CHANGING WHAT'S POSSIBLE

Electricity Markets for Process Engineers: Why can't you just give us a mass flow?

7/30/2019

Agenda

- Fundamentals of Electricity Economics
- Economic Decision Making for Generation Assets
  - Operational Decisions
  - Investment Decisions
- Implications for CCS Systems

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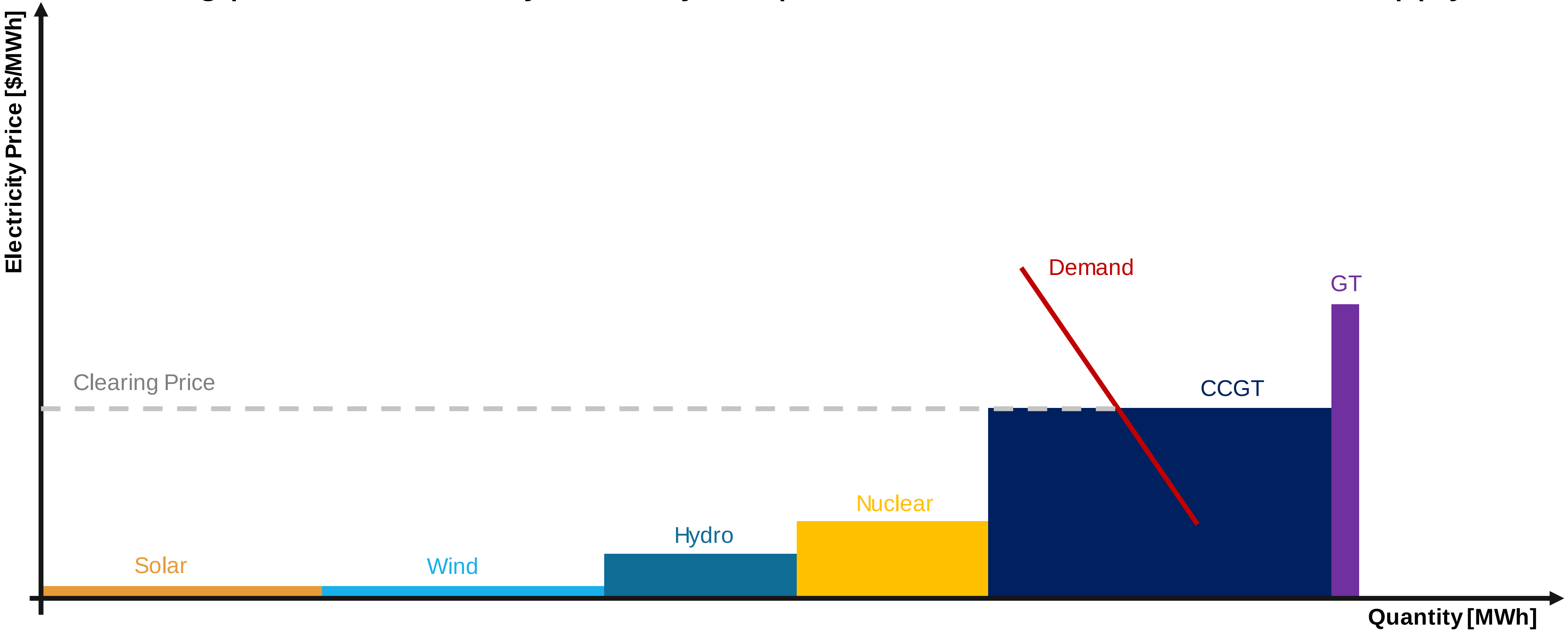
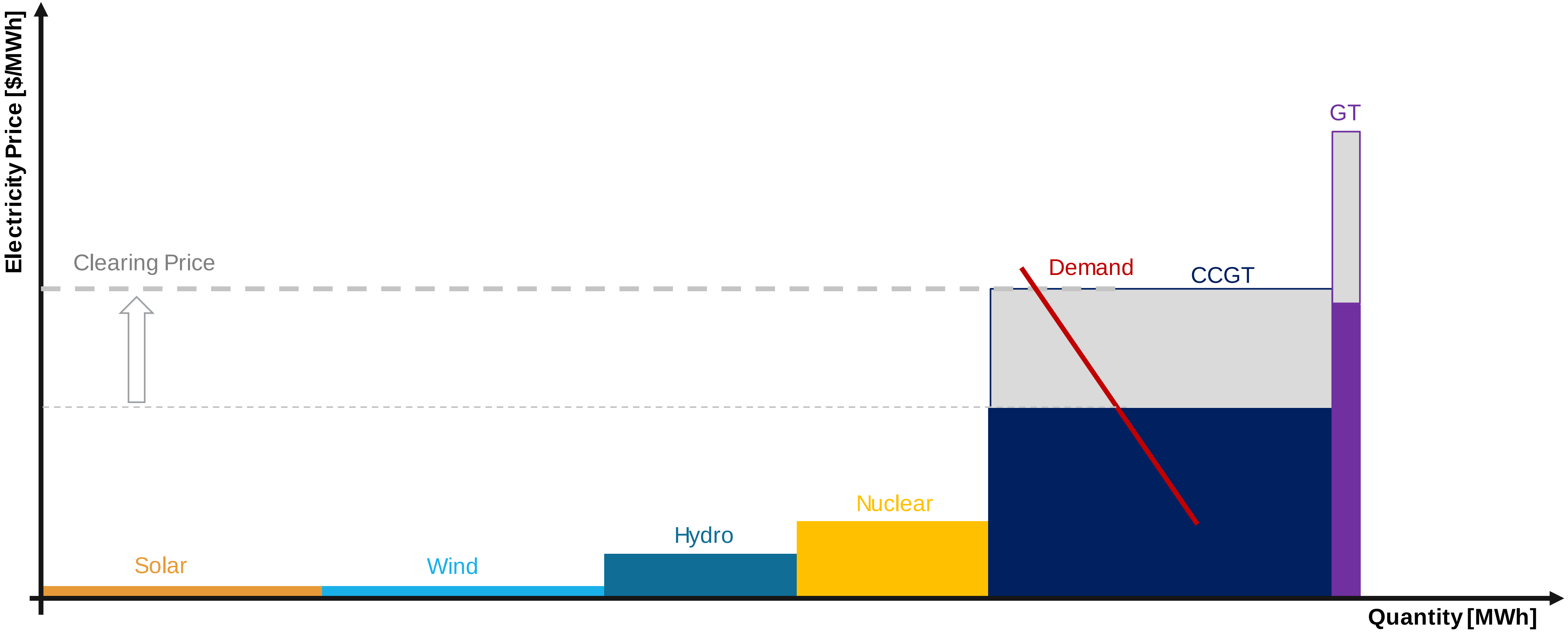
Fundamentals of Electricity Economics

- The electricity “supply stack” is built up from the marginal production cost for each generator in the system
  - Marginal cost consists of fuel cost plus any variable O&M costs
- The clearing price of electricity is set by the price where demand intersects supply



Applying a Carbon Price Increases the Marginal Cost of Emitting Resources

- A carbon price would manifest itself as a marginal cost for carbon emitting generators
- When a fossil generator is the price setting unit, this increases the market electricity price



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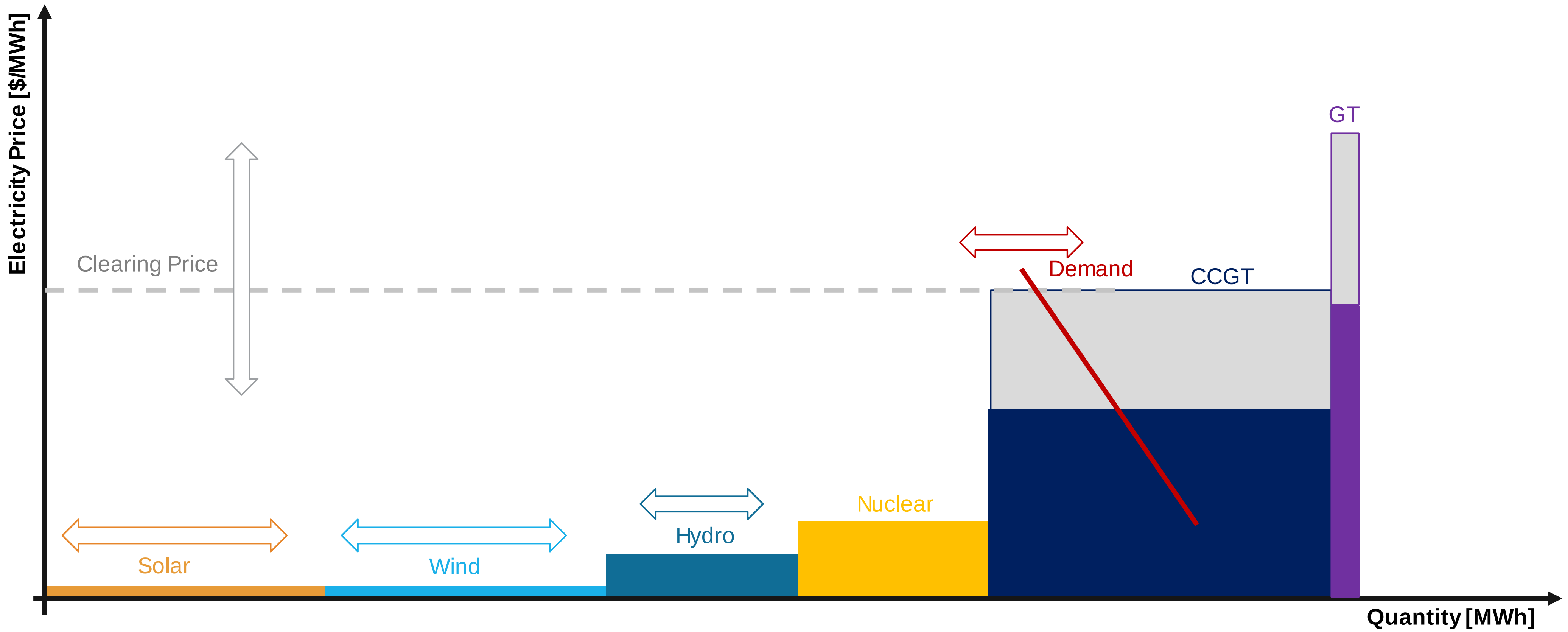
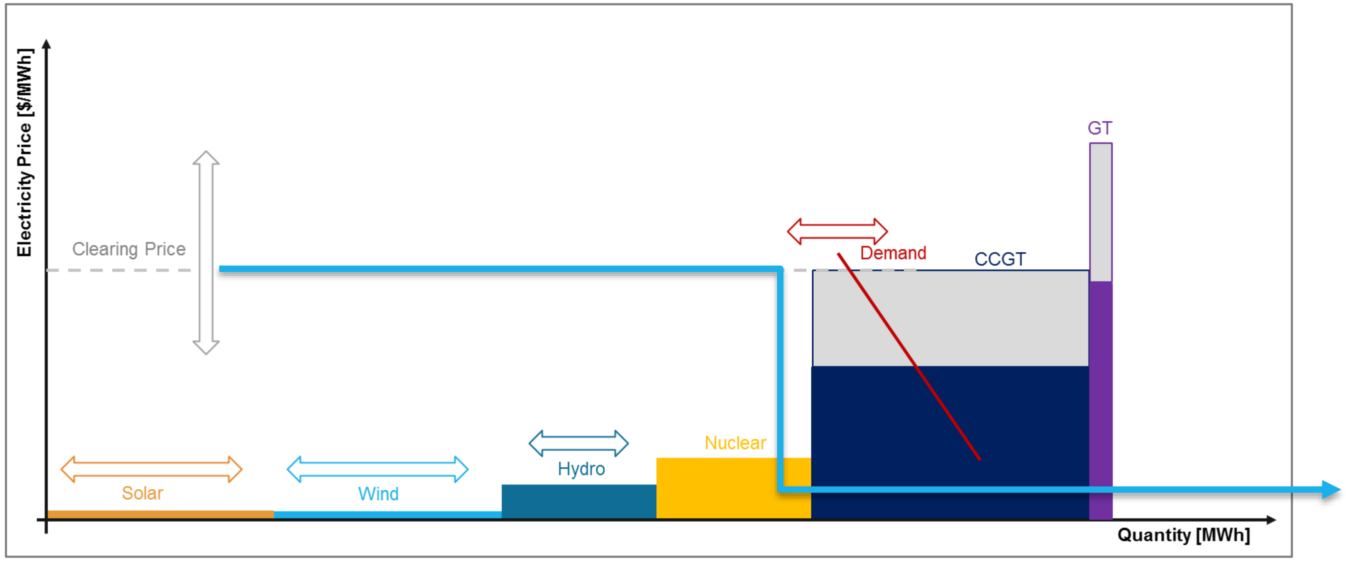
Continuous Balancing of Supply and Demand Results in Changing Price

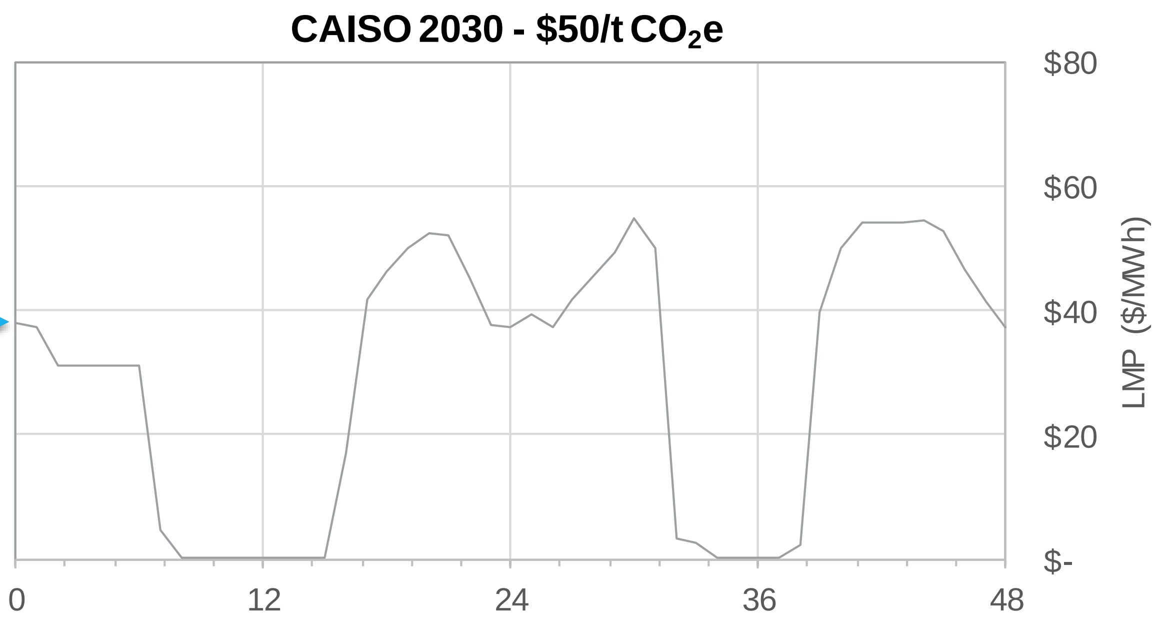
- Both the supply and demand characteristics of the market are continuously changing
- Output from variable resources shift the supply stack, while changes in electricity consumption move the demand curve



Electricity Value Represented by a Locational Marginal Price

- The continuous balancing of supply and demand leads to a shifting system price
- Physical system constraints (transmission) drive additional differences in price at each node within an electricity network
- The resulting price for electricity is the Locational Marginal Price (LMP)





2030 estimates from LBNL 50% RPS study (Balanced Portfolio scenario): Seel, Joachim, Andrew D. Mills, and Ryan H. Wiser. "Impacts of high variable renewable energy futures on wholesale electricity prices, and on electric-sector decision making." (2018).

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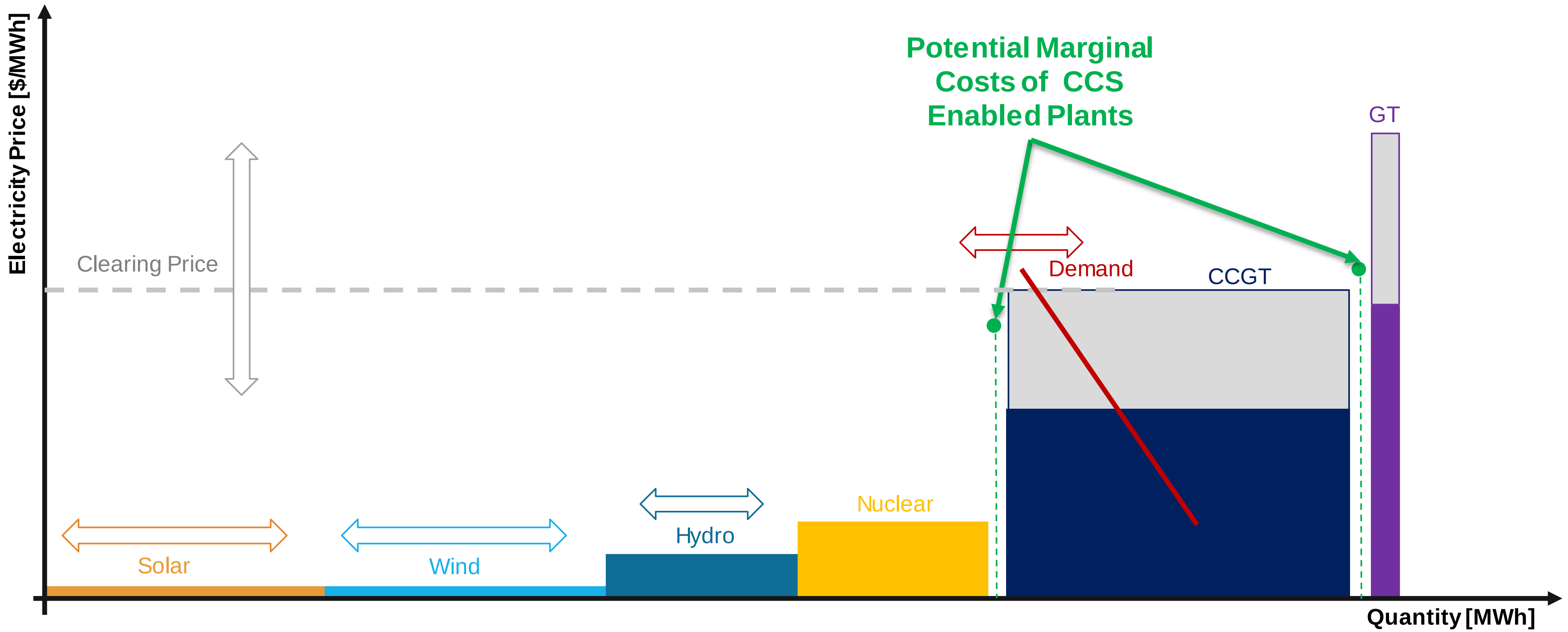
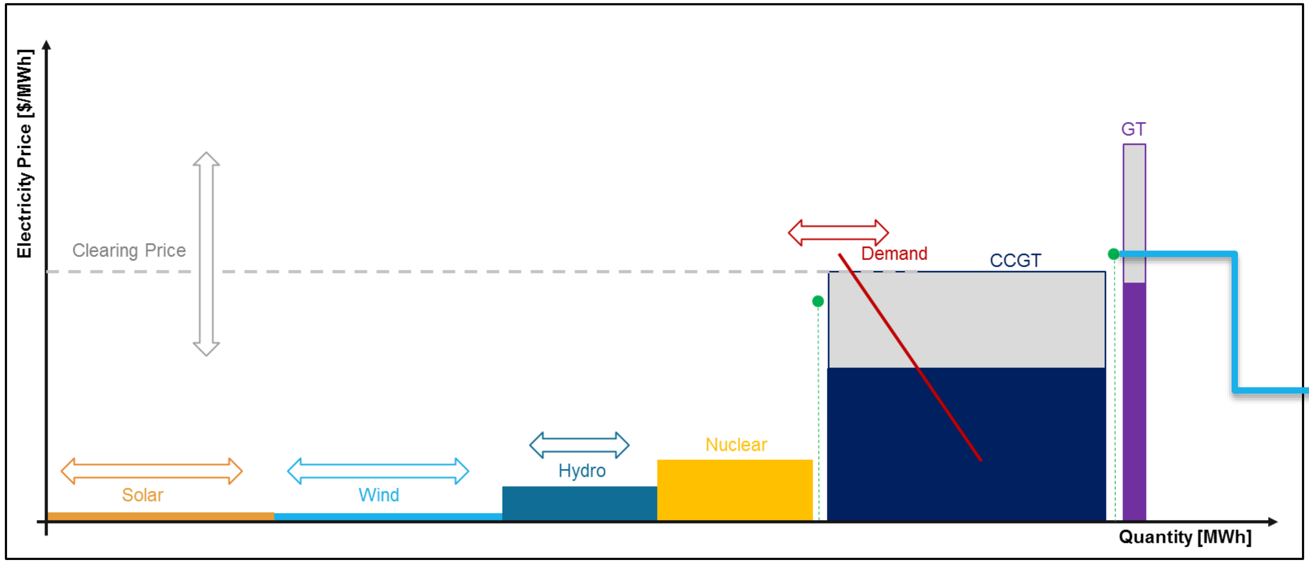
Marginal Cost of a CCS Enabled Plant Will Dictate Its Order in the Supply Stack

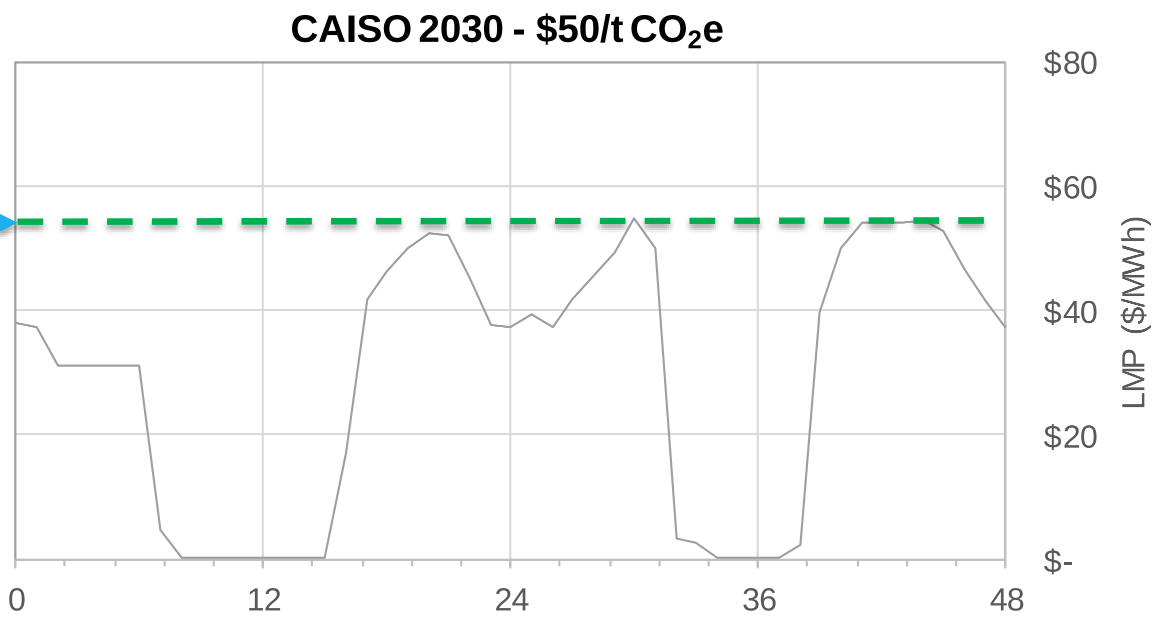
- Depending on the operational economics of a CCS enabled plant, its marginal costs may be higher or lower than a non-CCS unit subject to the carbon cost



High Marginal Cost CCS Unit

- If the marginal cost of the CCS enabled unit falls above other dispatchable resources on the grid, the price of electricity will rarely rise to a level that enables profitable operations
- In this scenario, the optimal economic decision is to not run the plant at all





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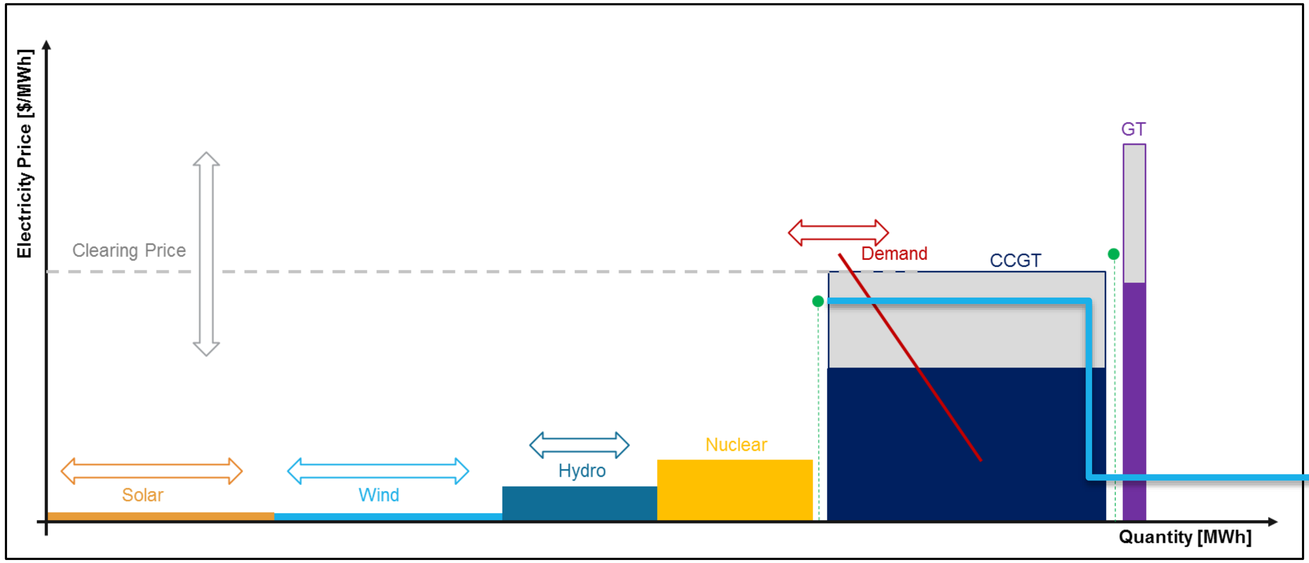
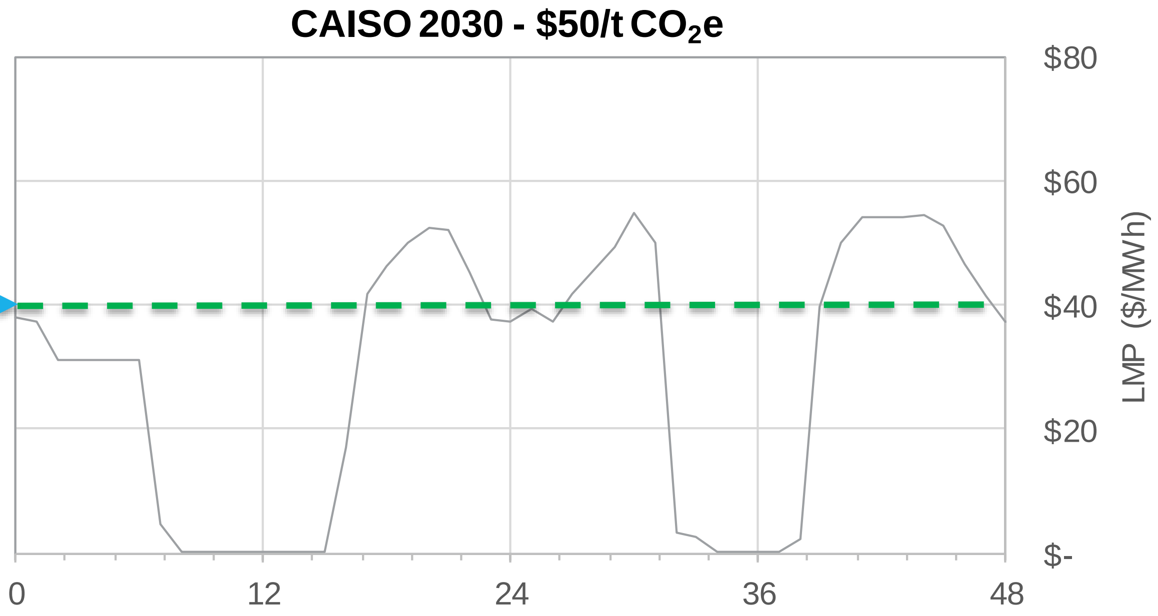
Low Marginal Cost CCS Unit

- When a CCS enabled unit represents a lower marginal cost option than other dispatchable generators, then the electricity price is likely to regularly exceed the level required for the plant to generate operational profits
- The plants operations will be optimized to maximize earnings and minimize losses





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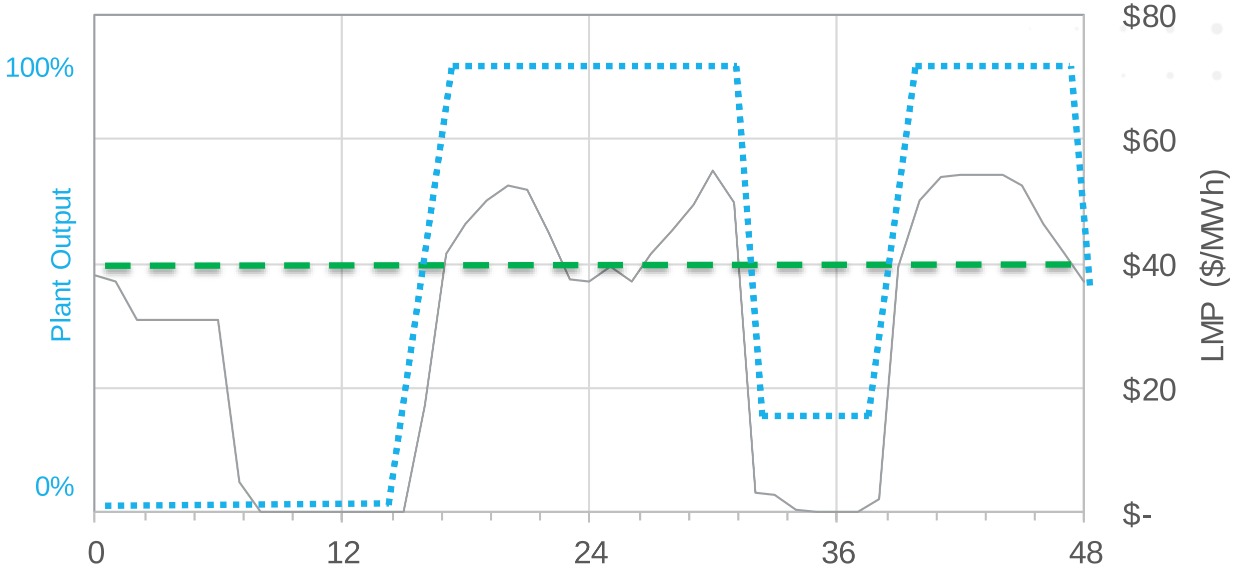
Idealized Unit Dispatch

- Plant ramps up to capture periods of profitability
- For extended periods of where prices fall below costs, plant is shut down
- For shorter loss-making periods, plant is ramped down, but not turned off
  - Avoids costs associated with startup
  - Enables faster ramp up
  - Reduces total losses



- **Physical constraints imposed by the CCS process will impact the economics of operation**

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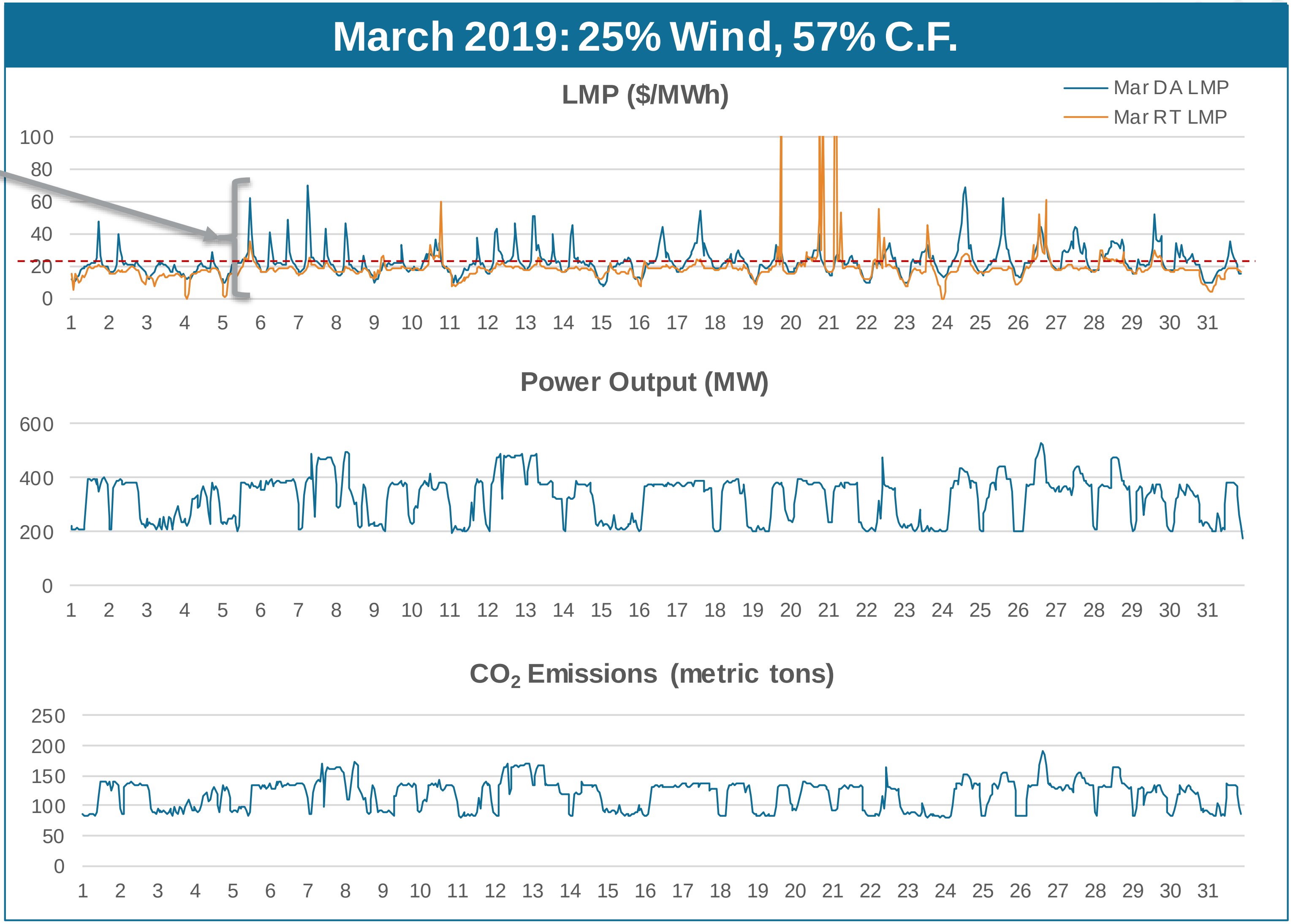
Real CCGT Unit Dispatch Example

Price swings due to fluctuations in both wind output and demand, including unexpected RT price swings

Sustained periods of pricing below variable cost with short irregular profitable periods



LMPs from ERCOT North Load Zone
Plant data from EPA's Air Markets Program Database (AMPD) for Wolf Hollow II plant

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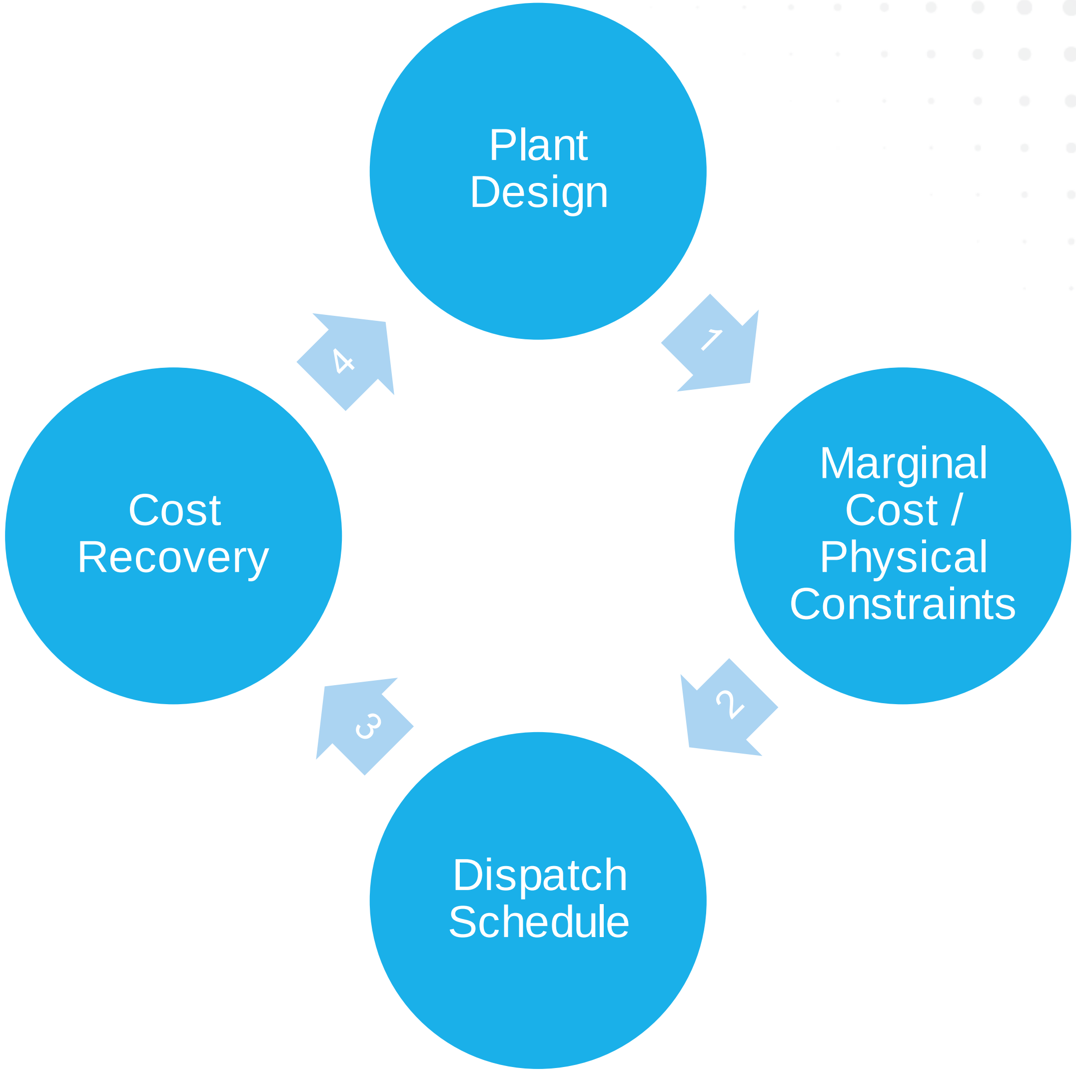
A (CCS equipped) plant's operating profile is linked to its design

1. The design of a plant determines how costs vary with respect to output

2. Under an economic dispatch framework, plants are scheduled for operation in accordance with their marginal costs

3. A plant's dispatch schedule dictates its capacity factor and the energy-based revenues that it earns

4. The anticipated earnings of a plant drive design and deployment decisions



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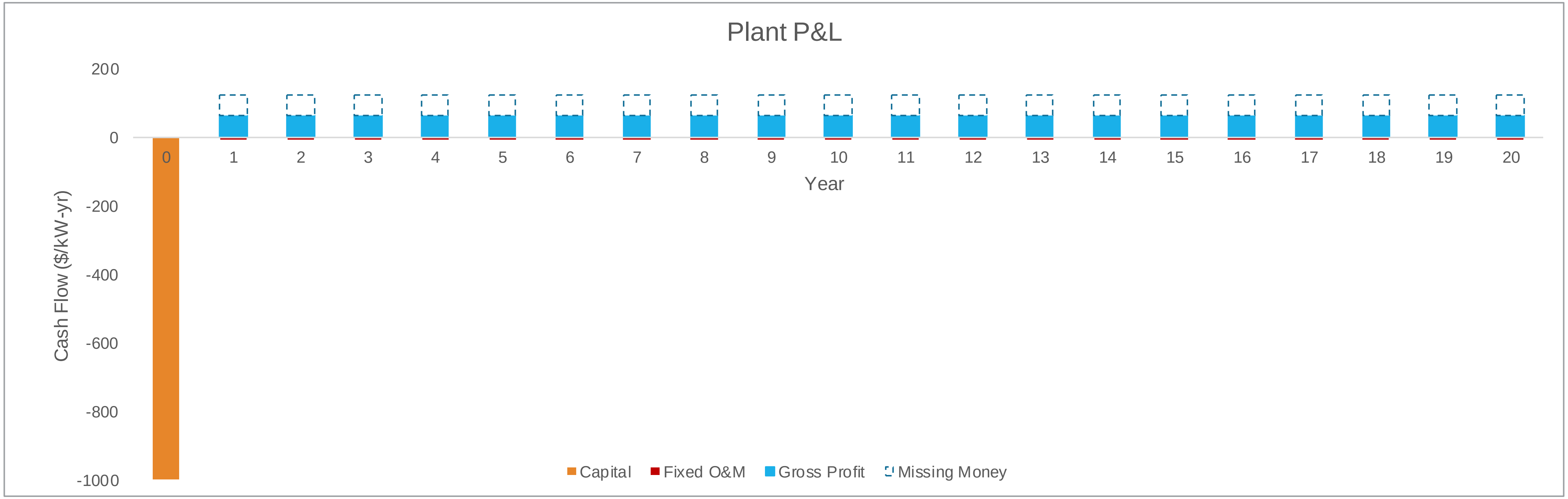
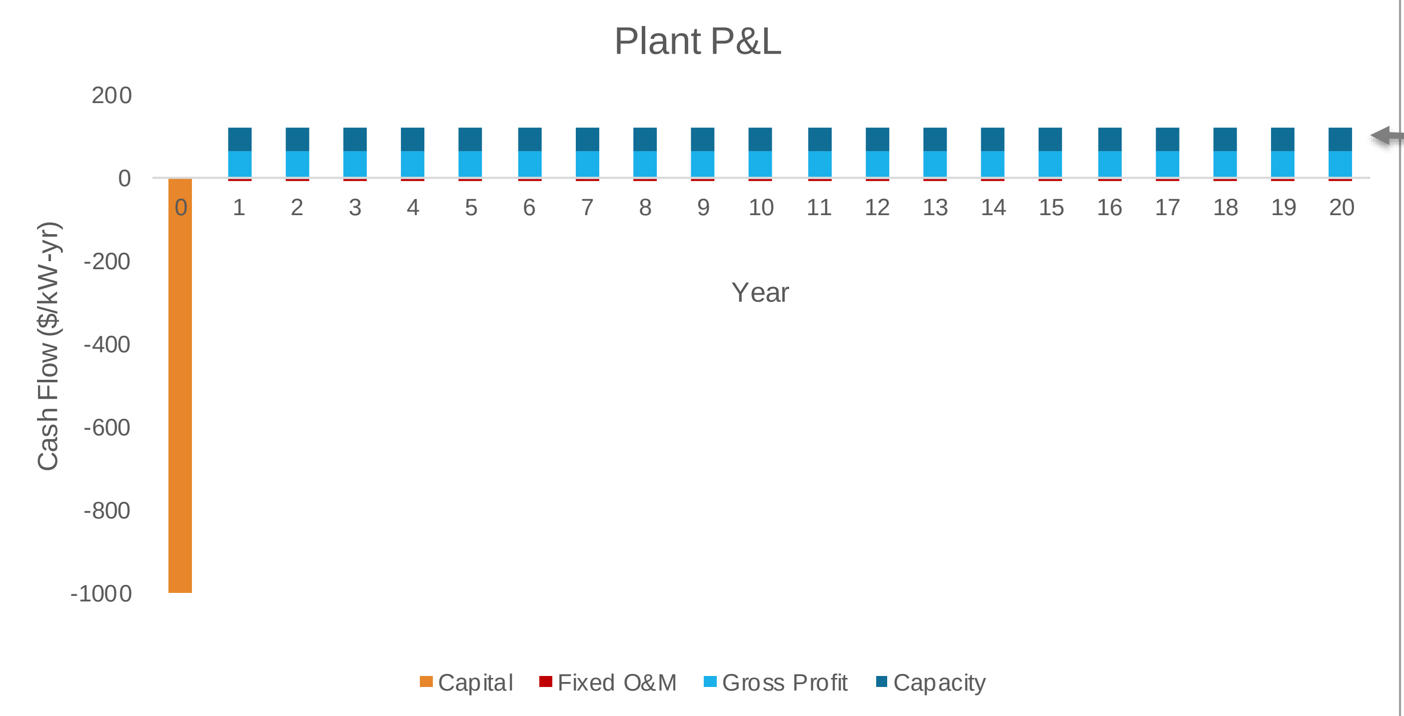
And Now, The Rest of the ~~Story~~ Money

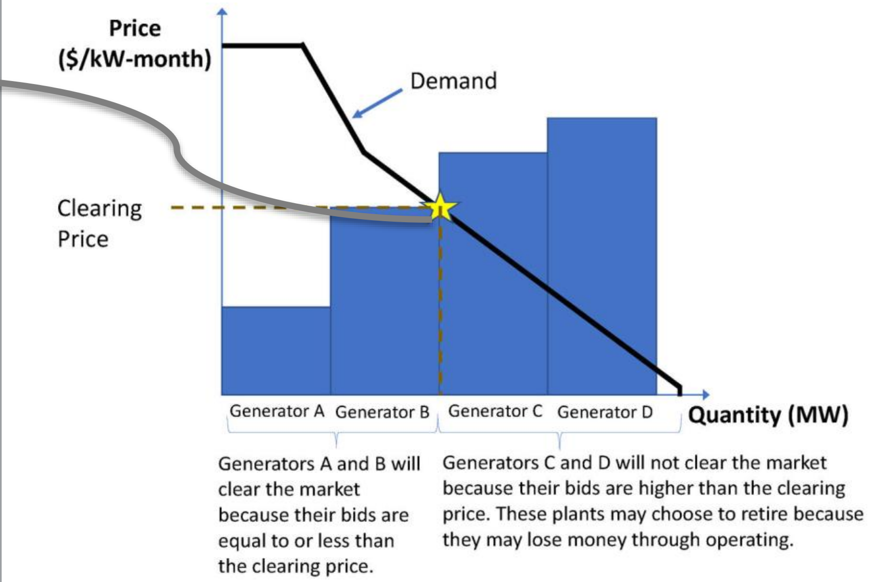
- An existing plant continues to operate if its gross profit exceeds its ongoing fixed costs
  - *Gross profit = [electricity revenues - variable costs]*
- A new plant, however, will only be constructed if justified by a sufficient rate of return
- The gap between these values is often referred to as the “missing money problem”



Finding the Missing Money

- In many markets, the "missing money" gap is filled by capacity payments
  - Texas' ERCOT market does not use this mechanism, instead has high scarcity pricing in its energy market
- 1st and Nth plants likely to have different capacity payment requirements
- **Designs that require lower capacity compensation can be more successfully deployed**





Source: NRDC

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Market Implications for CCS Systems

- Marginal costs of operating a CCS equipped power plant dictate its opportunities for generating operational profits
  - Maintaining a marginal cost lower than conventional generators exposed to a given carbon price likely critical for maintaining a sufficient capacity factor
- Physical constraints imposed on the power plant by the CCS unit can hamper the plants economic performance
  - Maintaining power plant flexibility (ramping rate and turndown) likely to be important
- Capacity payments likely to be a key source of revenue for CCS enabled plants – minimizing the capacity payments required will be important to drive initial investments
  - In the long-term, deployment of CCS enabled plants will impact energy revenues, shrinking any gains from the marginal cost advantage against a carbon price

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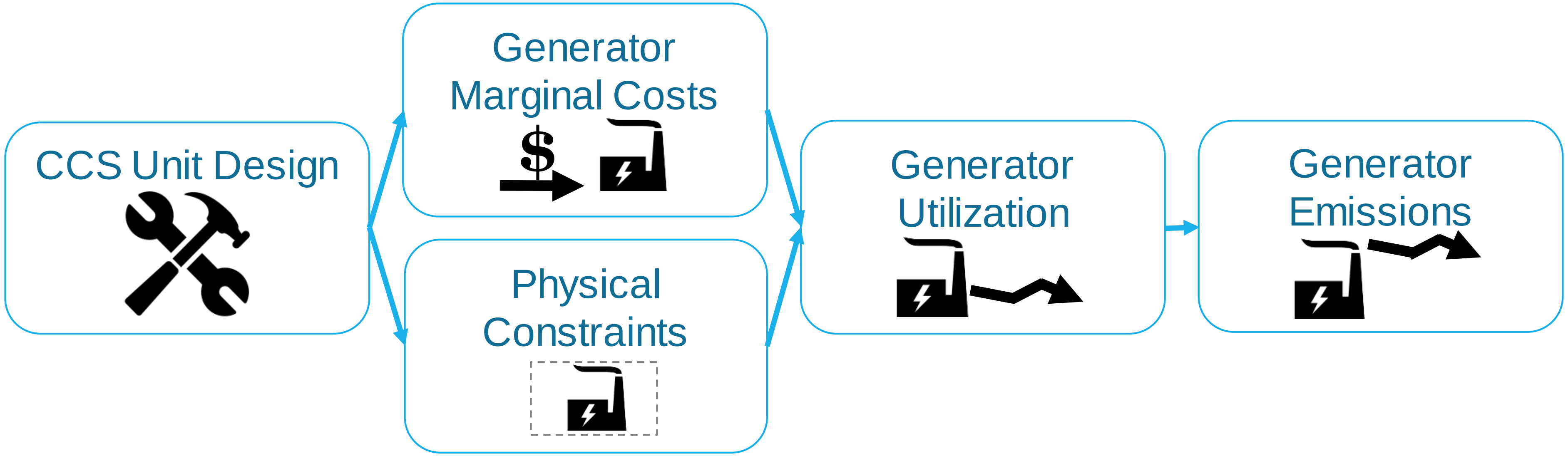
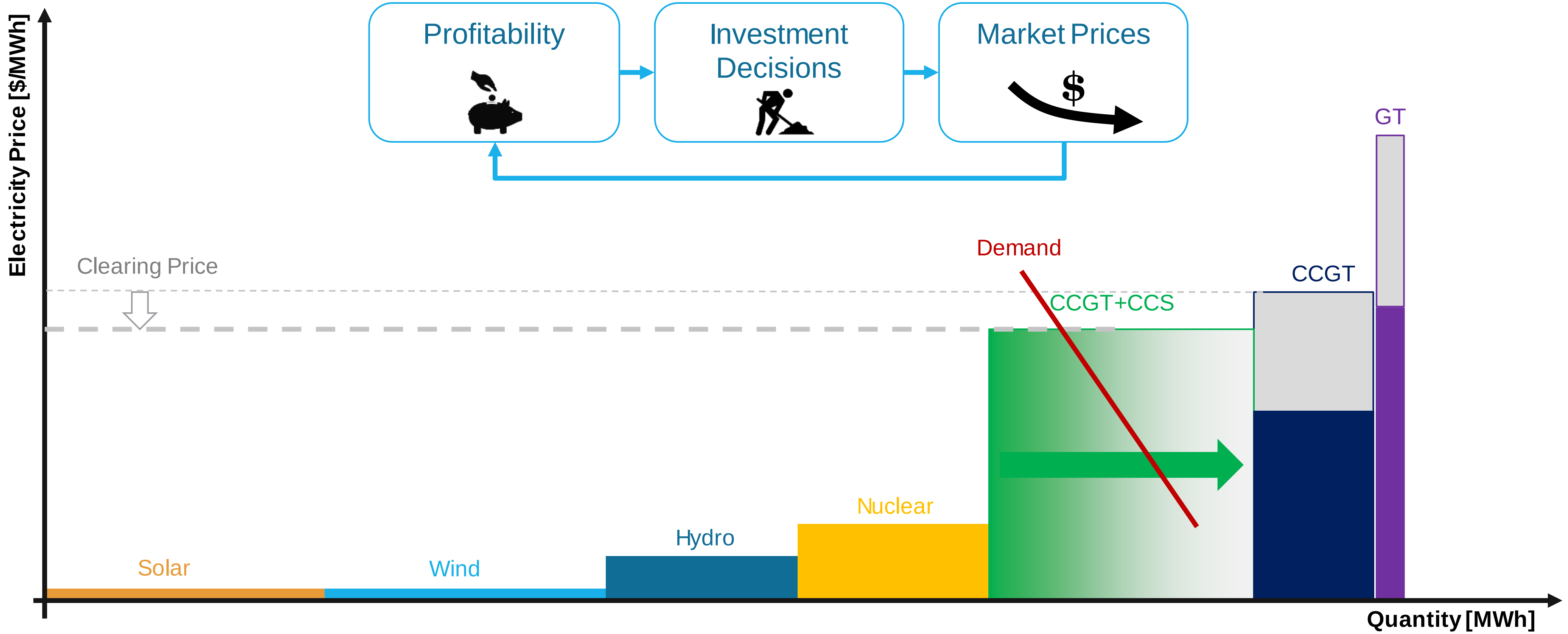
A deterministic CO_2 flow profile cannot be provided because the ultimate power plant generation profile will be a function of the design properties of the CCS unit



Market Conditions Are Not Static

- For a first of a kind plant, economics can be optimized for an one or more assumed LMP profiles
- As a technology becomes a meaningful component of the supply stack, it impacts market prices
- Capacity expansion models that analyze this feedback loop are used to evaluate capital expenditure decisions



Investment Planning Requires Long Time Horizon System Modeling

- The inner iterative loop, driven by a dispatch model, evaluates the ongoing operational performance of a plant
  - Optimizes for dispatch given physical characteristics and market signals
  - Evaluates design tradeoffs under given market characteristics

- The outer loop, capacity expansion, evaluates the scale of deployment for all available technologies and how that deployment impacts the market