WPMP)** for common adoption by all U.S. wholesale power markets
- About 50% of electric power generating capacity in the U.S. is now operating under some version of the WPMP market design (e.g. ISO-NE, MISO, PJM, NYISO, CAISO)

Initial Goal Accomplished: Development of an agent-based test bed (“AMES”) for dynamic wholesale power markets operating under core features of the WPMP market design

AMES = Agent-based Modeling of Electricity Systems
www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

AMES Market Test Bed

- ★ JReLM learning module
- ★ DC-OPF solver module
- ★ Working dynamic wholesale power market model

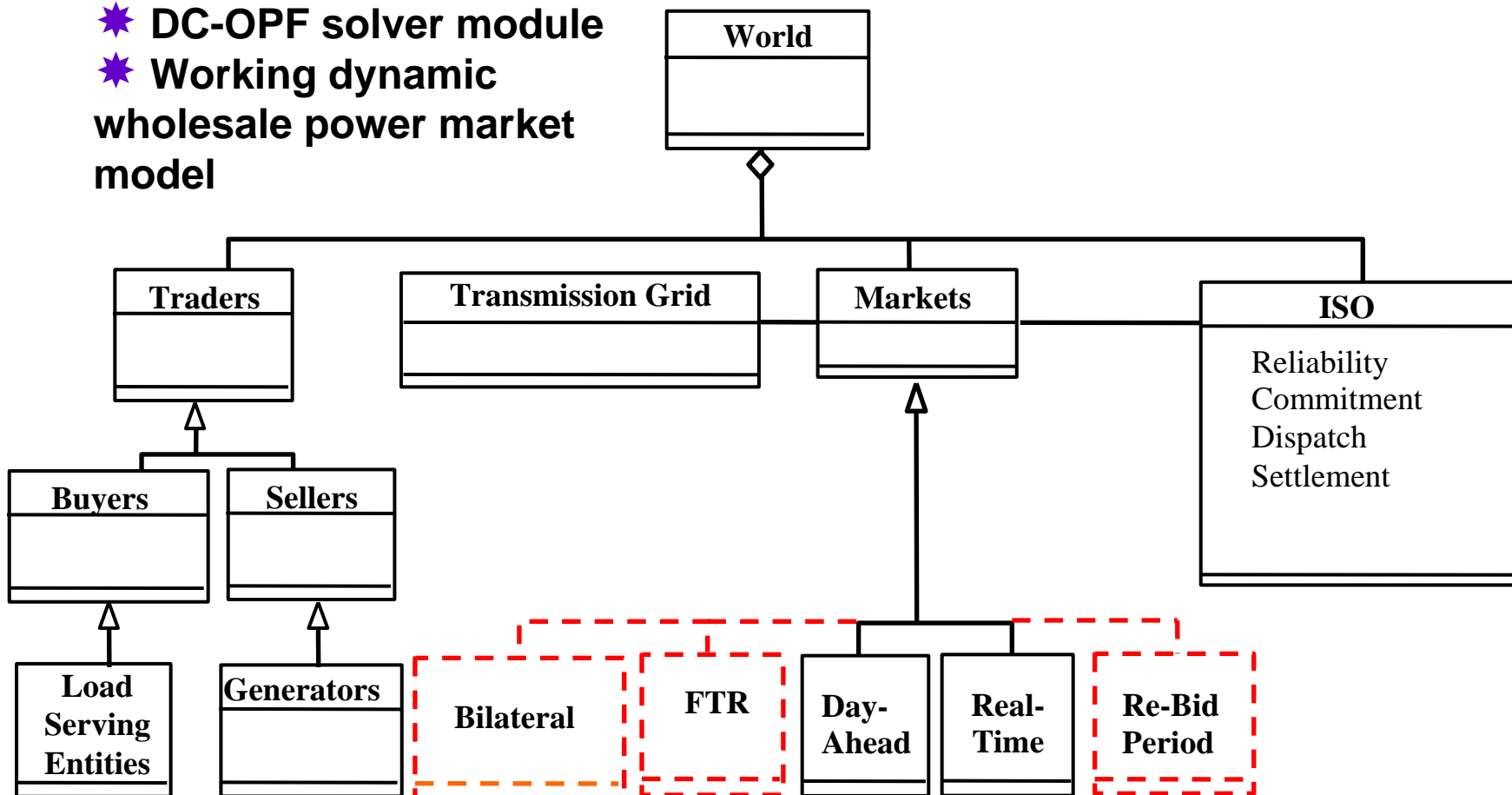
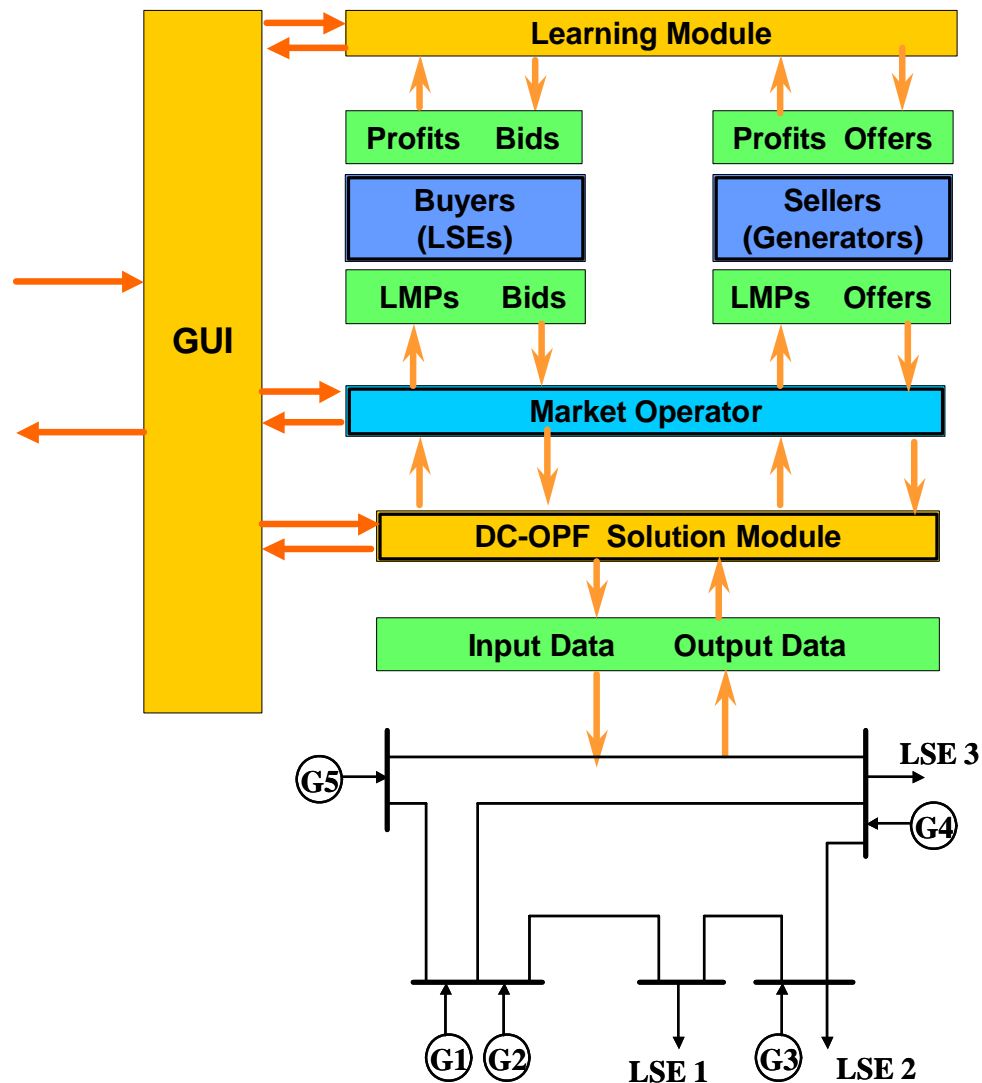
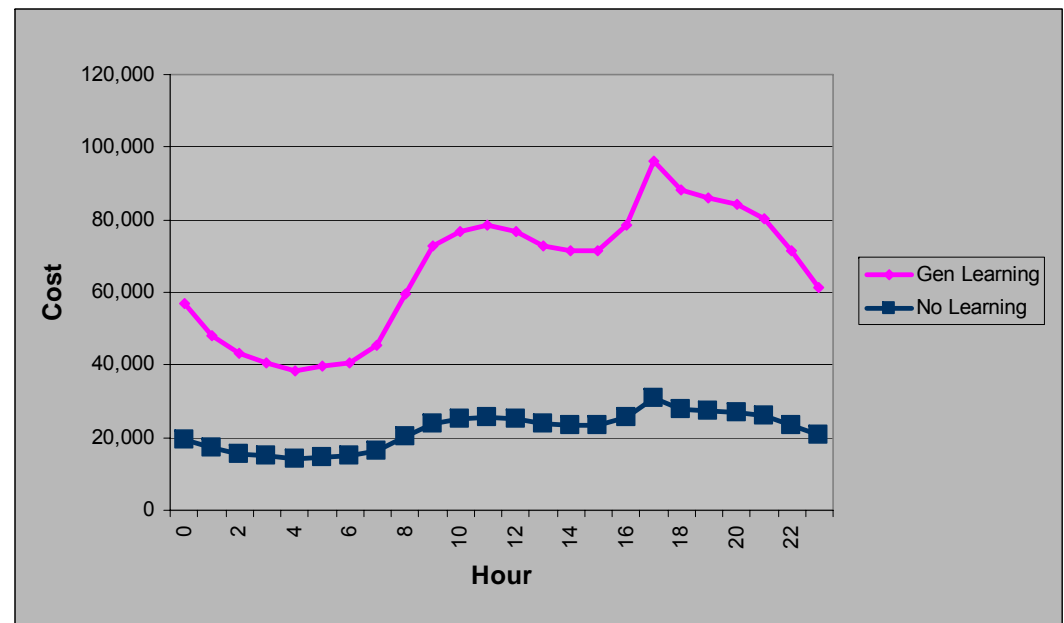
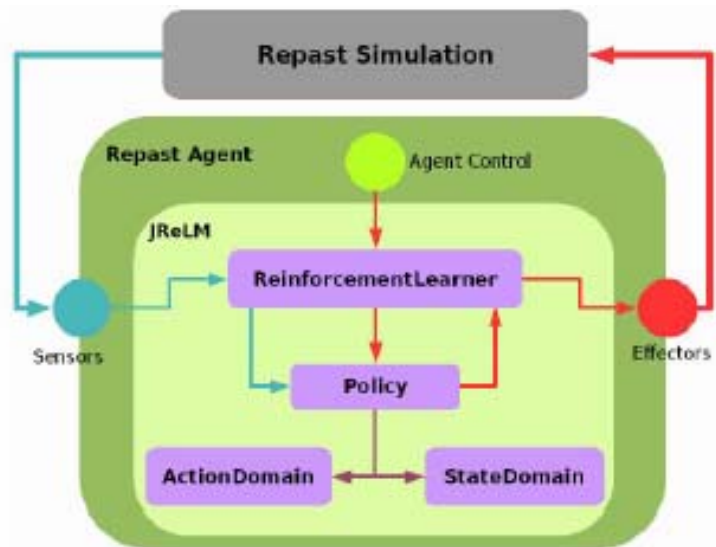


Illustration of Interactions in AMES: (No-Shock 5-Node Test Case)



Trader Learning in AMES

Trader learning and decision-making are implemented in AMES by means of a Java reinforcement learning module (JReLM) that incorporates insights from human-subject experiments and that permits a flexible representation of human learning and decision-making.



Potential Acceptance and Efficacy of New Policies for Energy Trade

Research Question: How might buyers & sellers of energy respond to potential new policies and market design features introduced to improve transparency and ease of trade?

Methodology: Acceptance of selected potential policies suggested by industry, government, and academic organizations to improve the transparency and ease of trade will be evaluated using both computational and human-subject laboratory experiments. Policy options will be integrated within simulated gaming experiments to determine the extent to which traders recognize the benefits of pursuing these policies for personal as well as social goals. Experiments might also reveal unanticipated costs and benefits of proposed policies.

Anticipated Products: Empirical and test-bed evaluations of the efficacy of policies aimed at maximizing net social benefits from market-based energy trading.

Public Acceptance of Additional High Voltage Line Construction

Research Questions: How might the public respond to plans to build additional high voltage transmission lines in designated national corridors?

Methodology: 1) Surveys of the general public to ascertain their responses to potential issues related to health concerns, environmental concerns, and state-level control over the routing of lines. These surveys also will assess the effect of the source of power generation (e.g., fossil fuels, wind power, nuclear) on public perceptions of transmission capacity building. 2) Face-to-face interviews with persons who attend scheduled public forums to discuss the building and operation of additional high voltage lines.

Anticipated Products: Empirical evaluation of potential public responses and the key determinants of these responses.

Publications

1. Ana Quelhas, Esteban Gil, James D. McCalley, and Sarah M. Ryan, **A Multiperiod Generalized Network Flow Model of the U.S Integrated Energy System: Part I - Model Description**, *IEEE Transactions on Power Systems*, Volume 22, Issue 2, May 2007, pp 829 - 836.
2. Ana Quelhas and James D. McCalley, **A Multiperiod Generalized Network Flow Model of the U.S Integrated Energy System: Part II - Simulation Results**, *IEEE Transactions on Power Systems*, Volume 22, Issue 2, May 2007 Page(s):837 - 844.
3. Junjie Sun and Leigh Tesfatsion, **"Dynamic Testing of Wholesale Power Market Designs: An Open-Source Agent-Based Framework,"** to appear in *Computational Economics*, 2008.
4. Junjie Sun and Leigh Tesfatsion, **DC Optimal Power Flow Formulation and Testing Using QuadProgJ,"** *Proceedings*, IEEE Power Engineering Society General Meeting, June 2007.
5. Steven Widergren, Junjie Sun, and Leigh Tesfatsion, **Market Design Test Environments**, *Proceedings*, IEEE Power Engineering Society General Meeting, Montreal, June 2006.