# World and North American Electricity—Dimensions and Methods

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# Suggested EIA Topics

1. Technology representation
   - Types and technology advancement
   - Cost and availability
   - Learning models
2. Geographic representation and considerations
   - Regional definition; country groupings
   - Region-specific macroeconomic factors
   - Regional considerations for planning reserves and resource adequacy
   - Regional renewable resource potential

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# Suggested EIA Topics (Cont.)

3. Capacity planning and dispatch models
   - Foresight and expectations
   - Expansion, retrofits and retirements
   - Integration of renewables; projections for nuclear
   - Load shape considerations
   - Time horizon and time step granularity
   - Selection of algorithms
4. Electricity pricing
   - Regional differences
   - Wholesale/retail; marginal cost/average cost
5. Scenario modeling; representing risk and uncertainty
   - Capability for global carbon policy scenarios
   - Country- or region-specific policy representation
   - Representing risk (resource, project, political)
   - Fuel price uncertainty, demand uncertainty

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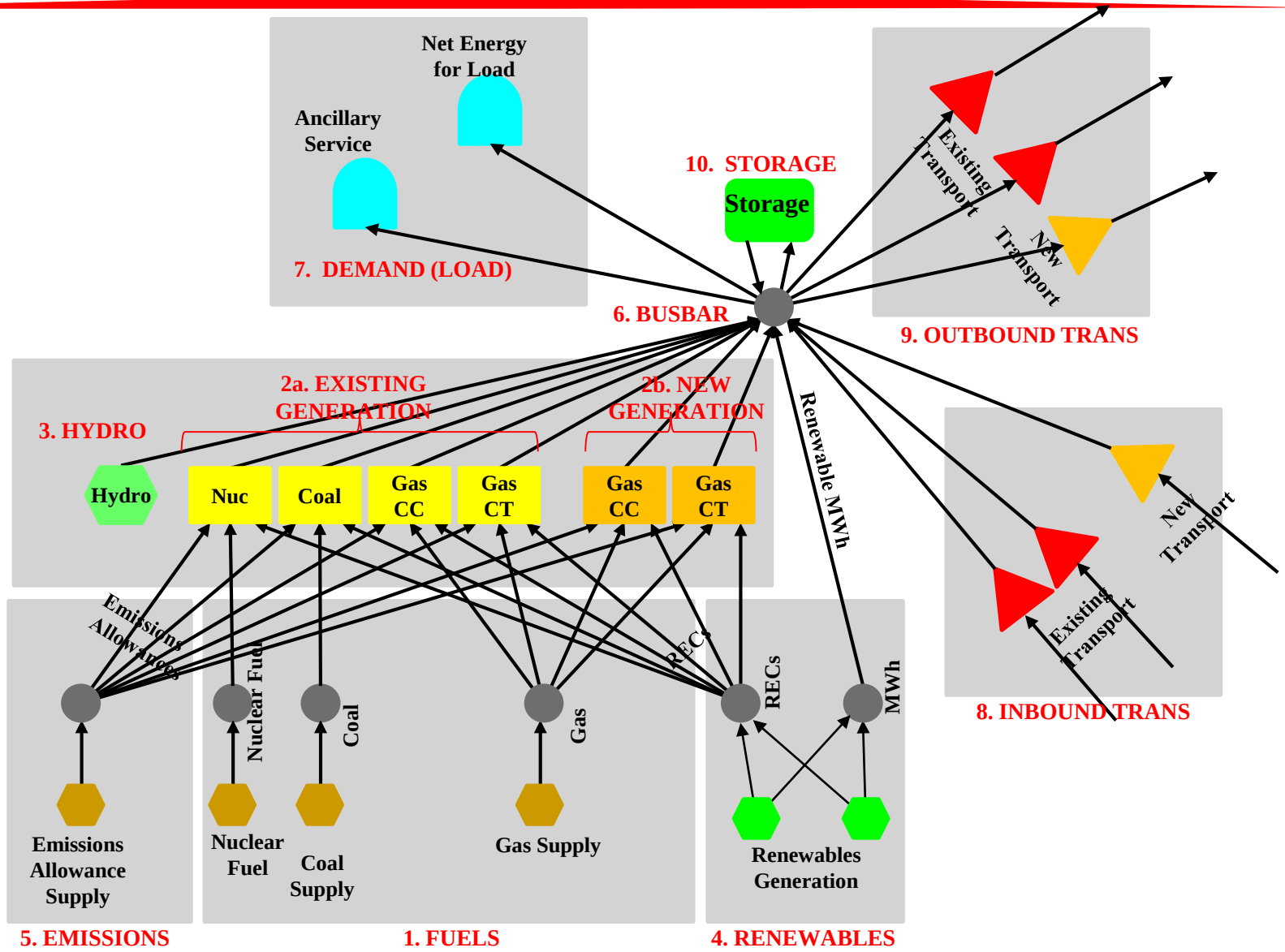
# Electricity Fundamentals

# Every Wholesale Power Subregion Contains Ten Critical Elements



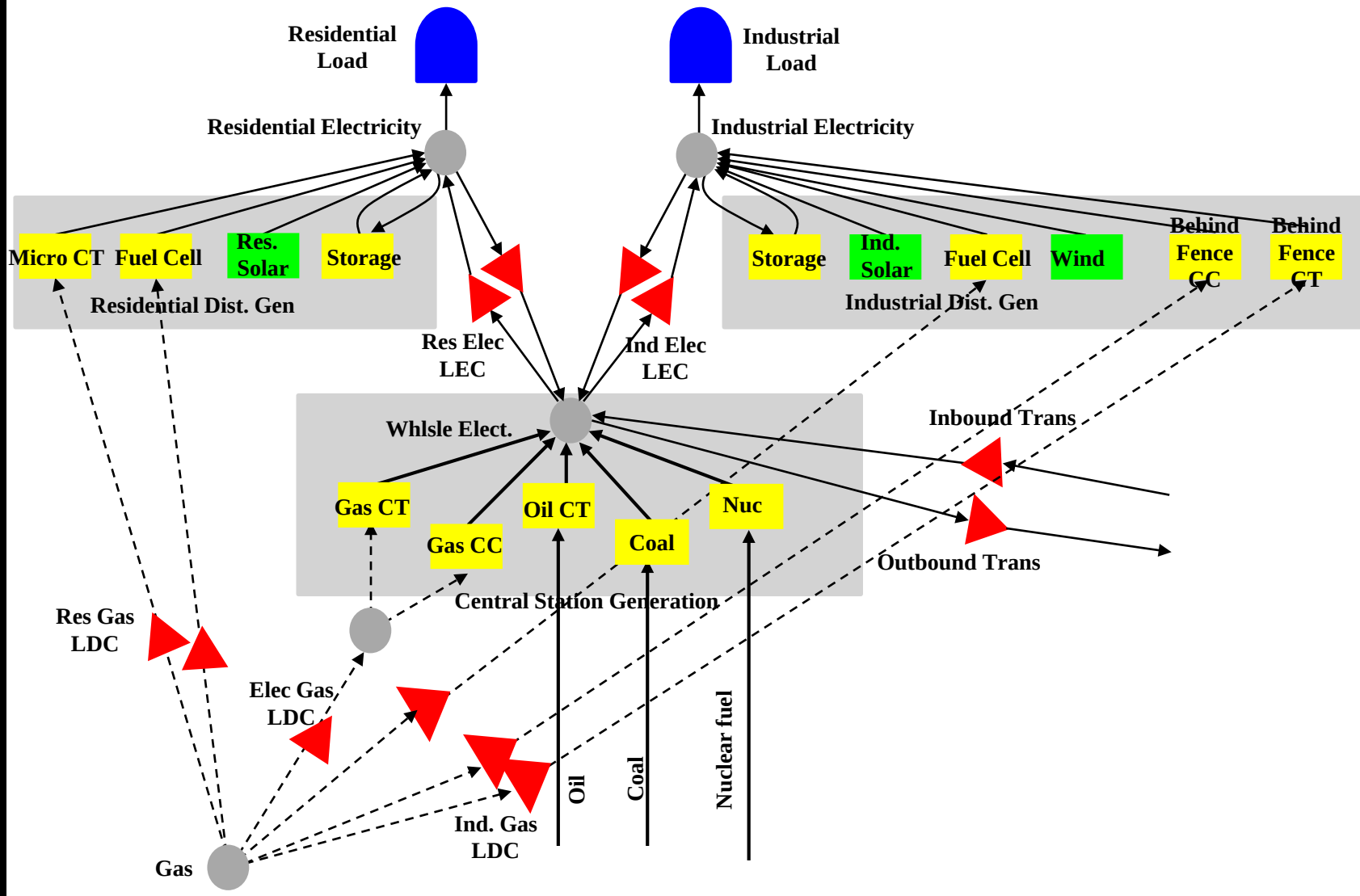
# Wholesale Power Model Critical Dimensions

1. Fuels
2. Thermal generation
   - Existing thermal generation
   - New thermal generation (endogenous/exogenous capacity additions)
3. Hydroelectric
   - Reservoir
   - Run of river
   - Pumped
4. Renewables and regulations
   - Mandates
   - RECs
   - Subsidies
5. Emissions and regulations
   - Retrofits
6. Price competition at the busbar
7. Load and (locational) reserves
8. Inbound transmission
9. Outbound transmission
10. Wholesale electricity storage

# For Power Models…

- Most people stop at wholesale; they assume that is good enough.
- Wholesale is NOT enough and is not good enough by itself.
- You have to couple and integrate end use (generally termed “retail”)

# Retail and Wholesale are Intimately Conjoined



# Retail Power Model Dimensions

1. Sectorization (residential, industrial, commercial, transportation)
2. Distributed generation
   - Thermal
     - Microturbine
     - MG
     - Fuel cell
   - Solar photovoltaic
   - Wind
   - Geothermal
3. Distributed storage
   - Battery
   - Capacitor
   - CAES
   - Thermal
4. Load control (DLC, clocks)
5. Reversible distribution lines
6. Conservation (technology, building shells, lifestyle changes, mode shifts)
7. New loads (e.g., electric vehicles)
8. Distributed reserves

# All the Wholesale and Retail Components Have to be Modeled or Approximated in an Integrated (Interconnected) Fashion

- ArrowHead is unique as far as we know because we can build a network representation.
- If you cant have the picture of your model BE your model, you are unlikely to succeed.

1. You have got to get the peak **dead on correct.**
2. You have got to get the basement **dead on correct.**
3. Increasingly, there is **no such thing as dispatch**, and there is **no such thing as optimization** (LP).
4. The **thermal fleet** remains pivotal (the "marginal source" always is!)

# You Have to Integrate Environment, Short Term Cost, and Operations

- *http://www.mge.com/about-mge/electricity/elec-glossary.htm#d*
- ***Dispatch, Dispatching*** *- The operating control of an integrated electric system to:*
  - *Assign generation to specific generating plants and other sources of supply to effect the most reliable and economical supply as the total of the significant area loads rises or falls.*
  - *Control operations and maintenance of high-voltage lines, substations and equipment, including administration of safety procedures.*
  - *Operate the interconnection.*
  - *Schedule energy transactions with other interconnected electric utilities.*
- There is no such thing as "dispatch." There is **running plants when they are in the money and not running then when they are not.**

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# Nesbitt, Have You Ever Done This Before?

- Yes, probably as much or more than just about anyone.
- Specific projects and applications available by inquiry

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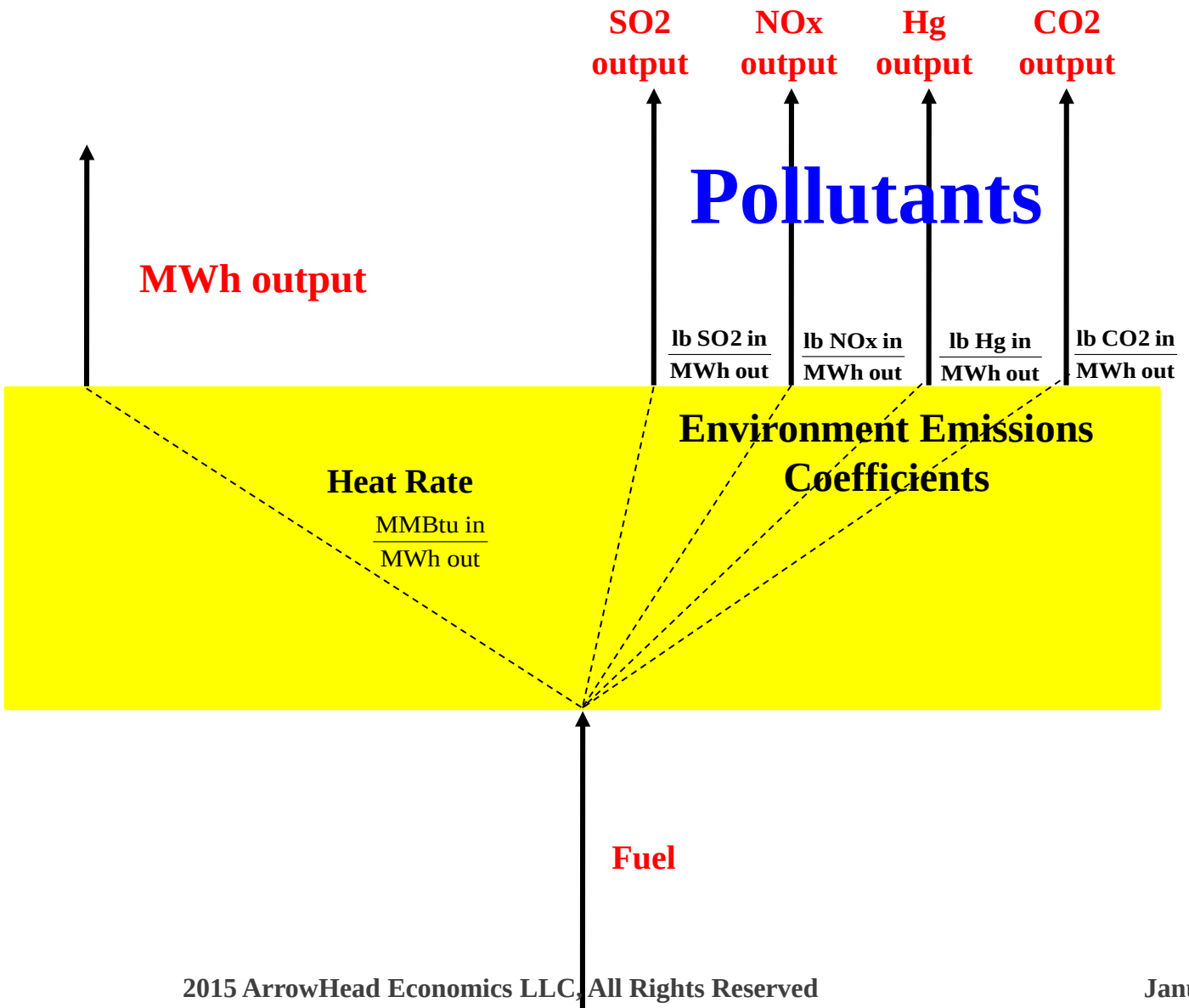
# How Do You Model That?

# Btu and Stoichiometric Balance Across Every Plant (or Aggregate)

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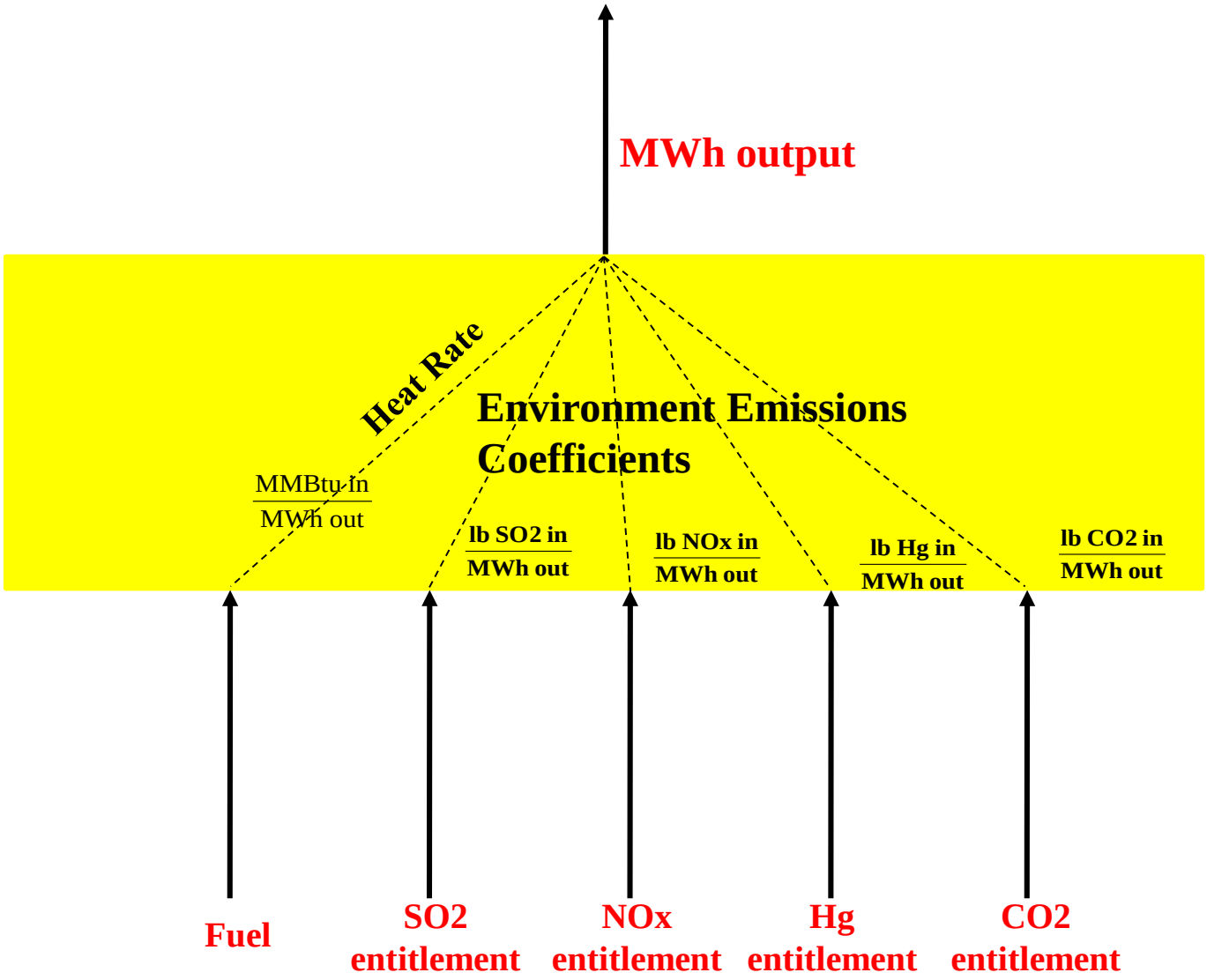
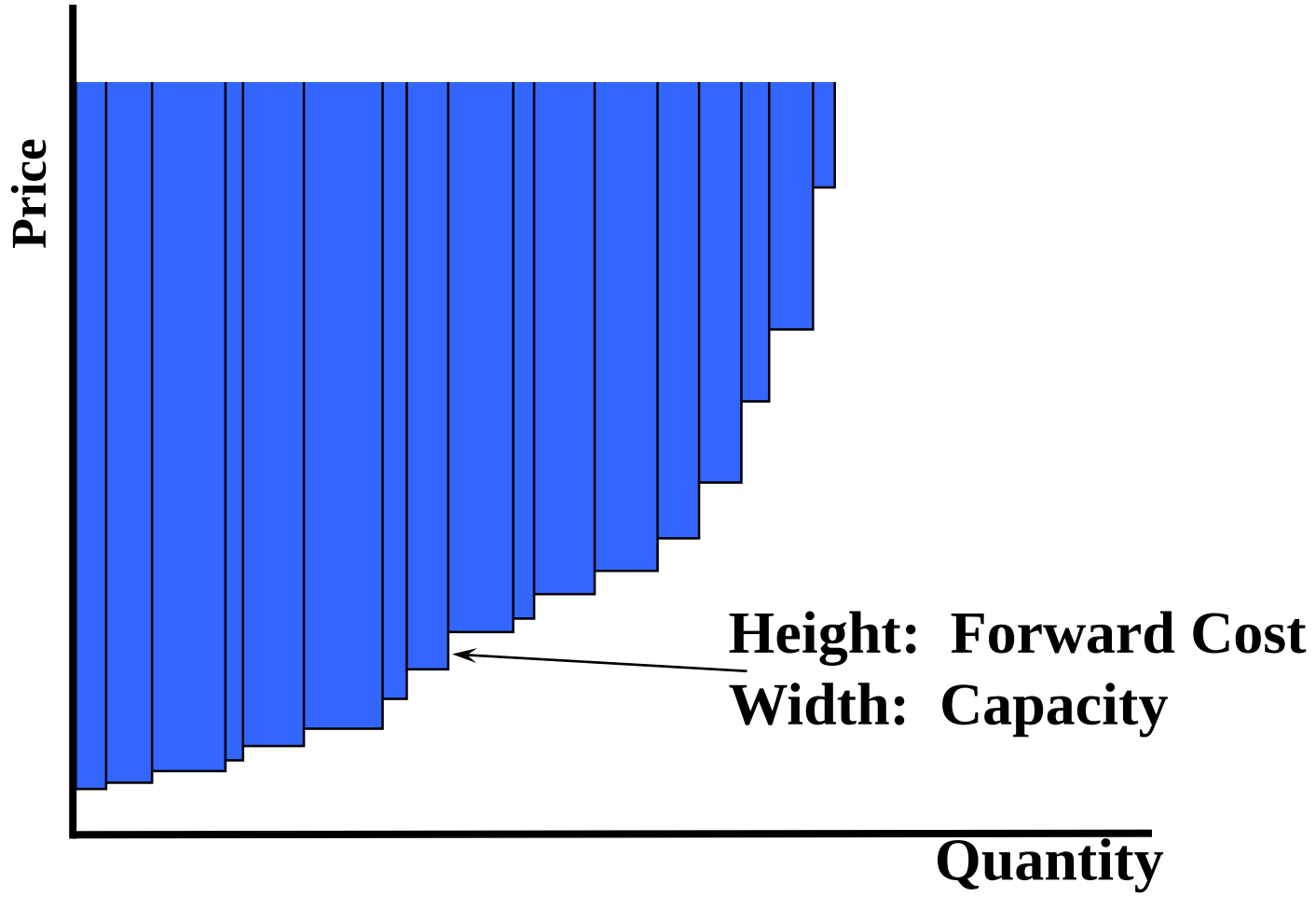
# Stoichiometry Represented as Consumption of Fuel and of Allowances to Pollute



# For Every Plant, "Layer In" Emissions Entitlement Costs

$$\text{Variable Cost} = \frac{p_{coal} h}{10^3}\frac{\$}{MWh} + \text{Nonfuel VOC}\frac{\$}{MWh}$$
$$+ p_{SO_2}\frac{\$}{\text{lb } SO_2} * IO_{SO_2}\frac{\text{lb } SO_2}{MWh}$$
$$+ p_{NO_x}\frac{\$}{\text{lb } NO_x} * IO_{NO_x}\frac{\text{lb } NO_x}{MWh}$$
$$+ p_{Hg}\frac{\$}{\text{lb Hg}} * IO_{Hg}\frac{\text{lb Hg}}{MWh}$$
$$+ p_{CO_2}\frac{\$}{\text{lb CO2}} * IO_{CO_2}\frac{\text{lb CO2}}{MWh}$$

# A Regional "Supply Stack" Based on Purely Economic Costs

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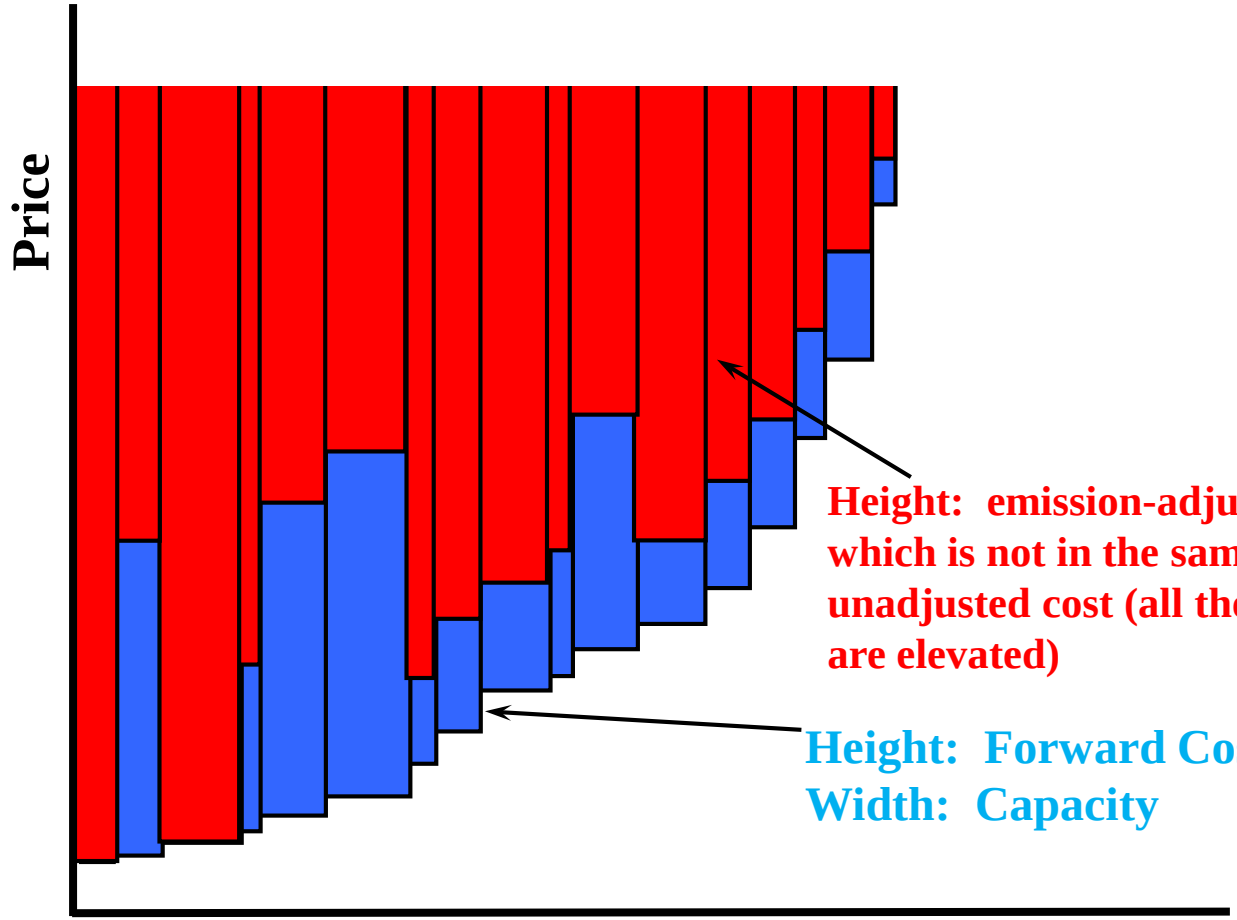
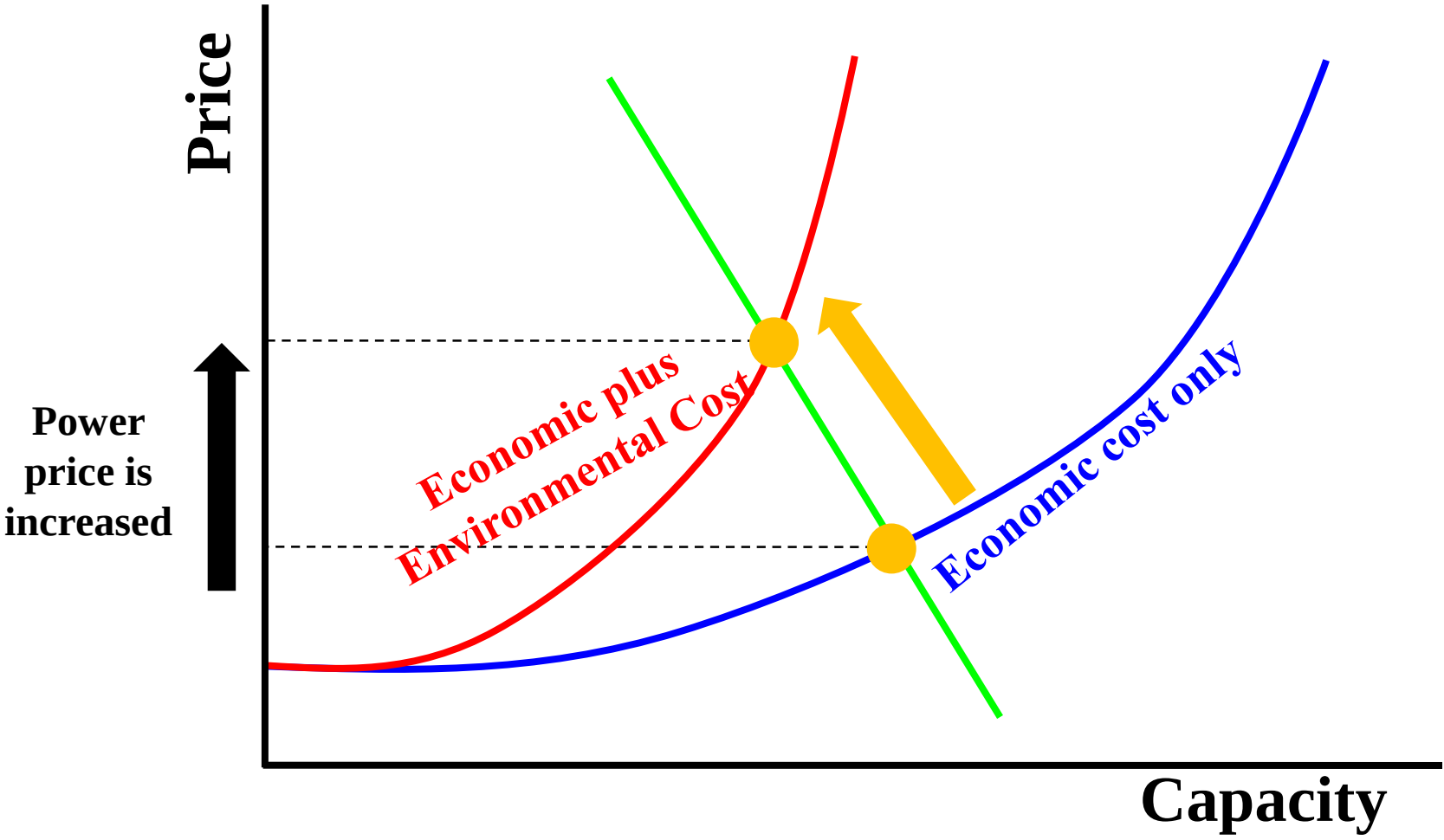
# Environmentally Adjusted Supply Stack

**The red stack in ascending order of cost is *VERY* different from the original blue stack in ascending order of cost**



# The Economic Supply Stack and the Environmentally Adjusted Supply Stack and Their Implications for Market Prices

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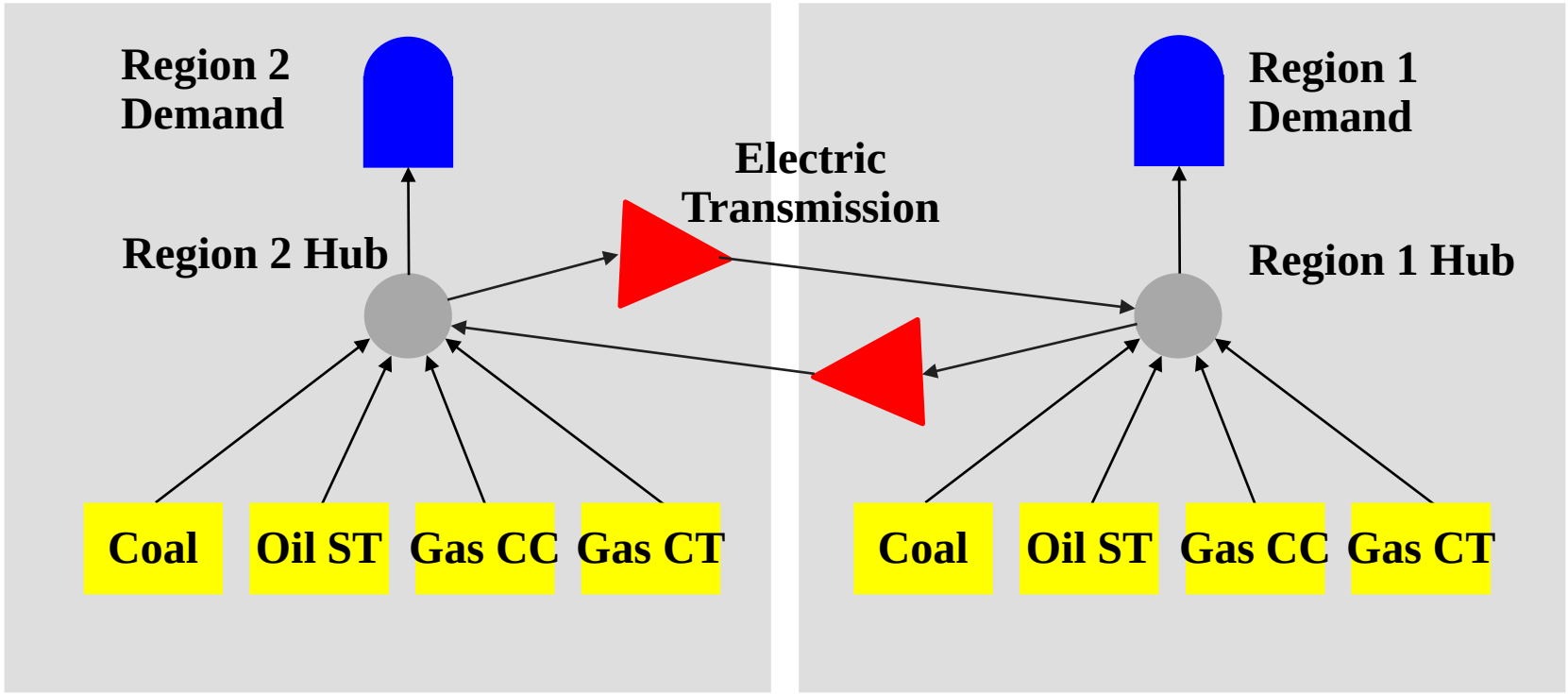
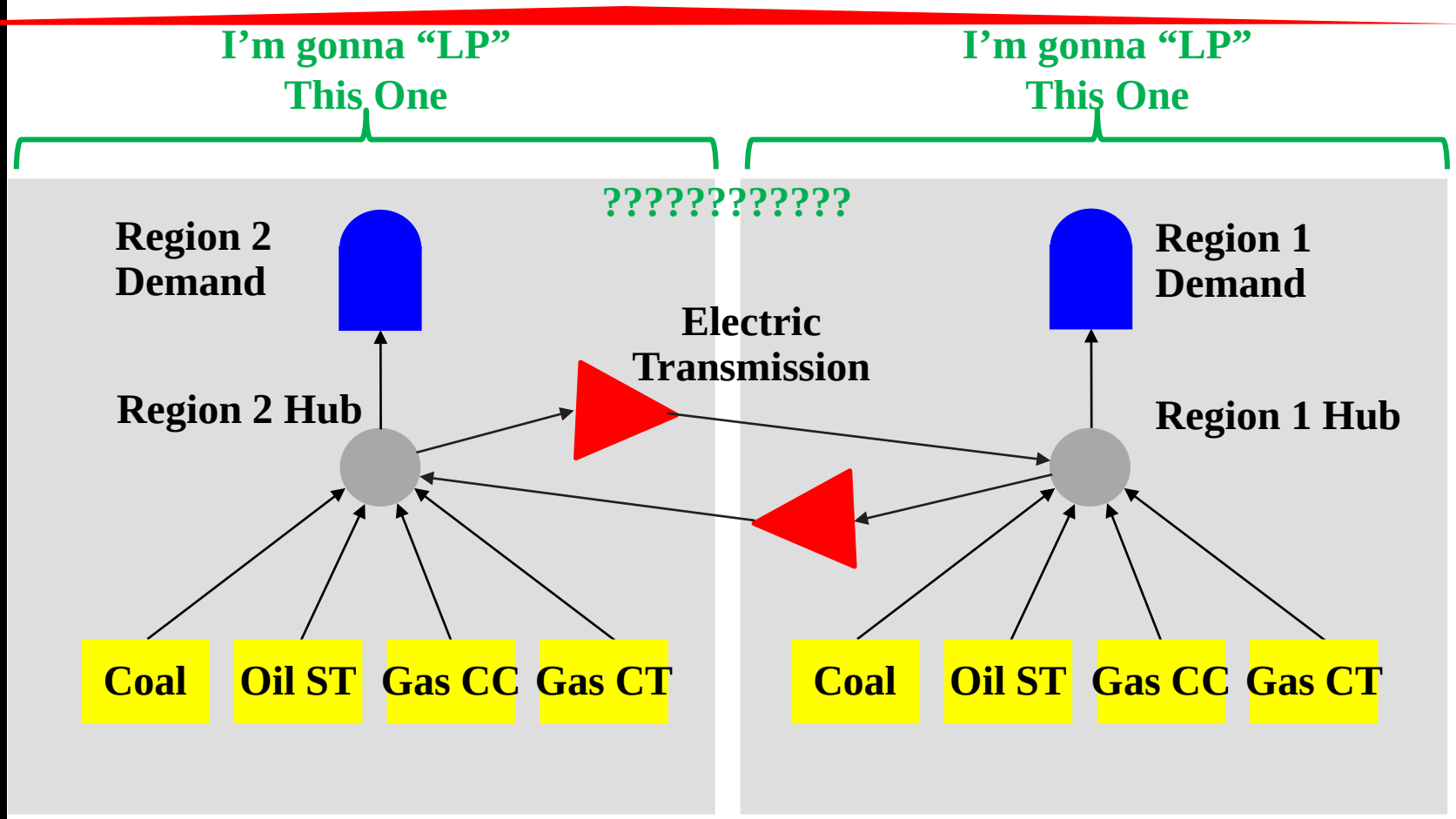
# Every Region Has This Structure—Many Regions Are Hooked Together

- If you don't have a network based technique, you will never get this drawn and done.
- **Spatial equilibrium is nontrivial. We have published on it (Nesbitt and Scotcher, Energy Journal, 2009)**
- Production simulation cant work. LP cant work.



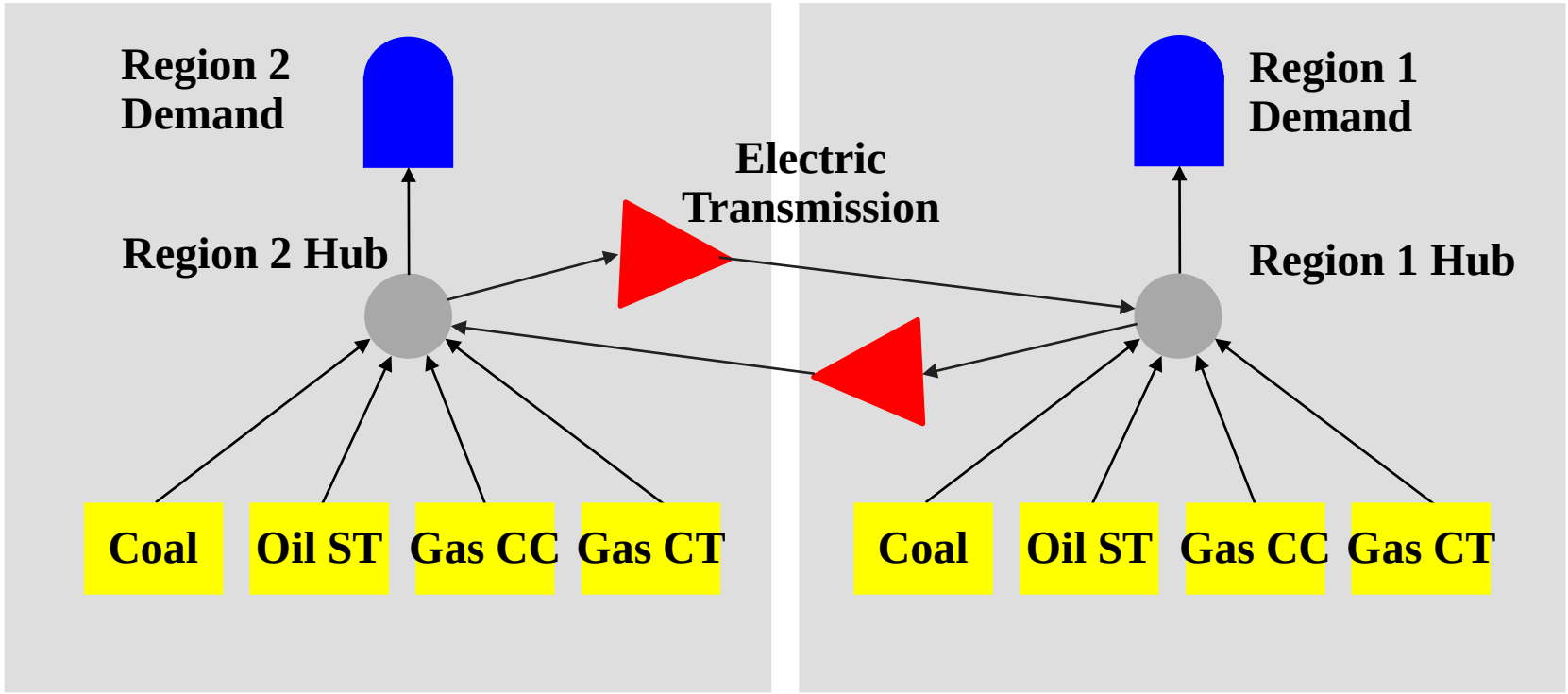
# You Cannot Optimize by Individual Region




How do you hook two independent optima together?
You cant! What if you had 25 such regions?

# You Sure as %^$&%#^ Cannot Optimize Both Regions Together!

I'm gonna "LP" the Whole Darn Thing




Where is the coercive dictator that forces the two regions to act in simultaneous collusive lockstep to minimize cost, foregoing their individual interests?

# If You Want to See Why Global Optimization of Distributed Systems (LP, NLP) Cannot Work

- Refer to my Component Design Report (CDR) on transportation and logistics submitted to EIA in December 2104 http://www.eia.gov/forecasts/documentation/workshops/
- Refer to Nesbitt, Dale M. and Scotcher, Jill N., "Spatial Price and Quantity Relationships in World and Continental Commodity Markets," ***Energy Journal***, *2009*, Special Issue.

# Regionality Is Not Generally Hard; Power Markets Are Generally Balkanized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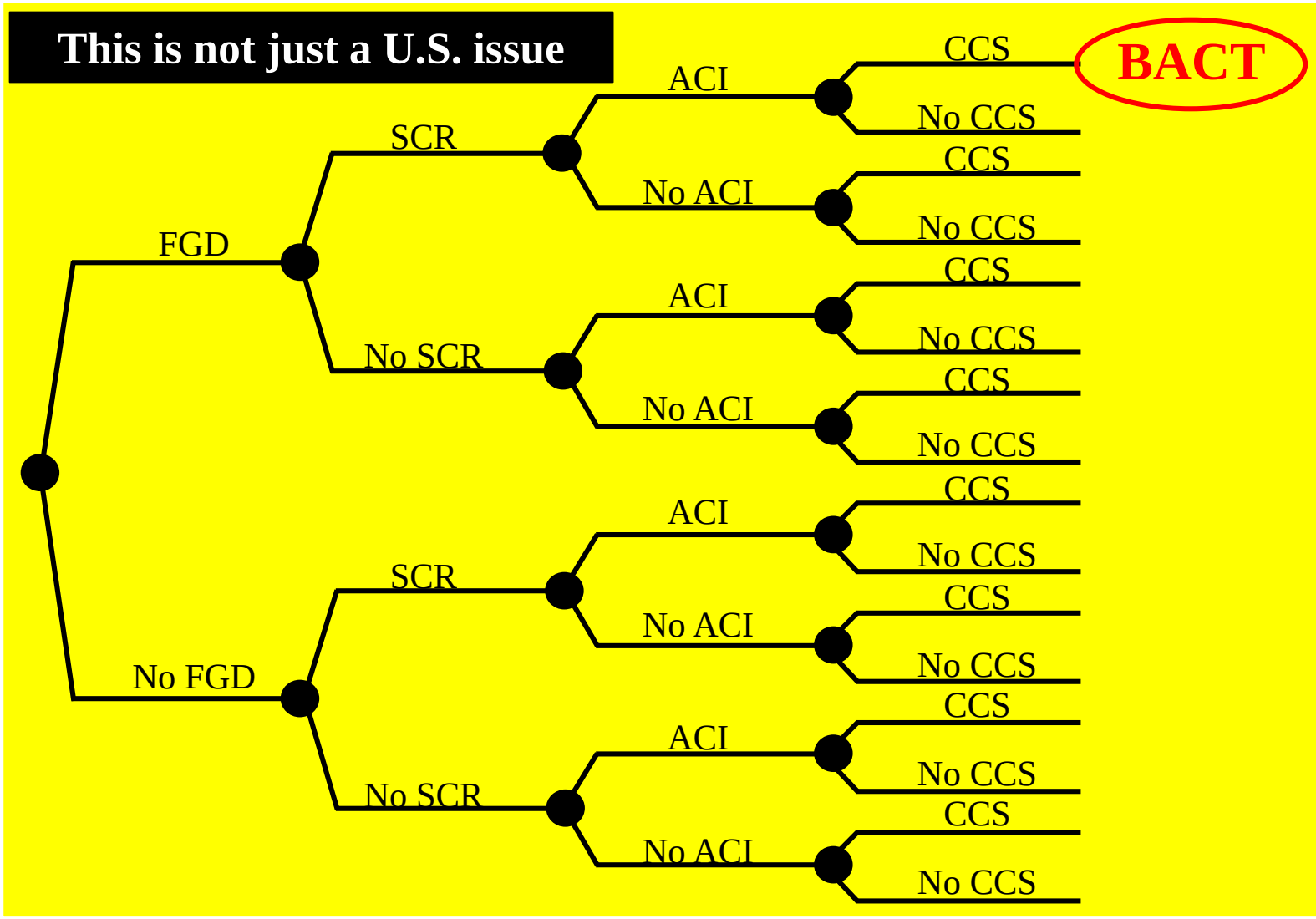
# Every Generation Node (Above) Must Endogenize Retrofit Alternatives for Every Plant

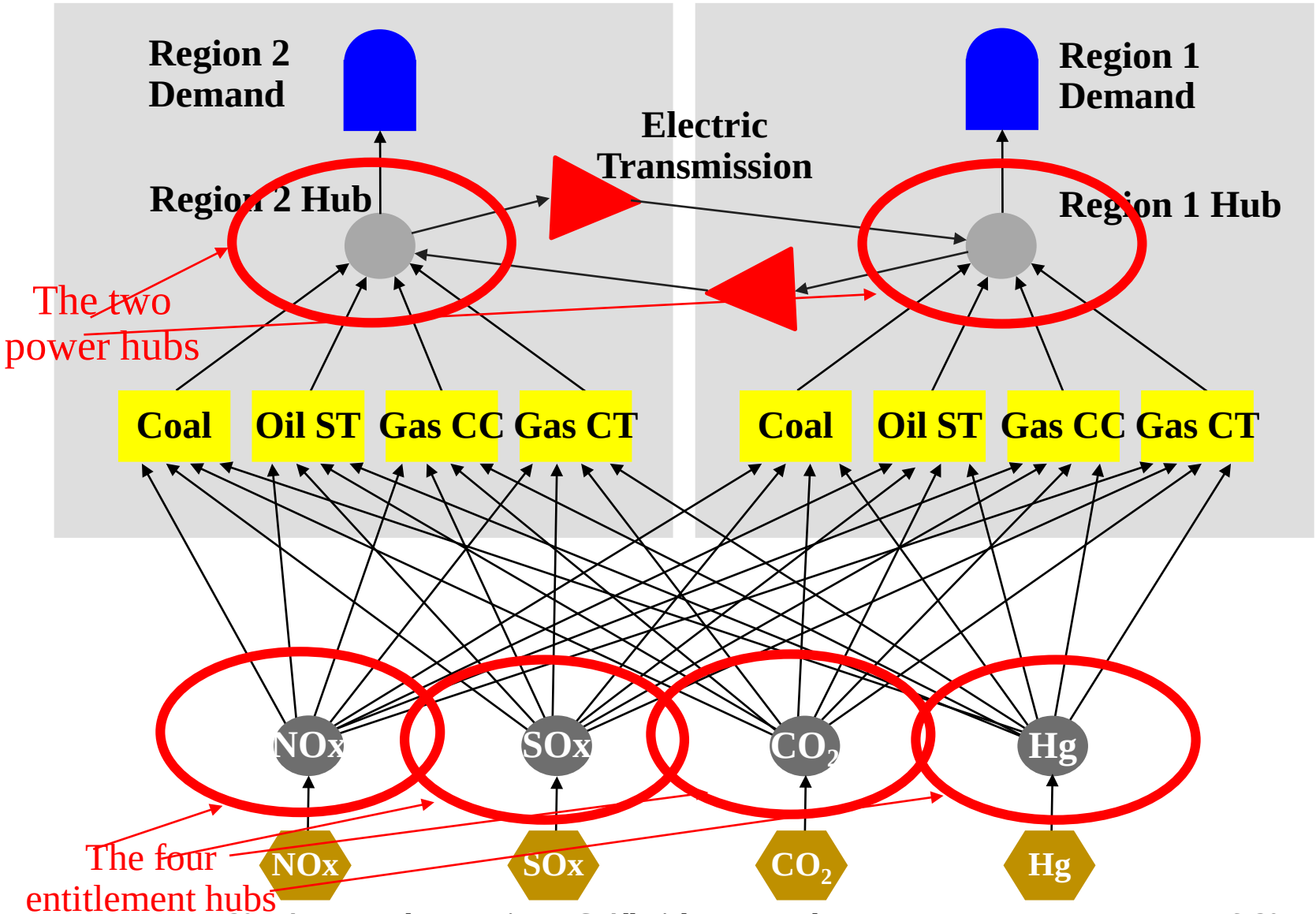


# Regulation Signals

- Individual node or generator level (point source reguations)
- Broader regional level (cap and trade)
- Country level (tax)

- Have to be customized to the specific situation.

# Power Prices Depend on Emissions Prices, and Emissions Prices Depend on Power Prices

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**Allocating Allowances and Passing Them Through in Rates is NOT Economically Neutral!**

It is economically distortionary, and you must model that.

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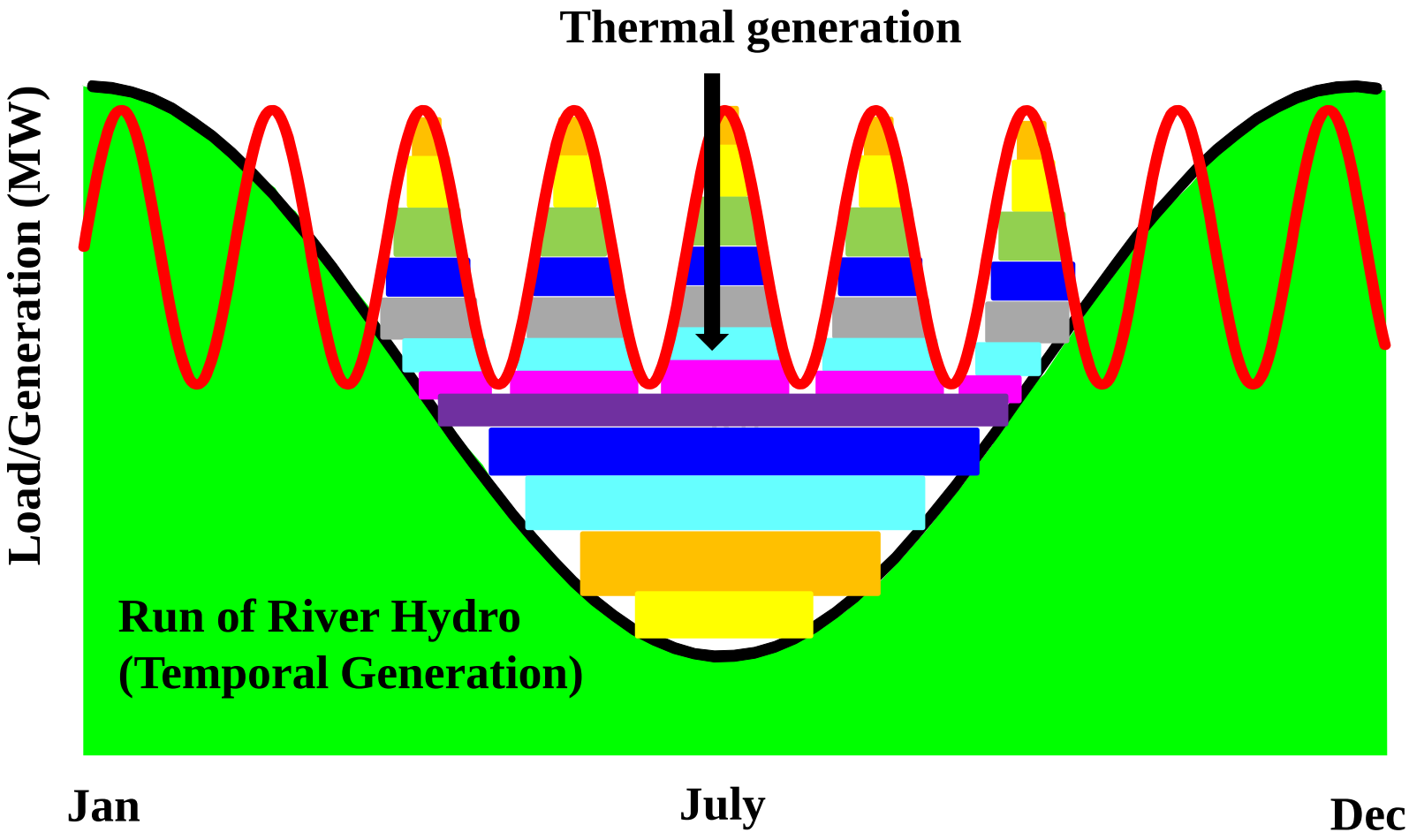
# “Layer In” the Intermittent Sources

# Renewables and Hydro Are Important Everywhere (e.g., Ecuador)

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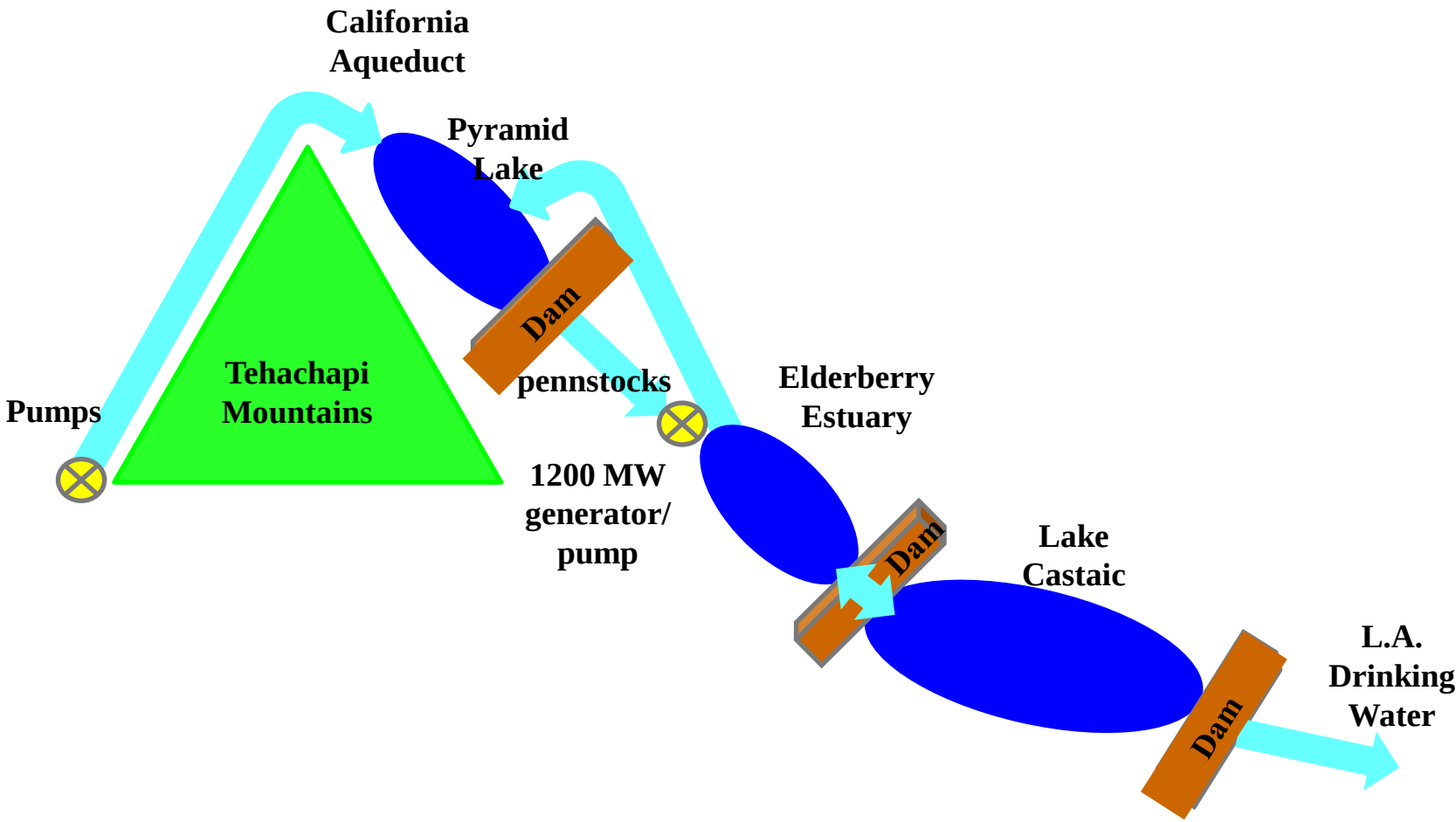
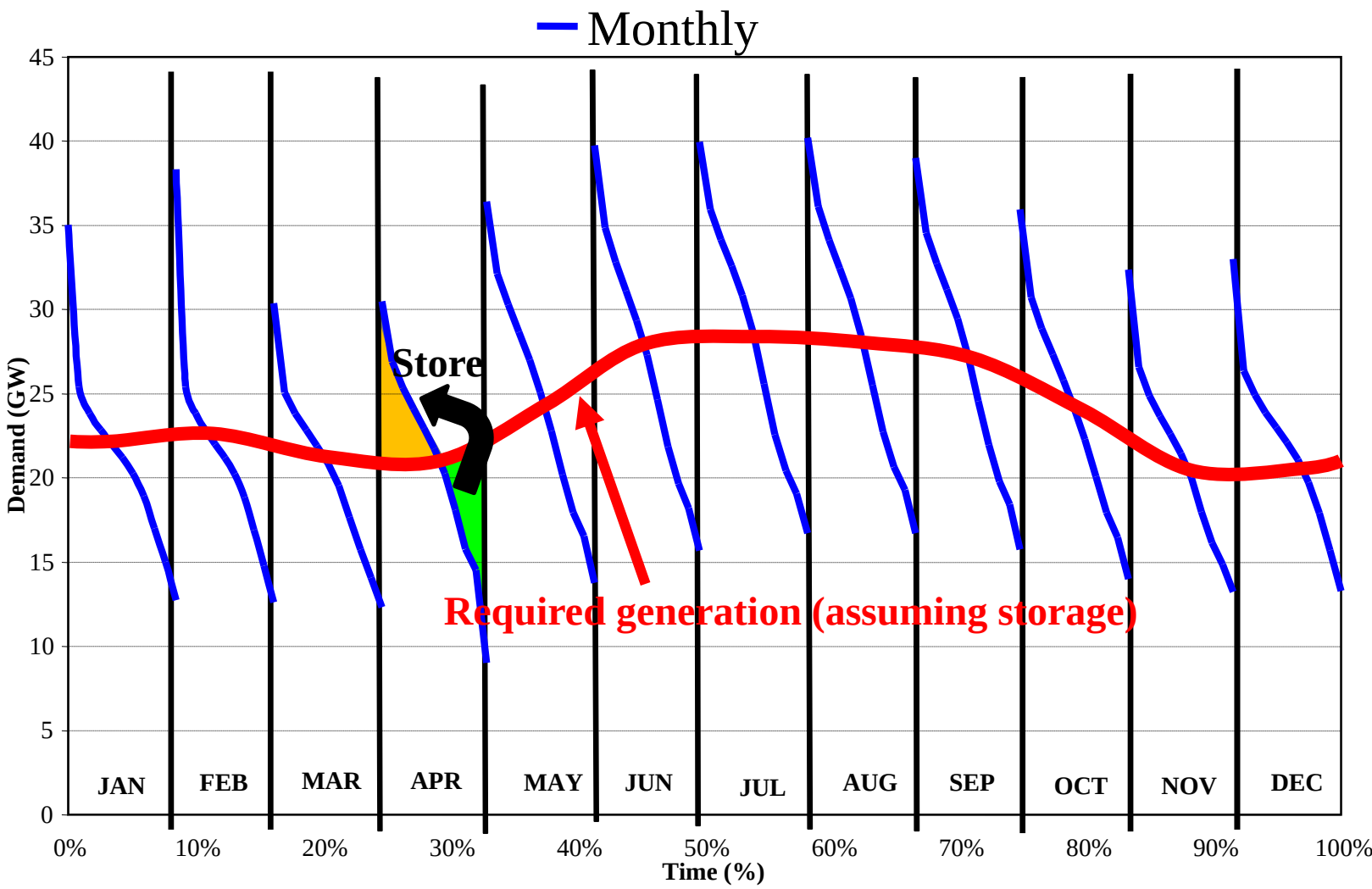
# Storage/Hydro

# Example: Castaic Pumped Hydro Project




You have to model **profit seeking behavior** and **impact of the project on the market**

# Monthly Load Duration Curves (FRCC) With Power Storage

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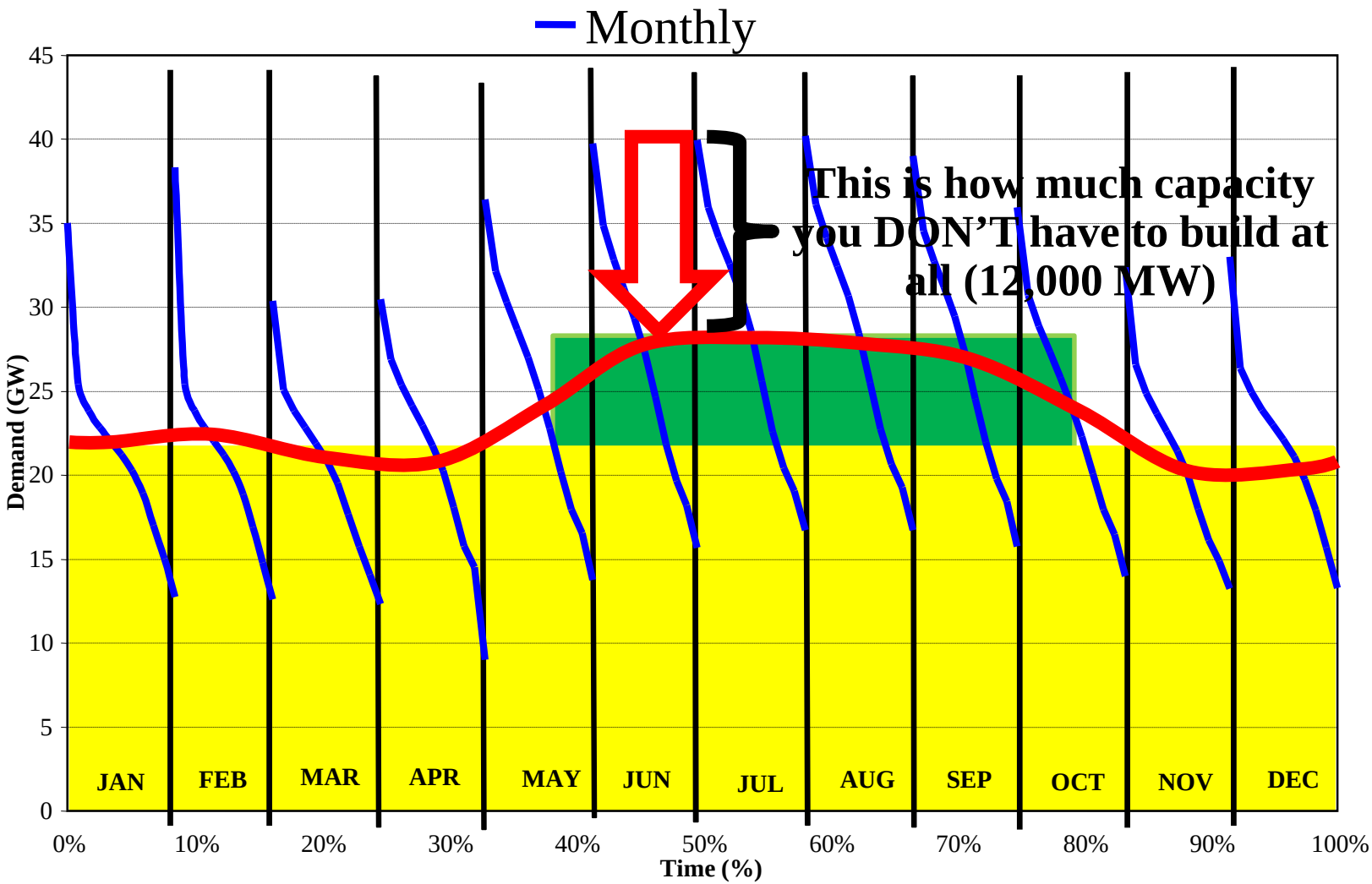


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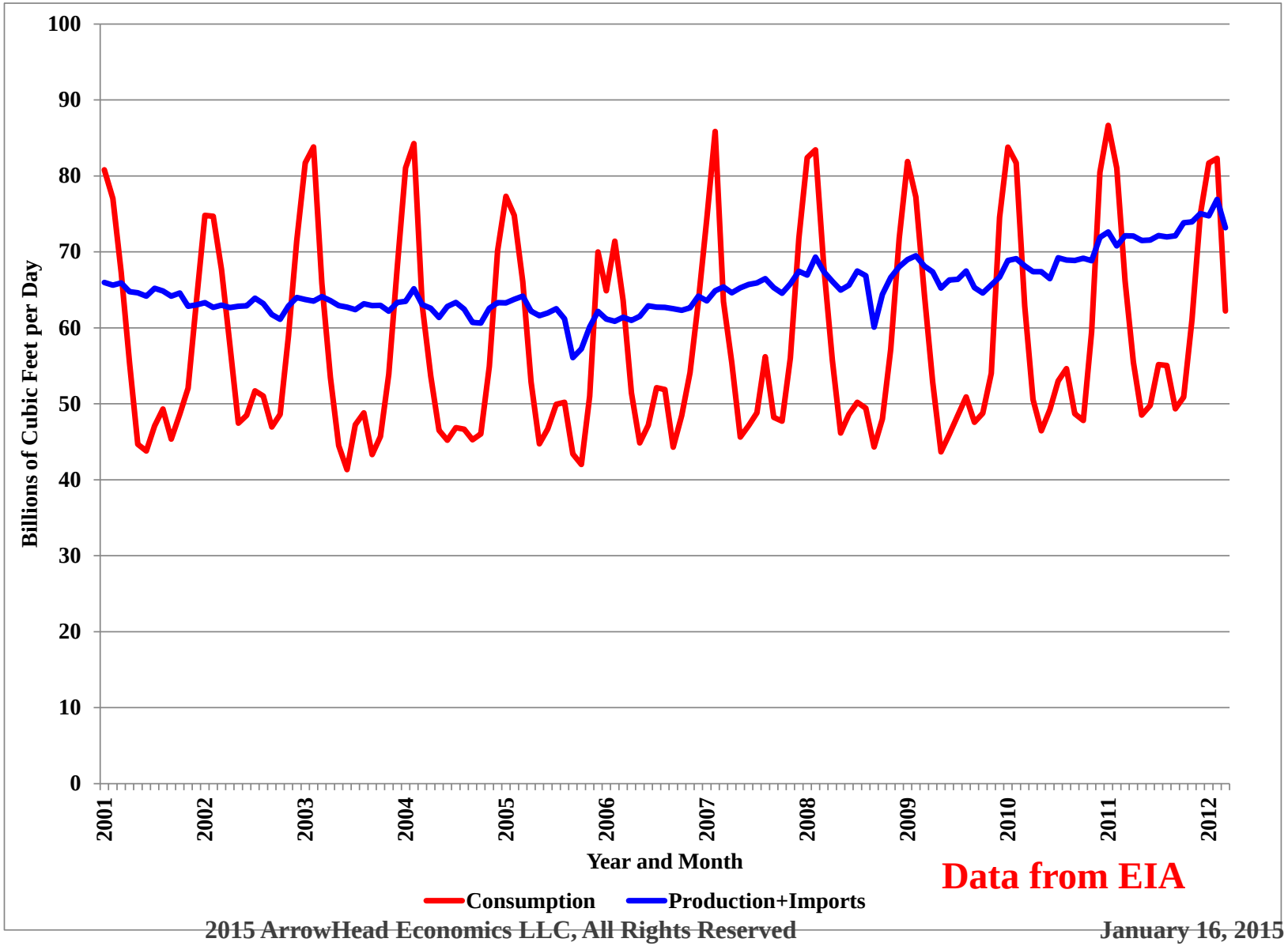
# U.S. Natural Gas Production Is Flat While Consumption Is Strongly Seasonally Peaked

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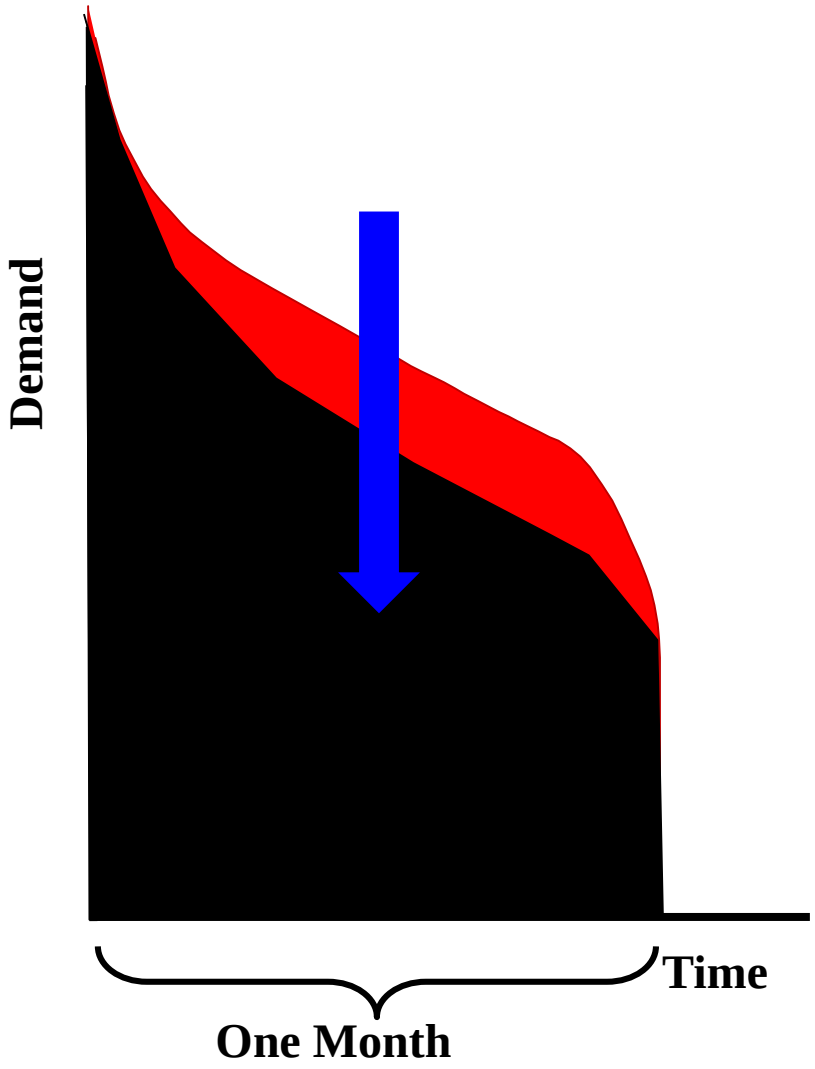
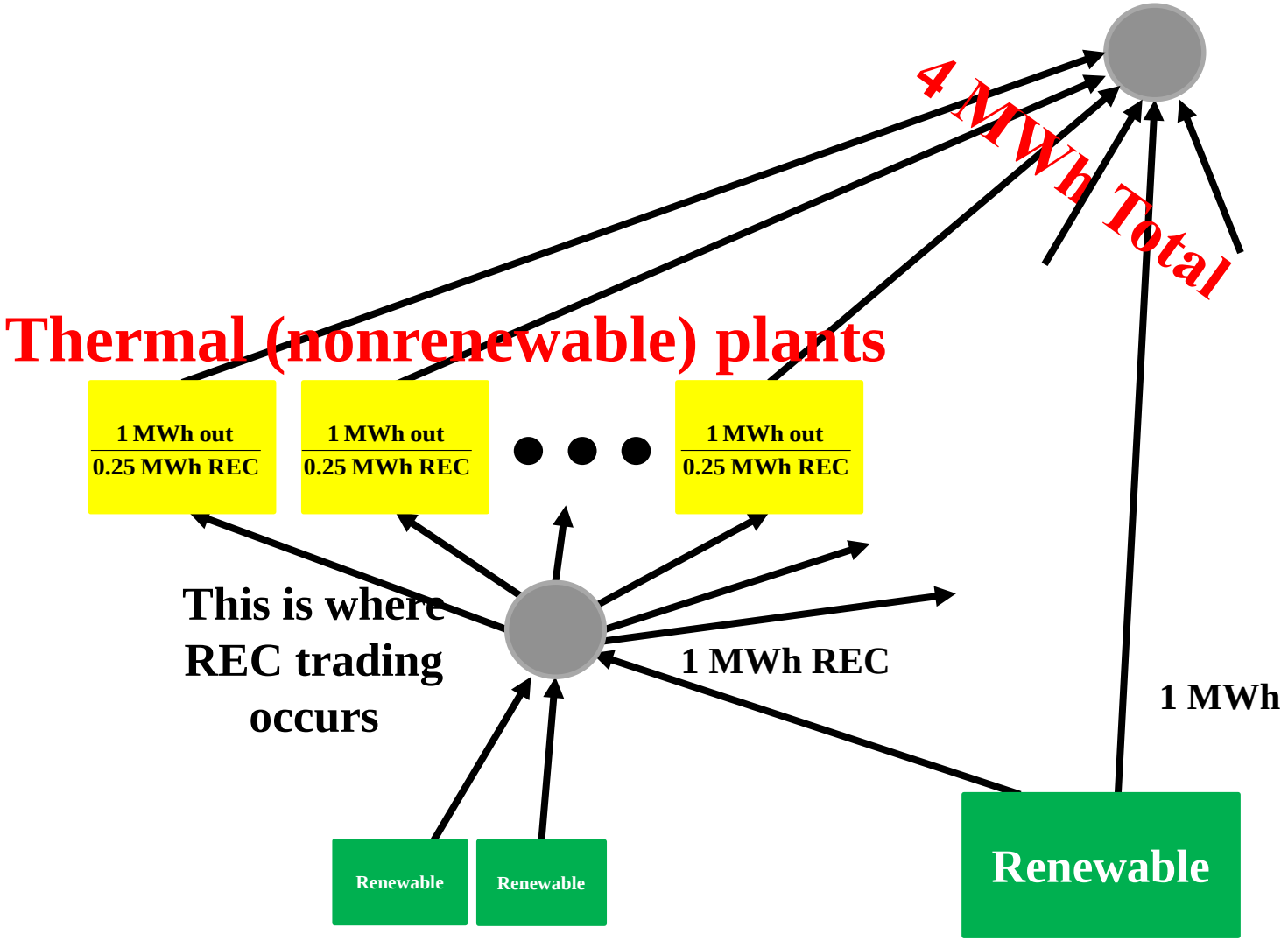
# Renewables, RECs, ROCs, RPS, etc.

# The Residual Thermal Load After Wind Looks Like This



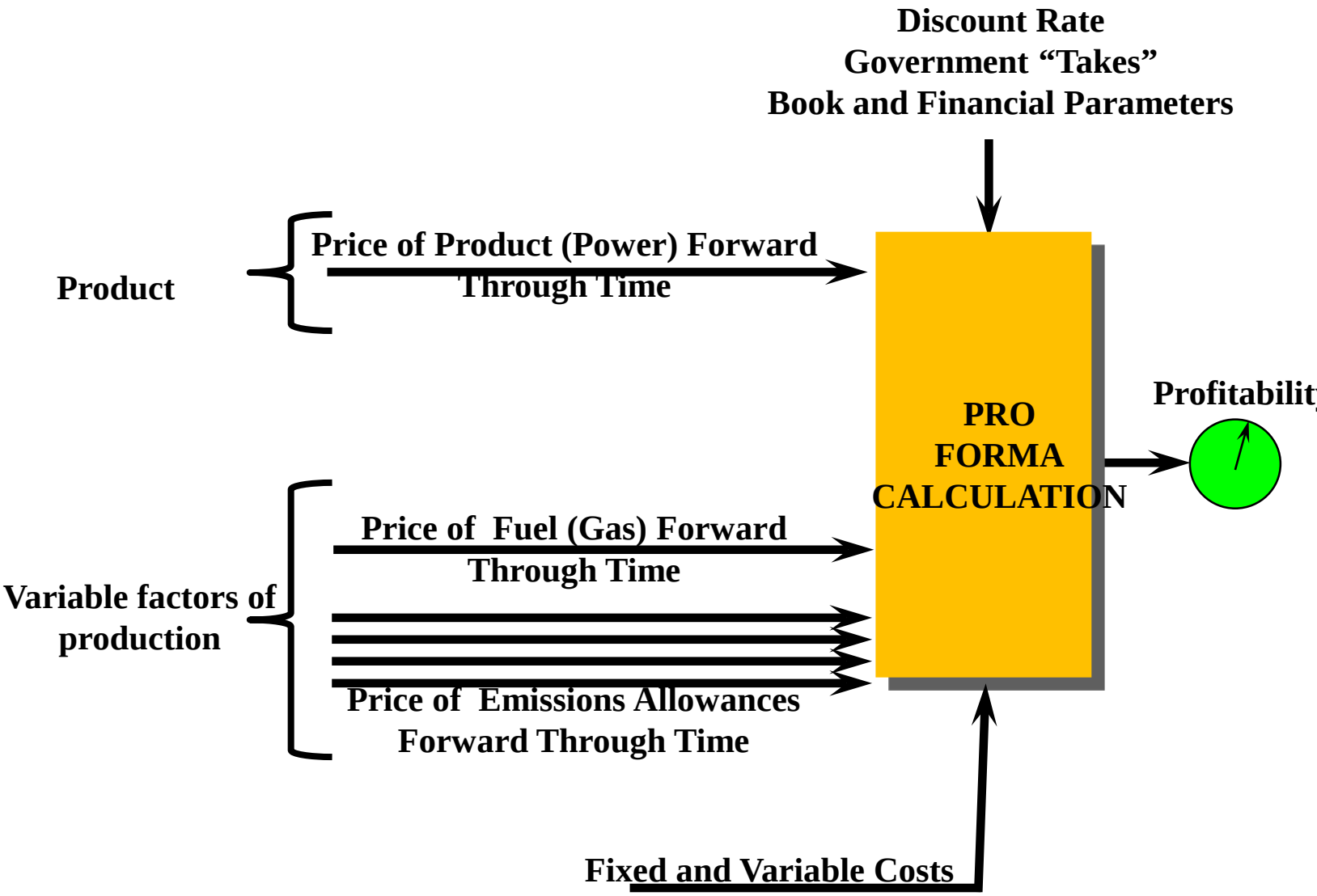

- Wind pushes down the off peak much more than the peak.
- This makes the load shape more peaked for the thermal plants.
- This is already happening in California and Texas; they dump wind energy at time of base and there is little or none at time of peak.
- You have to model this if you tranche your hours

# How Tradable RECs/ROCs Work



# Endogenous Capacity Entry

# Every Node in the Model Has a Pro Forma



# You Need All the Foregoing Issues Modeled non-Hierarchically

- You shouldn't assume one thing "first" and then model other things "second" (e.g., nuclear or renewables).
  - Nothing is hierarchical over something else.
- Agent based approach.
- Comprehensive network representation of all the elements.
- Customize the model for every region/country and link them together by transmission as appropriate.

# What's Hard in International Electricity Modeling?

- Getting fully shaped load (demand) data.
  - MWh aren't enough; you need MW(t)
  - Getting fully shaped load down to the hour like FERC 714s is impossible in many countries; you have to **model** load and load shape
- Country or regional interconnections
  - How is EU interconnected
    - Physically
    - Contractually
- Contracts (e.g., PPAs, transmission contracts, interconnection contracts)
- Identifying, quantifying, and inserting "behind the fence" generation
- Stochastics/reliability

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# Questions Welcome

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