

# An Agent-Based Tool for Infrastructure Interdependency Policy Analysis

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For Complex Systems and Policy Analysis:  
New Tools for a New Millennium

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# Agent-Based Infrastructure Interdependency Policy Analysis

- Many insights can be gained by viewing policy analysis from a Complex Adaptive Systems (CAS) agent-based perspective
- ANL has taken such a perspective to produce an integrated model of the electric power and natural gas markets
- This model focuses on the organizational interdependencies between these markets
- These organizational interdependencies are being strained by fundamental market transformations

# Market Transformations

- The electric power and natural gas markets are undergoing fundamental transformations
- These transformations include major changes in electric generator fuel sources
- Electric generators that use natural gas as a fuel source are rapidly gaining market share
- Electric generators using natural gas introduce direct interdependency between the electric power and natural gas markets
- Interdependency insights can be gained using the emergent behavior of CAS model agents

## SMART II+

- The CAS model agents within the Spot Market Agent Research Tool Version 2.0 Plus Natural Gas (SMART II+) can be used to gain electric power and natural gas market interdependency insights:
  - SMART II+ is an extension to SMART II the SwarmFest 2000 Best Presentation winner
  - The SMART models were featured in the Computerworld Technology Future Watch column (August 14, 2000)
- SMART II+ includes an integrated set of agents and interconnections representing each of the following:
  - The electric power marketing and transmission infrastructure
  - The natural gas marketing and distribution infrastructure
  - The interconnections between the two infrastructures in the form of natural gas fired electric generators

## SMART II+ Infrastructure Features

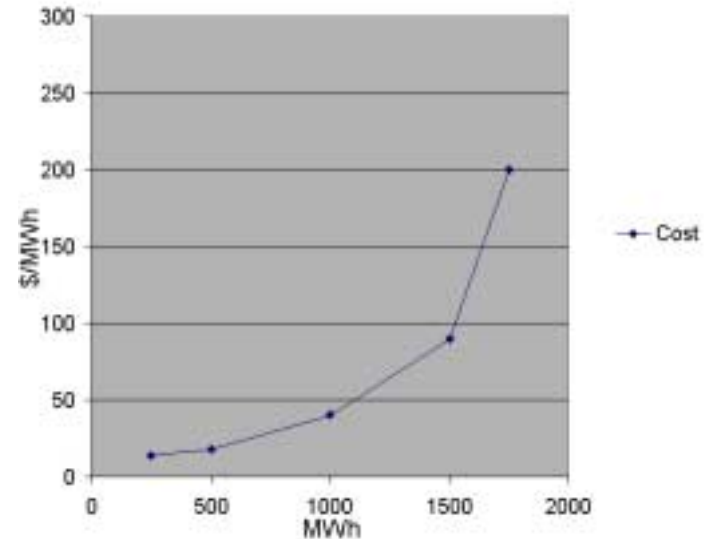
- Both SMART II+ infrastructures include many features:
  - Two different kinds of agents, producers and consumers, represent the market participants
  - Interconnections represent transmission or distribution systems with capacities on each line or pipe and complex routing
  - Important economic issues are considered such as investment capital, demand growth for successful consumers, new generation capacity for profitable producers, and bankruptcy for noncompetitive organizations
  - Components can be disabled interactively to simulate failures
- The electric power infrastructure includes the added feature of natural gas fired electric generators:
  - These generators buy fuel from the natural gas market
  - The resulting electricity is then sold in the electric power market

## SMART II+ Producers (1 of 3)

- Producers determine their production level based on the potential profit to be made
- Each producer has investment capital that is increased by profits and reduced by losses:
  - If a producer reaches a predetermined level of investment capital it can purchase additional production capacity in the form of new electric generators or new natural gas sources
  - New producers are similar to their owner and can connect to the distribution network in either the same location or a new one
  - Producers that run out of investment capital go bankrupt and no longer participate in the market
- Producers choose whether or not to sell energy based on either their cost curves or natural gas prices

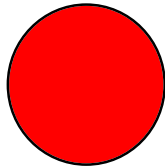
## SMART II+ Producers (2 of 3)

- Standard producers derive their costs and capacities from cost curves with maximum generation limits
- Natural gas fired electric generators derive their costs and capacities from the natural gas market:
  - These generators are consumers in the natural gas marketplace
  - Their costs are based on the price they pay for natural gas
  - Their capacities are based on both the amount of natural gas they can purchase and their design limits

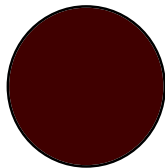


## SMART II+ Producers (3 of 3)

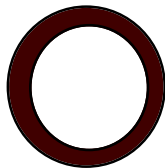
- Producer appearance is determined by current profit levels:



Profitable producers are highlighted



Unprofitable producers are dim



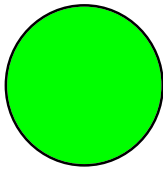
Bankrupt producers are hollow

## SMART II+ Consumers (1 of 2)

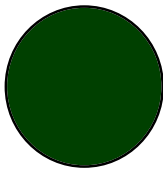
- Consumers buy energy for their own use:
  - Businesses buy fixed amounts of energy to remain in business
  - Populations buy fixed amounts of energy to live their lives
  - Natural gas fired electric generators buy natural gas to produce salable electric power
- Each consumer has investment capital that is increased by profits and reduced by losses:
  - If a consumer reaches a predetermined level of investment capital it can grow in the form of new consumers
  - Consumers that run out of investment capital go bankrupt and no longer participate in the market
- Investment capital represents several things:
  - For industrial users it is their total financial capital
  - For individuals it is the employment and personal opportunities that keep them in an area or encourage them to leave

## SMART II+ Consumers (2 of 2)

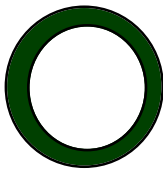
- Consumer appearance is determined by current profit levels:



Profitable consumers are highlighted



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## SMART II+ Interconnections

- Interconnections represent transmission lines or distribution pipes each with an individual capacity limit
- Individual capacity limits vary by interconnection type:
  - Central transmission lines or main distribution pipes have high capacity limits and are drawn with thick marks
  - Outlying transmission lines or secondary distribution pipes have moderate capacity limits and are drawn with medium marks
  - Feeder lines or pipes have low capacity limits and are drawn with thin marks
- Interconnection color represents contents and usage

Electrical lines are red

Low Usage is Dark

High Usage is Light

Natural gas pipes are blue

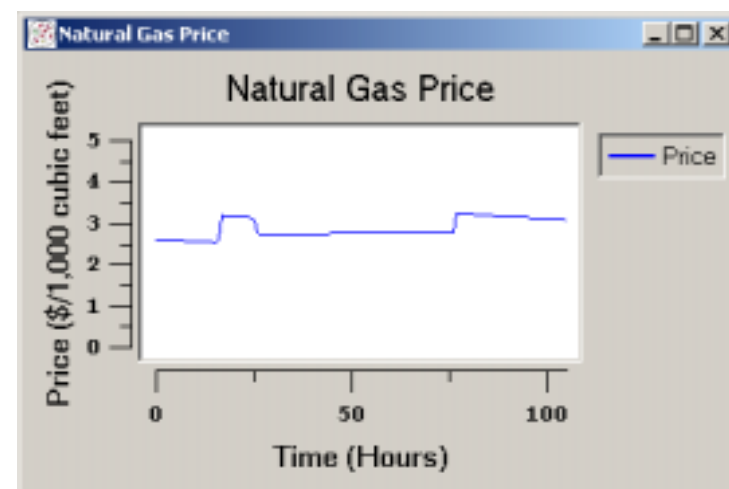
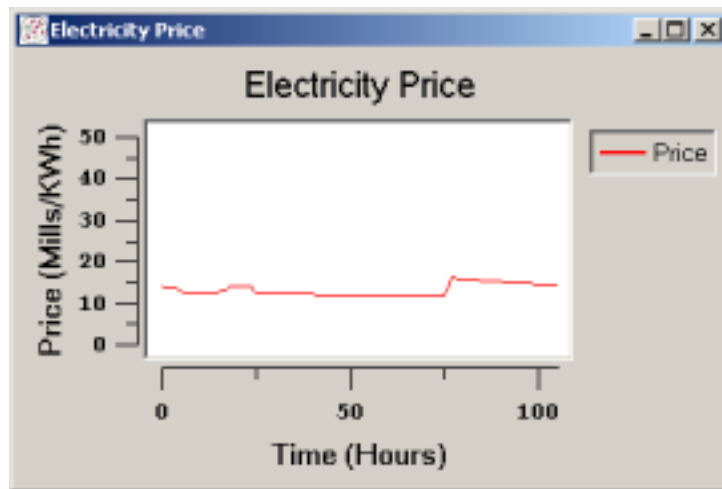
# Key Market Indicators

- There are a variety SMART II+ market indicators including the following:
  - Market prices
  - Unserved energy
  - Natural gas fired electrical generator market share
- These selected key SMART II+ indicators are represented by graphs updated in real time



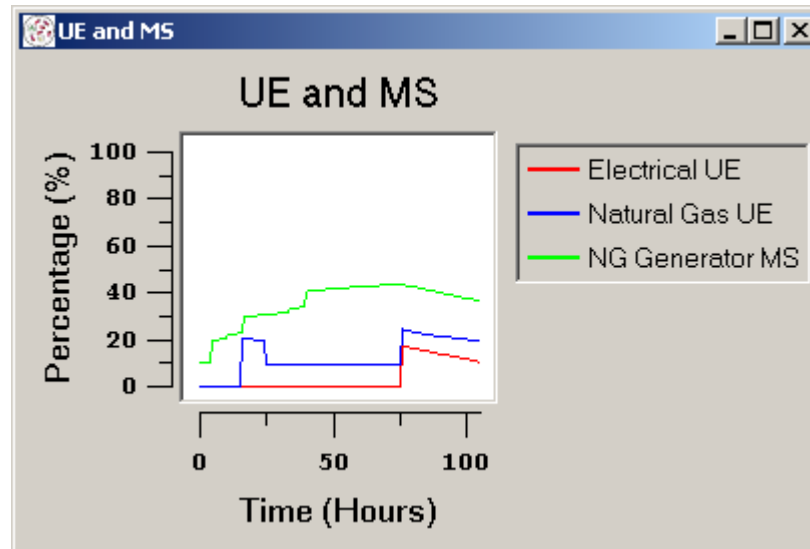
# Key Market Indicators: Price

- Market price is the per unit purchase price of the given energy resource or system marginal price (SMP):
  - Electric power SMP is given in tenths of a cent per kilowatt hour (Mills/KWh)
  - Natural gas SMP is given in dollars per thousand cubic feet (\$/1,000 cubic feet)



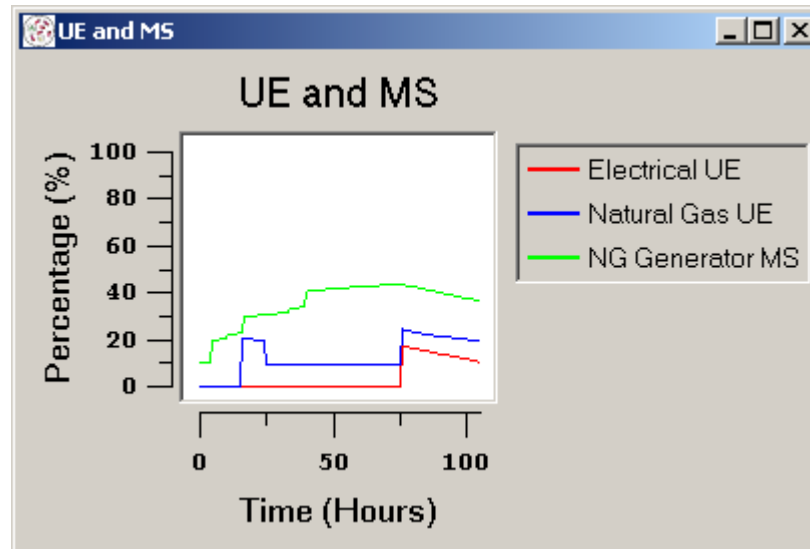
# Key Market Indicators: Unserved Energy

- Unserved energy (UE) is the energy demand that was not met by the market:
  - UE represents a form of market failure
  - UE is given as a percentage of total energy demand



# Key Market Indicators: Natural Gas Market Share

- Natural gas fired electric generator market share (NG Generator MS) is a measure of the electric generation capacity that is supplied by natural gas units:
  - NG Generator MS is a key to infrastructure interdependency
  - NG Generator MS is given as a percentage of total capacity



## SMART II+ Emergent Behavior (1 of 2)

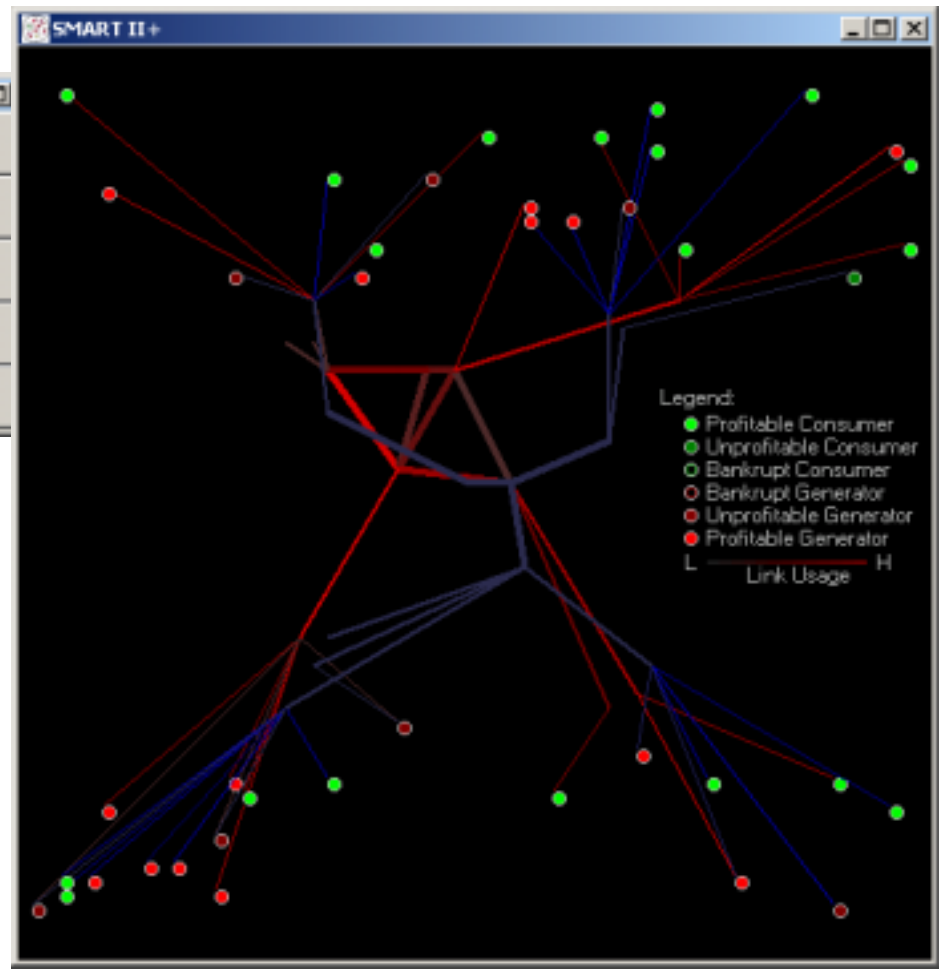
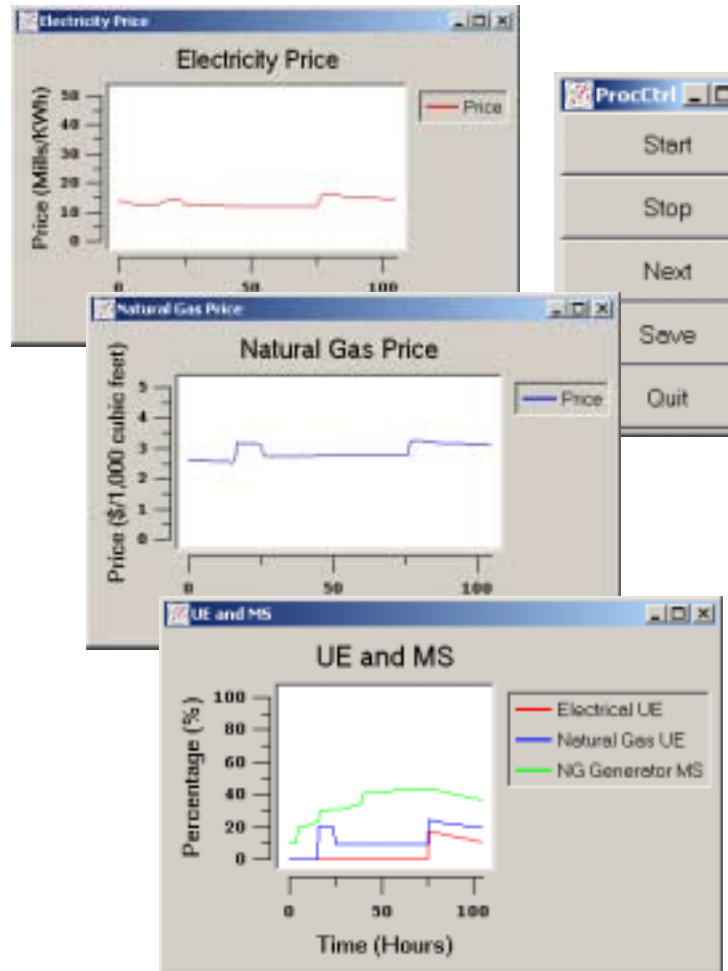
- The emergent behavior of SMART II+ agents allows insights into the interdependencies between the electric power and natural gas markets
- Preliminary SMART II+ emergent behavior indicates:
  - Natural gas fired electrical generators are highly competitive which causes their market share to rapidly rise
  - Rising natural gas fired electrical generator market share radically increases market interdependence
  - Increasing market interdependence pits the electric power and natural gas markets against one another during simultaneous failures since both markets are fighting for the same underlying resource, natural gas

## SMART II+ Emergent Behavior (2 of 2)

- Natural gas fired electric generator market share is rapidly rising in the current market place
- This fact suggests the following:

Emergency natural gas purchases by electrical generators need to be carefully monitored to prevent electrical failures from spreading to the natural gas infrastructure

# SMART II+ Demonstration



## An Agent-Based Tool for Infrastructure Interdependency Policy Analysis

- Developing the initial capability to create CAS models requires substantial organizational investment
- Once this initial investment has been made tools can be created that allow many policy analysis insights
- To learn more please visit the following web site:

[WWW.CAS.ANL.GOV](http://WWW.CAS.ANL.GOV)

- Questions?

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