Power Sector Modeling 101

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DOE's Technical Assistance Website
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Presentation Description – DOE Power Sector Modeling 101

With increased energy planning needs and new regulations, environmental agencies, state energy offices and others have expressed more of an interest in electric power sector models, both for (a) interpreting the results and potential applications of modeling from other groups, and (b) informing future modeling efforts a state air agency may want to initiate. This presentation covers the basics of power sector capacity expansion modeling, and briefly touches on other types of modeling and analytical tools available to provide data on the electric power system. Capacity expansion models simulate generation and transmission capacity investment, given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation.

Capacity expansion modeling topics covered in this presentation include:

- typical model outputs,
- needed model inputs,
- types of questions these models are well suited to answer and those they are not,
- key considerations when selecting a model, and
- key considerations when comparing model results or designing modeling scenarios.

For more information on technical assistance resources available to state, local and tribal officials, visit DOE's Technical Assistance website at www.energy.gov.ta, or submit a request at TechnicalAssistance@hq.doe.gov.

Overview

1. Power System Questions
2. Model Types
   - Data and Analysis Tools
   - Capacity Expansion Models
   - Production Cost (Grid Operations/Unit Commitment and Dispatch) Models
   - Network Reliability Models
3. Summary

Key Consideration: Identify the question(s) you want to answer, and *then* pick the tool that will most effectively provide this information.

(As opposed to picking a tool, and then finding out its not the appropriate resource to provide the information you need.)

Examples of Power System Questions

Data and Resource Assessment

What are the local wind and solar resources? How much available natural gas capacity is in the region? What is the cost of avoided/saved energy consumption?

Generation and Transmission Capacity Expansion

How to plan a resource portfolio for the future (i.e., generation, retirements)? What type of generation should be built to meet demand? How much of it? Will it necessitate development of new transmission capacity? How does the optimal system change with constraints on emissions, or with local economic development goals? How can the system be optimized to deliver reliable power at least-cost under specified environmental constraints? What are the costs, rate impacts, and welfare implications of alternative power sector policies or regulations? What are the key drivers of the system?

Generation and Transmission System Operation

Given a generation and transmission system what is the lowest cost way to operate the system while maintaining reliability under uncertainty and meeting other types of constraints (e.g., emissions)?

Power System Questions

Network Reliability

Will the transmission system work under periods of high load? Will the system be able to remain stable after a loss of a large power plant? Will a loss of transmission line or power system cause instability and cause individual generators or sections of the network to disconnect from the rest of the grid?

Model Types

1. Data and Analysis Tools – generally accessible
2. Capacity Expansion Models
3. Production Cost (Grid Operations/Unit Commitment and Dispatch) Models
4. Network Reliability Models

Model Types

1. Data and Analysis Tools – generally accessible
2. **Capacity Expansion Models**
3. **Production Cost (Grid Operations/Unit Commitment and Dispatch) Models**
4. **Network Reliability Models**

Requires expert modeler – to manage inputs, run the model, and interpret the outputs

Data and Analysis Tools (1 of 2)

Data

- **Power System Tracking -** capacity, generation, fuel use, fuel prices, electricity price, electricity consumption, energy efficiency savings, policies (e.g., state renewable portfolio standards, state energy efficiency policies)
- **Resource Assessment -** spatially and temporally explicit assessment of renewable energy resources
- **Key Resources**

Zero Cost

  - U.S. Energy Information Agency (EIA)
  - Database of State Incentives for Renewables and Efficiency (DSIRE)
  - DOE's State and Local Energy Data (SLED)
  - National Electric Energy Data System (NEEDS)
  - EPA's Emissions & Generation Resource Integrated Database (eGRID)
  - EPA's Air Markets Program Data (AMPD)
  - National Renewable Energy Lab's Report - Estimating Renewable Energy Economic Potential in the United States
  - ABB (ASEA Brown Boveri) Velocity Suite
  - SNL Energy

Data and Analysis Tools (2 of 2)

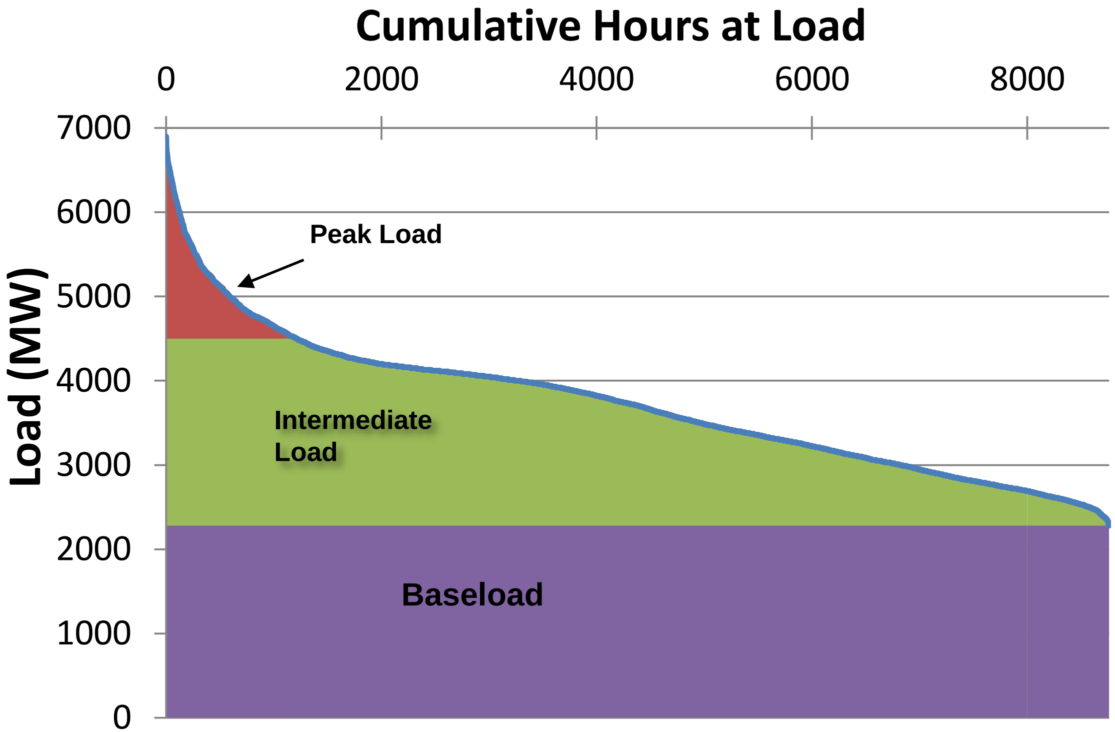
Analysis Tools: *spreadsheet tools* or simple calculators that allow users to conduct high-level gross analyses of the power sector

- EPA's AVoided Emissions and geneRation Tool (AVERT) - estimates the emissions implications of energy efficiency measures and new renewable generation capacity
- ACEEE's State and Utility Pollution Reduction Calculator Version 2 (SUPR 2) – 19 different policies and technologies to choose from to build a compliance scenario to EPA's Clean Power Plan, including energy efficiency, renewable energy, nuclear power, emissions control, and natural gas.
- Synapse's Clean Power Plan Planning Tool (CP3T) and MJ Bradley's & Associates CPP Compliance Tool - both *Excel-based spreadsheet* tools for performing first-pass planning of statewide compliance with EPA's Clean Power Plan
- Advanced Energy Economy (AEE) State Tool for Electricity Emissions Reduction (STEER) - an open access integrated resource planning model that constructs a merit order for dispatch from generator-level cost data and simulates generation based on least-cost strategies (currently available for PA, MI, AR, VA, and IL (more will be forthcoming).

These analysis tools are free and publicly available.

Capacity Expansion Models

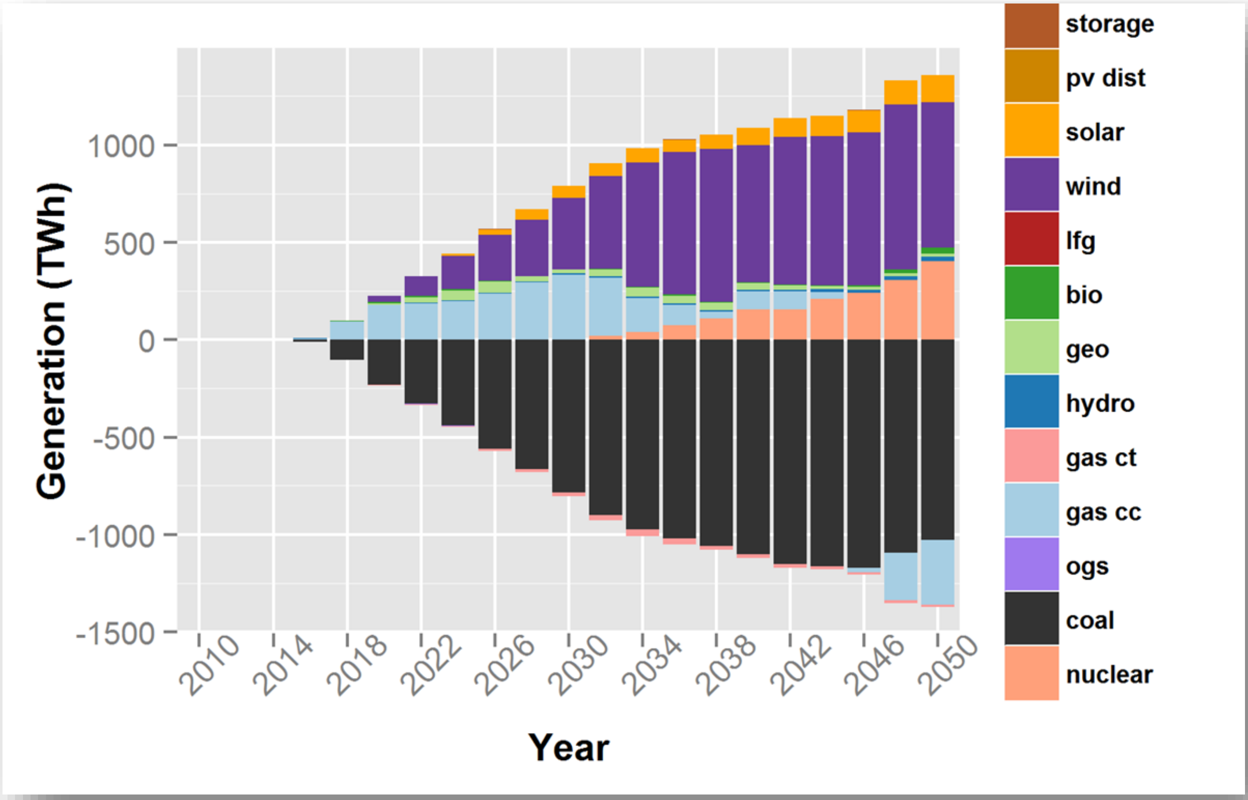
- Capacity expansion models simulate generation and transmission capacity investment, given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation
- What mix of generators should we build to meet load?
- Does a policy affect cost of service regions and competitive regions in different ways?



Capacity Expansion Models

Typical Outputs

- Annual generation, generation and transmission capacity builds/retirements, emissions, fuel consumption, electricity prices, credit/allowance prices



Capacity Expansion Models (1 of 2)

- **Examples of Capacity Expansion Models:**
  - **National-Scale:** National Energy Modeling System (NEMS), Regional Energy Deployment System (ReEDS), Integrated Planning Model (IPM), Haiku, MARKAL (MARKet Allocation)
  - **Utility-Scale:** Resource Planning Model (RPM), Aurora, System Optimizer, Strategist, PLEXOS
    - Typically have higher spatial and temporal resolution
    - Often used for Integrated Resource Plans (IRPs)
  - In addition to having staff or paying an expert to run these models, the commercial models also require a licensing fee

Capacity Expansion Models (2 of 2)

- **What do these models do particularly well?**

  Examine the impacts of power sector policies (or alternative technology/fuel trajectories) on the generation and capacity mix in the mid- to long-term

- **What don't they do?**

  Many do not have chronological unit commitment (i.e., every hour of the year chronologically); some use aggregate (model) plants for dispatch; transmission and power flow are a stylized representation (pipe flow or DC)

- **What kinds of questions/analyses can the model answer/address?**

  Quantifying the impacts of environmental policies on generation and capacity? What are the cost implications of alternative pathways to a low greenhouse gas emissions future? How will alternative future prices of natural gas impact capacity investment? What is the change in consumption and expenditures? What are the efficiency and distributional effects of various policy designs?

Capacity Expansion Model Capabilities - Key Considerations in Model Selection (1 of 2)

- **Regionality**
  - Geographic scope (state, regional, national)
  - Cost-of-service vs. competitive regions
- **Temporal Resolution**
  - Time of day, Seasons
- **Time Steps**
  - Building new capacity, dispatch
- **Time Horizon**
  - Near-term: 2015-2020, Long-term: 2015-2050
- **Representation of Generating Units**
  - Individual Plants or Model Plants
  - Representation of capital costs and other production costs
- **Representation of Transmission and Associated Constraints**
  - Pipeflow or DC Powerflow; Individual transmission lines or aggregated

Capacity Expansion Model Capabilities - Key Considerations in Model Selection (2 of 2)

- **Representation of Renewable Energy (RE)**
  - RE technologies represented in the model
  - Underlying resource dataset – spatial and temporal resolution
  - Accessibility cost (connecting RE resources to load)
  - Accounting for variability and uncertainty in generation (e.g., representation and treatment of curtailments and capacity value of RE technologies)
- Consideration of other parameters (e.g., electric power sector model vs. economy wide model, representation of environmental constraints)

Capacity Expansion Model Analyses- Key Considerations when Comparing Model Results or Designing Modeling Scenarios (1 of 2)

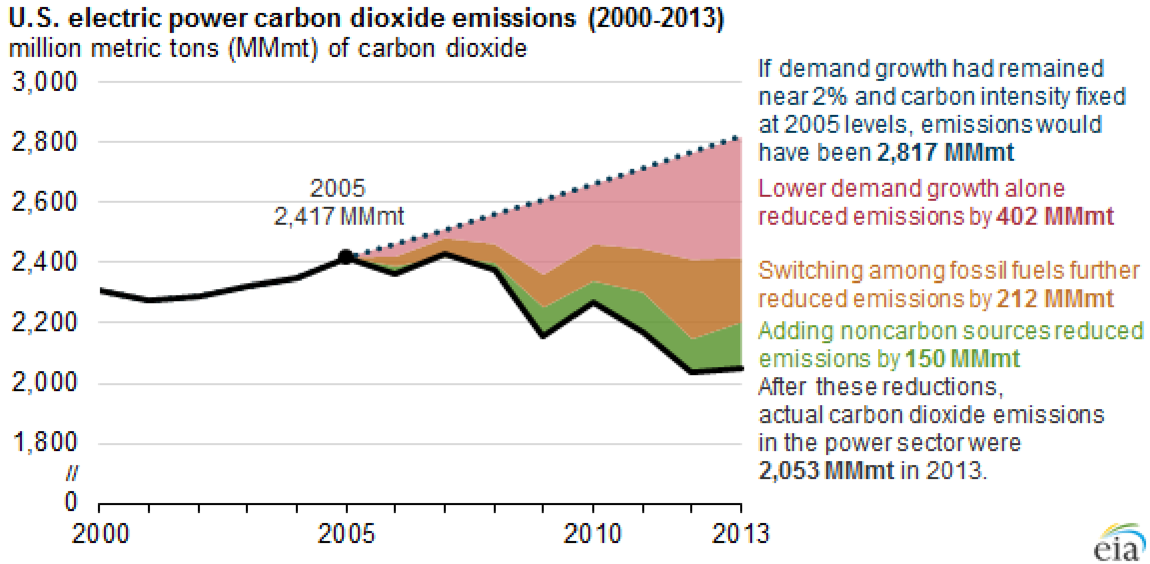
- **Input Assumptions**
  - Fuel prices (exogenous or endogenous)
  - Technology cost and performance assumptions: e.g., capital cost, fixed and variable O&M costs, capacity factors (exogenous or endogenous)
  - Constraints on deployment or use of specific technologies
- **Representation of Electricity Demand**
  - Baseline
  - Exogenous or endogenous; demand elasticity
  - Energy efficiency representation
- **Cost/Benefit Metrics**
  - Welfare, total cost, allowance/credit prices
  - Distributional impacts - consumer/producer surplus, regional cost metrics
- **Electricity Bills and Prices**
  - Competitive vs. cost-of-service
  - Wholesale vs. retail

Capacity Expansion Model Analyses- Key Considerations when Comparing Model Results or Designing Modeling Scenarios (2 of 2)

- **Retirements**
  - Exogenous or endogenous
- **Detailed Representation of Policies**
  - Ex: Carbon Policies
    - Rate vs. mass vs. price
    - Covered sources
    - Total emissions vs. covered emissions
    - Treatment of nuclear plants, existing renewables, biomass, etc.
    - National uniform vs. patchwork policy
    - Trading parameters
    - Over what time period are constraints applied (annually, compliance periods, etc.)
    - If applicable, how is auction revenue used?
    - If applicable, are allowances freely allocated and to who? On what basis (historic or updating)?

Energy Efficiency (EE) in Capacity Expansion Models

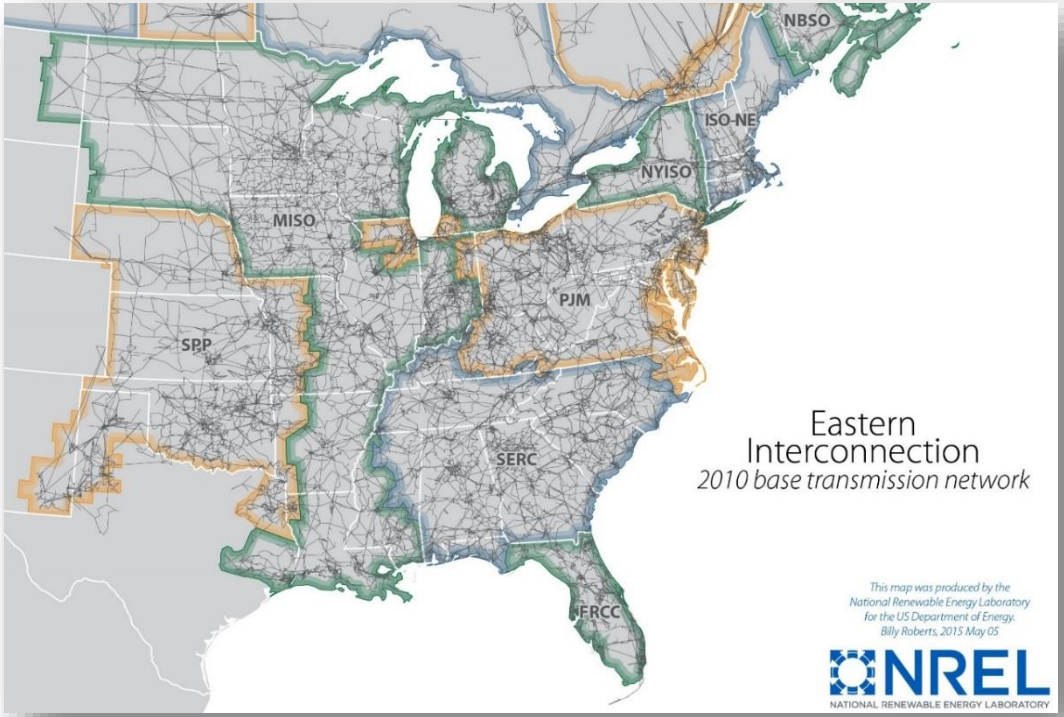
- EE is an energy planning resources that can reduce energy bills and lower regulatory compliance costs
- EE representation in capacity expansion models
  - Endogenous - rebates
  - Exogenous
    - Resources: EE Potential studies and EERS Goals



Source: EIA Energy Today 10/23/14; 2013 Annual CO_2 Analysis

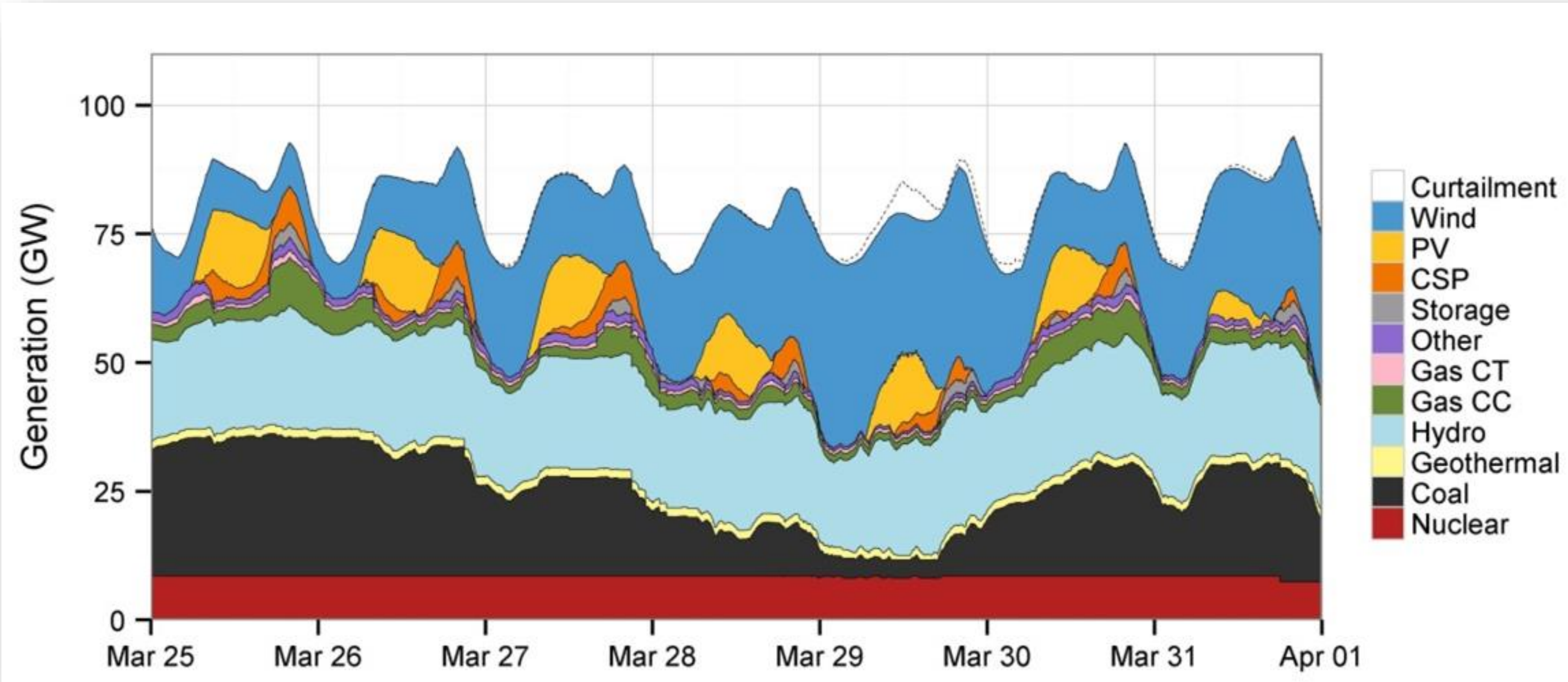
Production Cost (Unit Commitment and Dispatch) Models

- Simulate operation of a specified power system over a relatively short period compared to Capacity Expansion Model (1-week to 1-year), but at higher temporal resolution (hours to 5-minutes)
- What is the least cost dispatch of a complex system of interconnected generators to reliably meet load in every hour of the day at every location?
- Capacity Expansion Output -> Production Cost Input



Production Cost (Unit Commitment and Dispatch) Models

- **Typical Outputs:** Sub-hourly unit level generation, powerflow, locational marginal prices, emissions, fuel consumption, loss of load, ancillary service prices (prices of ancillary services to balance transmission system), curtailments



Production Cost (Unit Commitment and Dispatch) Models

- **Examples of Production Cost Models:**

  PROMOD, GE-Maps, PLEXOS, GridView

- **What do these models do particularly well?**

  Simulate detailed (hourly to sub-hourly) operation of a given system; Assess resource adequacy and other aspects of reliability of a system; Analyze the impact of changes in the system (e.g., retirement/addition of capacity) on system operation; Assess transmission congestion and locational marginal prices; Describe the daily pattern of emissions

- **What don't these models do?**

  Build/invest in new generation or transmission capacity; Typically cannot model the entire US simultaneously - regional focus is required; Do not address all aspects of reliability

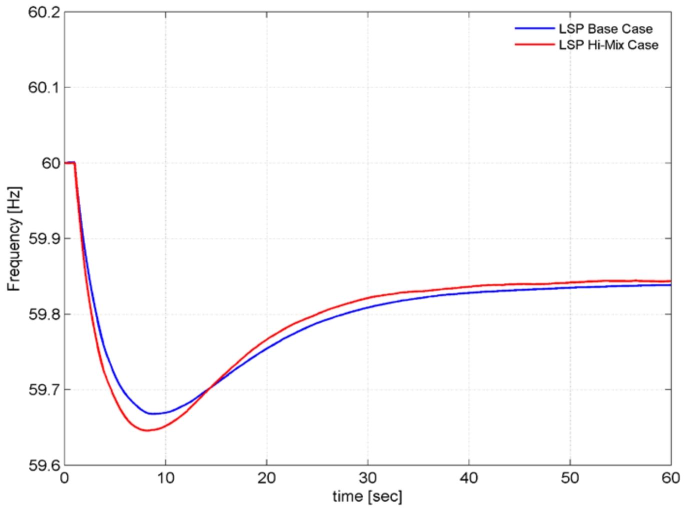
- **What kinds of questions/analyses can the model answer/address?**

  What are the operations, emissions, and resource adequacy impacts of retirement of coal or nuclear units in a given region? What is the maximum potential for redispatch from coal steam units to NGCCs? What is the value of storage, demand response, and solar power to the power system?

Network Reliability Models: AC Powerflow and Dynamics

- Perform "deep-dive" simulations of the transmission network to address specific situations. Simulates very short time periods (~ 30 sec to 1 min).

  Analysis includes:
  - **AC Powerflow:** Simulates the AC transmission network to check operational feasibility (steady state)
  - **System Dynamics:** Simulates dynamic events in the power system to examine reliability under fault conditions
- Simulation of contingency events to examine frequency response Example output: frequency nadir (lowest frequency), settling frequency
- Simulation of transient stability
  - Will generators remain synchronized with voltage spike? (e.g., lightening)
- Production Cost Output/Input <--> Network Reliability Input/Output



Network Reliability Models: AC Powerflow and Dynamics

- Network Reliability Models are typically run by ISOs/RTOs, reliability organizations, large utilities, and consultants
- **Examples:** Positive Sequence Load Flow (PSLF), Power System Simulator for Engineering (PSSE)
- **What do these models do particularly well?**

  Detailed simulations of the transmission network including dynamic events that can occur in seconds (and cause big problems); these models aren't run on a day to day basis – they are only run to examine significant changes to an existing system
- **What don't these models do?**

  Anything related to system operation in "economic" time frames (typically more than about 30 seconds)
- **What kinds of questions/analyses can the model answer/address?**

  Will the system remain able to maintain frequency after retirement of large synchronous machines with set generation and transmission mix? Will the system maintain reliability to respond to a voltage swing or other transients?

What Aspects of Reliability do Different Types of Models Address?

Model Type	Generator (Resource) Adequacy	Flexibility Requirement	Transmission Adequacy	Generator Contingencies	Transmission Contingencies	Frequency Stability	Voltage Stability, Voltage Control
Capacity Expansion	Often	Somewhat/ depends	Typically No	No	No	No	No
Production Cost (Unit Commitment and Dispatch)	Yes	Yes	Partially	Somewhat	Somewhat	Somewhat	No
Network Reliability (AC Power Flow, Dynamics)	No	No	Yes	Yes	Yes	Yes	Yes

Summary

- Wide range of tools/models to address a wide range of questions
- Within a particular type or class of model or tool, different models have different strengths and weaknesses
  - Selection of a specific model or tool needs to be closely tied to the analytical application
  - Many assumptions to consider when comparing results from different models or modeling analyses
- Results of a modeling analysis need to be interpreted in the context of the limitations of the model
- Questions?

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Appendix

Key Data Resources (1 of 2)

Key Data Resources

- U.S. Energy Information Agency (EIA) - independent agency that collects, analyzes, and disseminates independent and impartial energy information
- Database of State Incentives for Renewables and Efficiency (DSIRE) – national and state incentives and policies that support renewable energy and energy efficiency
- DOE's State and Local Energy Data (SLED) - Get basic energy market information that can help state and local governments plan and implement clean energy projects, including: Electricity generation; Fuel sources and costs; Applicable policies, regulations, and financial incentives
- National Electric Energy Data System (NEEDS) - database contains the generation unit records used to construct the "model" plants that represent existing and planned/committed units in EPA modeling applications of IPM
- EPA's Emissions & Generation Resource Integrated Database (eGRID) - data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include: air emissions for nitrogen oxides, sulfur dioxide, carbon dioxide, methane, and nitrous oxide; emissions rates; net generation; resource mix; and many other attributes

Key Data Resources (2 of 2)

Key Data Resources

- EPA's Air Markets Program Data (AMPD) – tool which allows users to search EPA data to answer scientific, general, policy, and regulatory questions about industry emissions
- National Renewable Energy Lab's Report - Estimating Renewable Energy Economic Potential in the United States – geographic economic potential for renewable energy technologies
- ABB (ASEA Brown Boveri) Velocity Suite – commercial data set that includes fuel production, costs, electricity generation and capacity, market data, and more
- SNL Energy – commercial energy information that integrates news, data and analytics in real time on a Web-based platform. Access to comprehensive financials, breaking news, proprietary regulatory research, market pricing and fundamentals of supply and demand

What Aspects of Reliability do Different Types of Models Address?

Model Type	Generator (Resource) Adequacy [a]	Flexibility Requirement [b]	Transmission Adequacy [c]	Generator Contingencies [d]	Transmission Contingencies [e]	Frequency Stability [f]	Voltage Stability, Voltage Control [g]
Capacity Expansion	Often [1]	Somewhat/ Depends [3]	Typically No [4]	No	No	No	No
Production Cost (Unit Commitment and Dispatch)	Yes [2]	Yes	Partially [5]	Somewhat [6]	Somewhat	Somewhat [8]	No
Network Reliability (AC Power Flow, Dynamics)	No	No	Yes	Yes [7]	Yes	Yes [9]	Yes

Footnotes for Reliability Table (slide 1 of 2)

a) Defined as having adequate capacity to meet demand measured by loss of load probability in each time interval or cumulative loss of load expectation. Considers resource availability in each time period but typically does not measure flexibility, or the ability to ramp from one state to another
b) Defined as having adequate generator flexibility to ramp from one demand period to another
c) Defined as not violating transmission thermal, voltage and stability limits
d) Defined as maintaining system reliability upon the failure of large generators, including the single largest generator
e) Defined as maintaining system reliability upon the failure of transmission lines, including the single largest line
f) Defined as maintaining system frequency by provision of inertia, primary frequency (governor) response and regulating reserves.
g) Defined as the ability to maintain system voltage by provision of reactive power. NOTE we are not including the third leg of the stability trifecta – transient/rotor angle stability. Network reliability models are the only class of models that do this.

1) Large-area capacity expansion models will often inforce a peak capacity requirement that is a proxy for resource adequacy. Commercial models may often include resource adequacy calculations
2) Most production cost models can provide full Loss of Load Expectation/Loss of Load Probability (LOLE/LOLP) calculations. There are also several dedicated models that perform resource adequacy calculations, including stochastics
3) Most capacity expansion models do not include full chronology. However many have the ability to capture some aspect of the need for flexibility, by either running chronological dispatch during some sub set of time periods, or imposing a flexibility constraint in the objective function
4) Most capacity expansion models have a very rudimentary treatment of transmission. However some will enforce constraints that require additional transmission when new resources are added
5) Most production cost models now include DC optimized power flow which measures some aspects of transmission adequacy (such as thermal limits on certain lines) However due to computational complexity, full transmission power flow analysis is not possible
6) PCMs simulate the holding of reserves in each time period. These reserves should be adequate to meet contingency events, but the actual consequences of contingencies cannot be tested with a PCM.
7) Actually simulates a contingency event to ensure reliable operation
8) As with contingency reserves, PCMs can enforce holding of regulating reserves (and potentially even primary frequency response) but cannot simulate the operation of reserves to check frequency stability
9) Most network reliability models don’t simulate regulation reserves, which kick in after inertia and primary frequency response. There is a limited set of models (I only know of one) that can simulate the full response to frequency deviations, because they combine physics-based dynamic models with semi-economics/rule-based automatic generation control models.

Models – writers or owners (1 of 2)

Capacity Expansion Models

- National Energy Modeling System (NEMS) – U.S. Energy Information Agency
- Regional Energy Deployment System (ReEDS) – National Energy Renewable Laboratory
- Integrated Planning Model (IPM) - ICF
- Haiku – Resources for the Future
- MARKAL (MARKet Allocation) – International Energy Agency
- Resource Planning Model (RPM) - National Energy Renewable Laboratory
- Aurora - EPIS
- System Optimizer - ABB
- Strategist - ABB
- PLEXOS – Energy Exemplar

Models – writers or owners (2 of 2)

Production Cost Models

- PROMOD – ABB
- GE-Maps – General Electric
- PLEXOS – Energy Exemplar
- GridView – ABB

Network Reliability Models

- PSLF – General Electric
- PSSE – Siemens