PennState College of Earth and Mineral Sciences

Earth and Mineral Sciences Energy Institute

Initiative for Sustainable Electric Power Systems

Coupling for IAV: Energy

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Outline

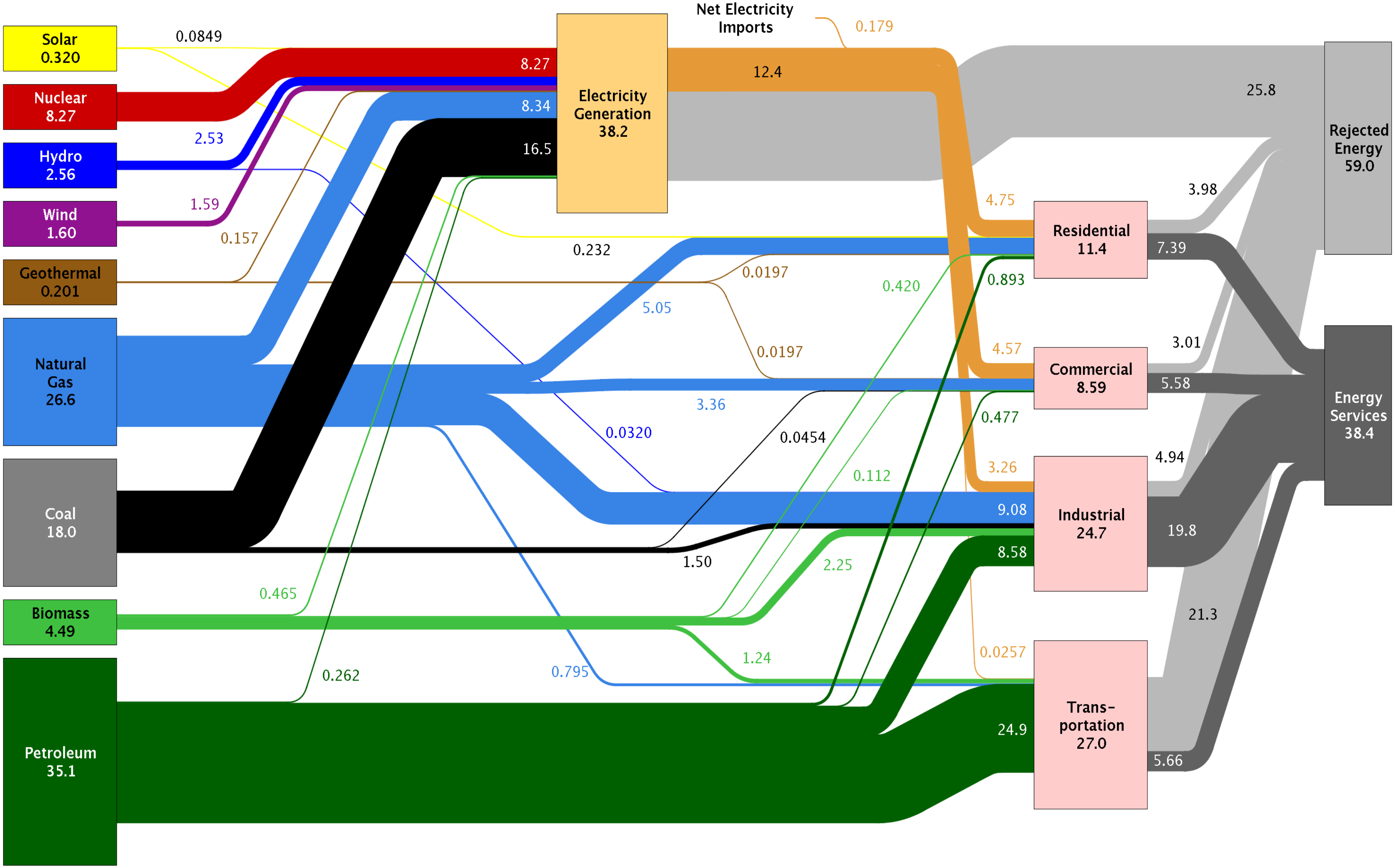
- Motivation: Why couple?
- Energy Sector Model Types
- Example Science Questions
- Illustrative Example
- Information Requirements
- Challenges to Coupling
- Discussion

Motivation

- Typical Integrated Assessment Models
  – Large spatial/temporal domain
  – Many processes included
  – Any one sector will be simplified
- For IAV/sectoral studies, need to resolve individual components to answer the questions
  – How many coal plants will retire?
  – Where should gas pipeline capacity be added?

Estimated U.S. Energy Use in 2013: ~97.4 Quads

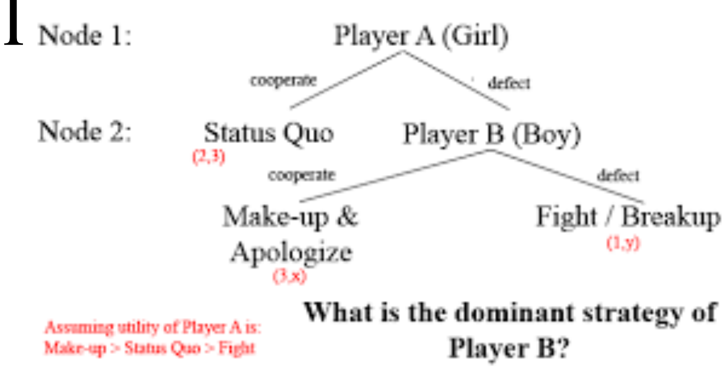
Lawrence Livermore National Laboratory



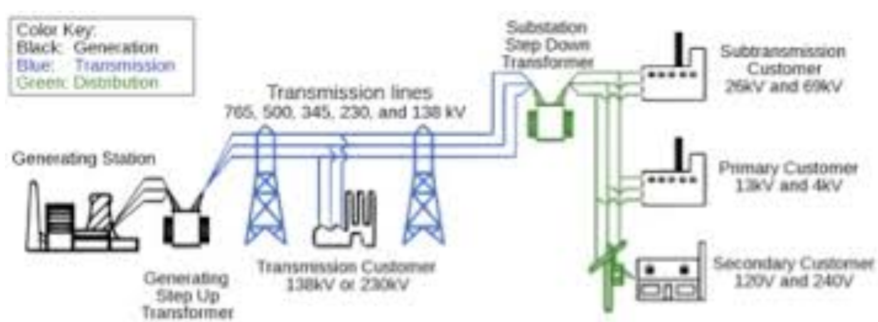
Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Categories of Energy Sectoral Models

- Economics / Market Model
  - Partial Equilibrium
  - Game-theoretic



- Engineering Models
  - Electric Power (dispatch, planning, etc)
  - Natural Gas Pipeline models
  - Transportation Models

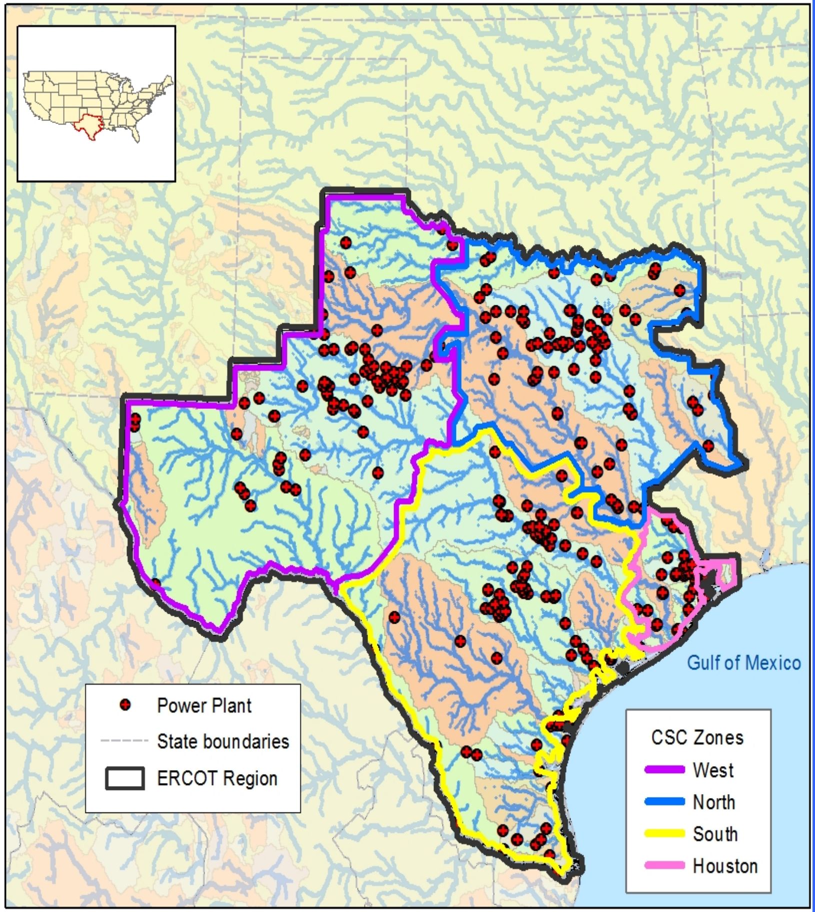


IAV Science Questions Re: Energy Sector

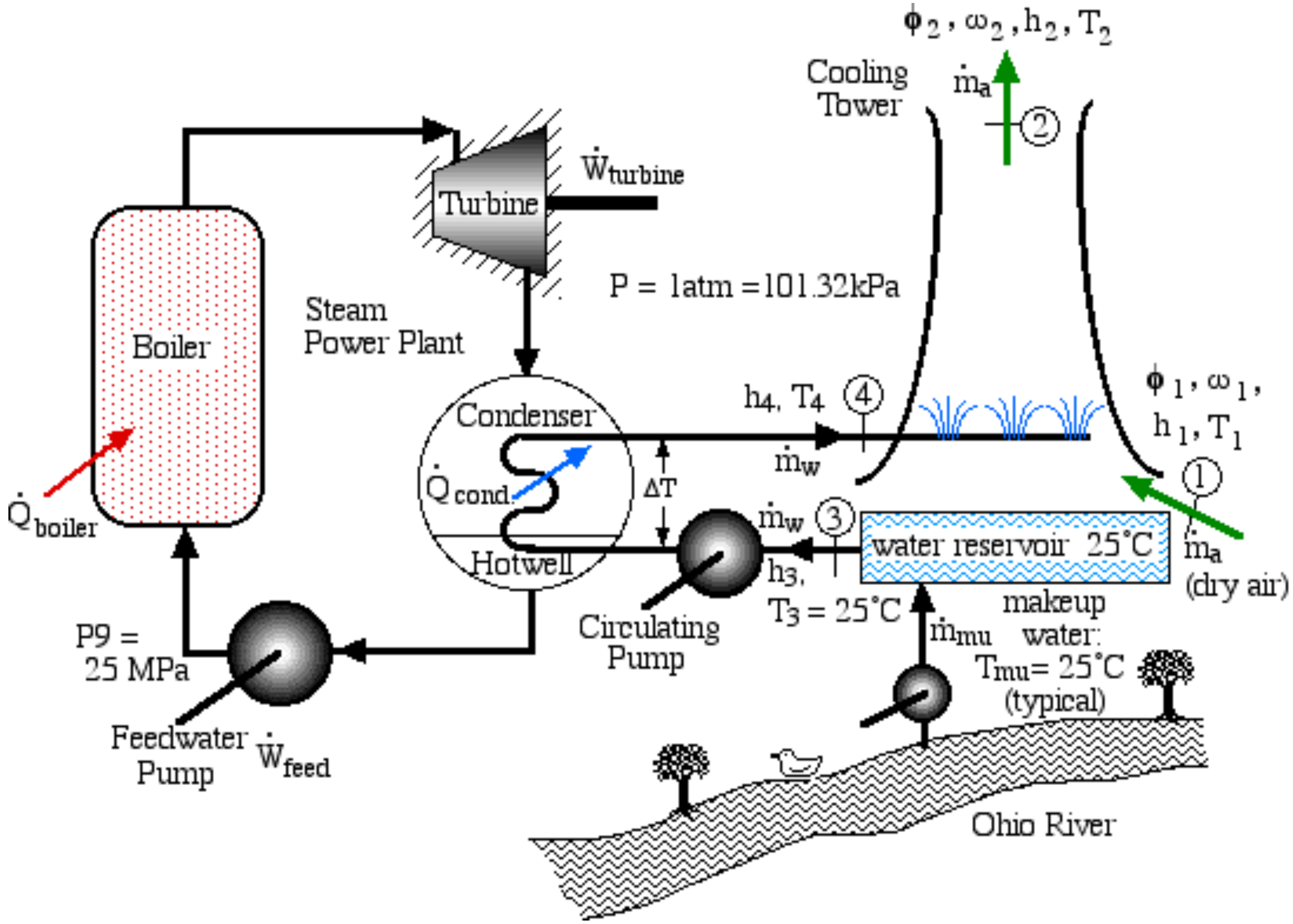
- Increase in cost
- Changing shares of fuels/technologies
- ***Reliability***
  - Is supply always available?
- ***Resilience***
  - Are disruptions of supply quickly resolved and/or limited in scope?
- ***Adaptation***
  - What changes to infrastructure will improve reliability and/or resilience

A Concrete Example

- Climate Change
  - Hydrological cycle changes
  - Less water available for cooling power plants
- Questions
  - If not enough water, can we redispatch?
  - Is there sufficient transmission capacity?
  - What is the preferred adaptation: low-water gens, new trans, move water?
- Case Study: Texas (ERCOT)



Water for Cooling Electric Power Generation



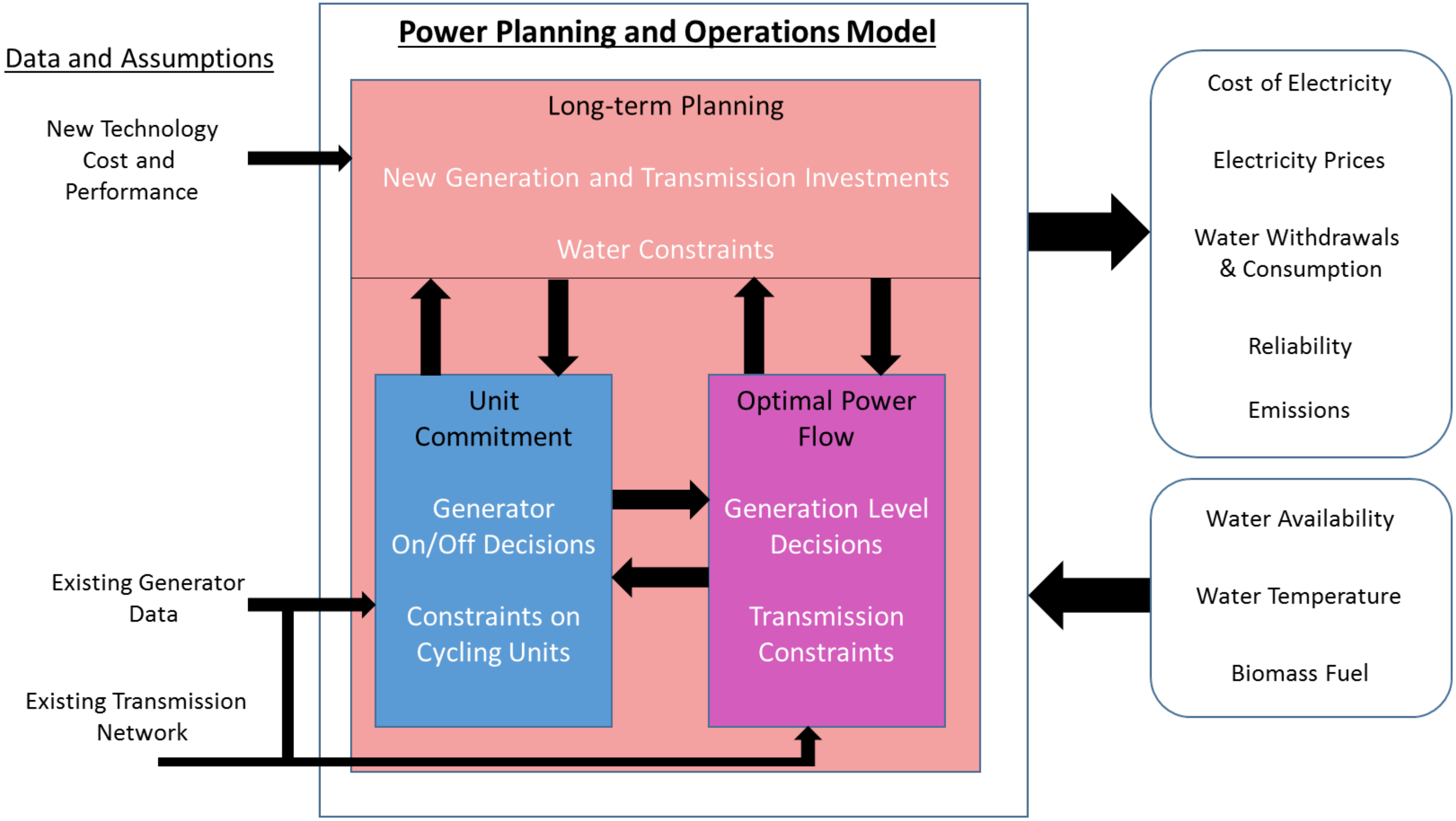
Reasons for interruption of power:

- **Water volume too low**
- **Water Temperature too low**

Information Needs (This Example)

- Inputs to Power Model
  - Water flows, volume, temperature (by sub-basin)
  - Electricity demand and/or temperatures
  - Fuel prices
- Outputs to IAM
  - Electricity generation by fuel/tech/location
  - Water withdrawals and consumption

Information Needs (This Example)



Challenges to Coupling: Multi-Time Scale

- Power Systems Dispatching must solve hourly
  - Decisions each hour constrained by hours before and after
- Power Systems Planning (what to build)
  - Is solved over years/decades

Multi-Time Scales in Electricity Models

Larger temporal spatial scales

Full Economy Model

Transmission Capacity Expansion

Generation Capacity Expansion

Hydro-Thermal Coordination

Unit Commitment

Optimal Power Flow (Transmission Constraints)

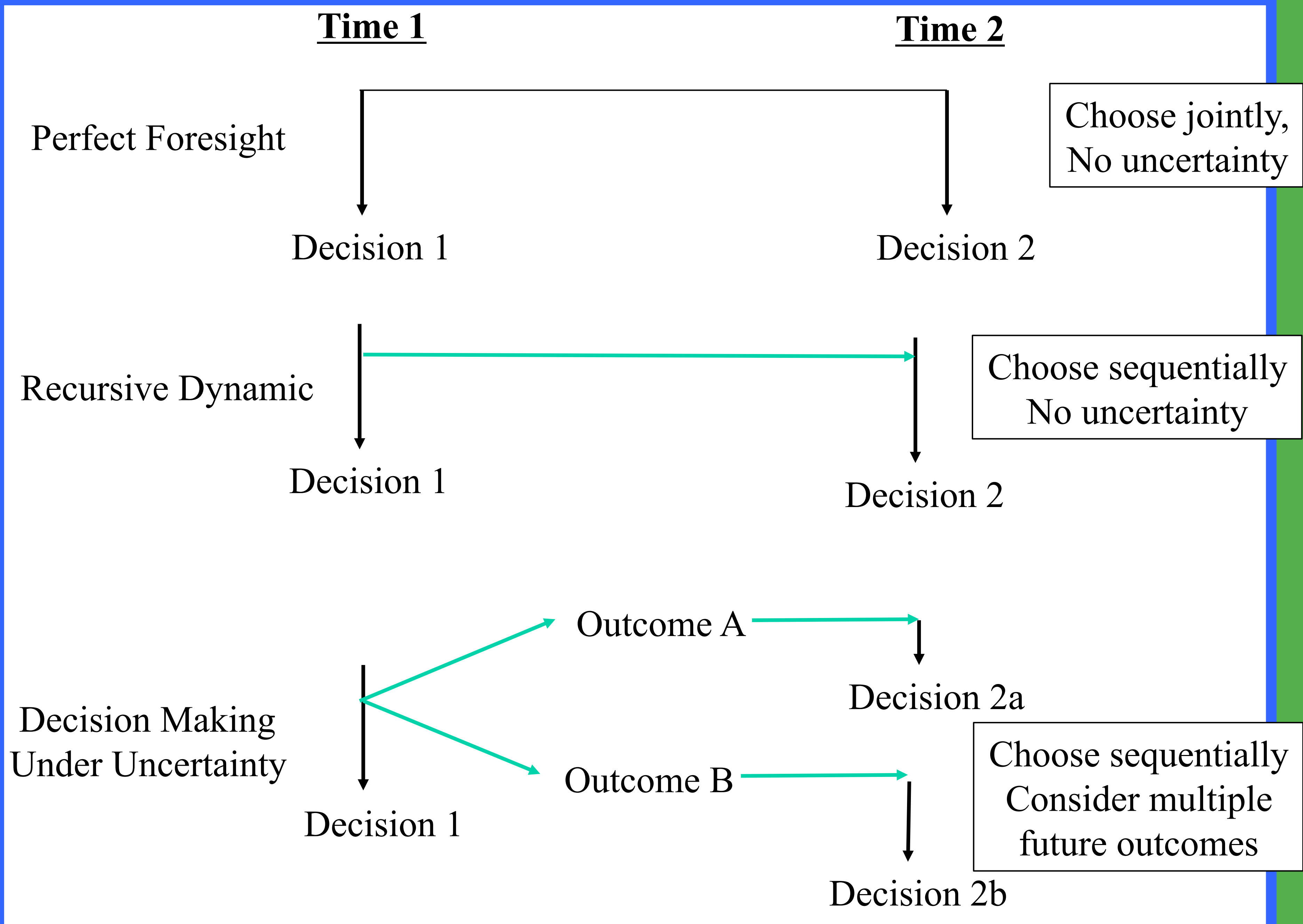
Economic Dispatch

Challenges to Coupling: Multi-Time Scale

- Power Systems Dispatching must solve hourly
  - Decisions each hour constrained by hours before and after
- Power Systems Planning (what to build)
  - Is solved over years/decades
- Water Balance Model solves monthly/daily
- IAMs use multi-year time steps

➢ *How to couple models in a computationally tractable way?*

➢ *How to be consistent with forward-looking and myopic components coupled?*


Time 1
Time 2
Perfect Foresight
Decision 1
Decision 2
Choose jointly,
No uncertainty
Recursive Dynamic
Decision 1
Decision 2
Choose sequentially
No uncertainty
Decision Making
Under Uncertainty
Outcome A
Outcome B
Decision 1
Decision 2a
Decision 2b
Choose sequentially
Consider multiple
future outcomes

Challenges to Coupling: Uncertainty and Consistency

- For this problem, neither perfect foresight nor myopic models capture the true problem
- Requires stochastic optimization to represent sequential decisions under uncertainty
  - Vastly increases the computational complexity
  - Challenges to coupling/consistency of expectations
- Units between CGE (values) and eng. models (physical quantities) difficult to translate
- Existing methods (E.g., Rutherford) are iterative for a single time step and sample path

Discussion

- What is needed?
- Algorithms and approximation schemes for
  - Multiple coupled temporal scales
  - Stochastic multi-stage problems
  - Consistency of temporal information flow and expectations
- More applications coupling energy models with IAMS and other system models

Questions?