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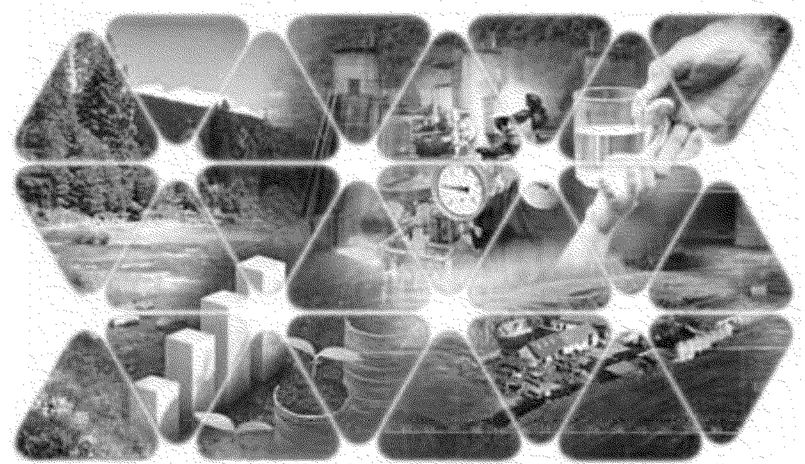
Economic Value of Fossil Fleet Operational Flexibility

Modeling and Insights in US-REGEN



John Bistline, Ph.D.
Senior Technical Leader

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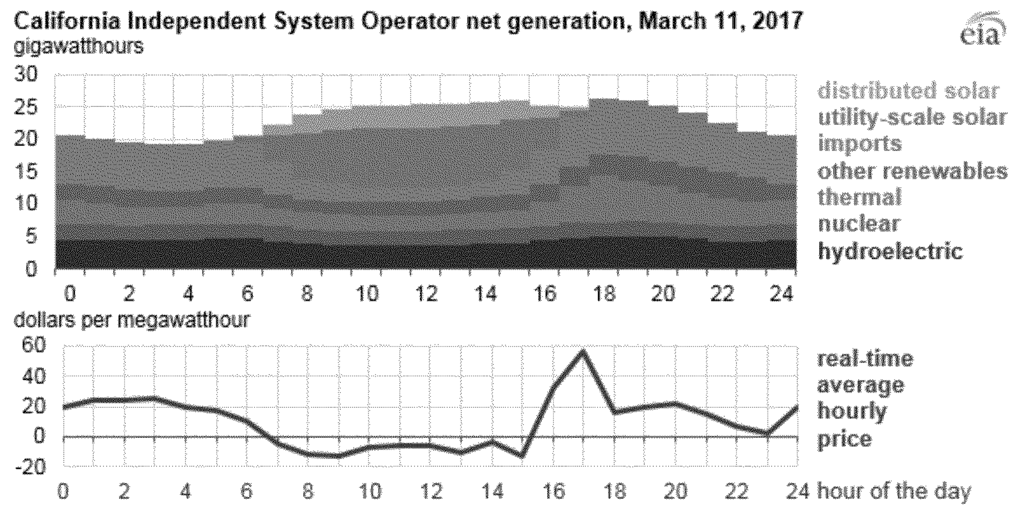
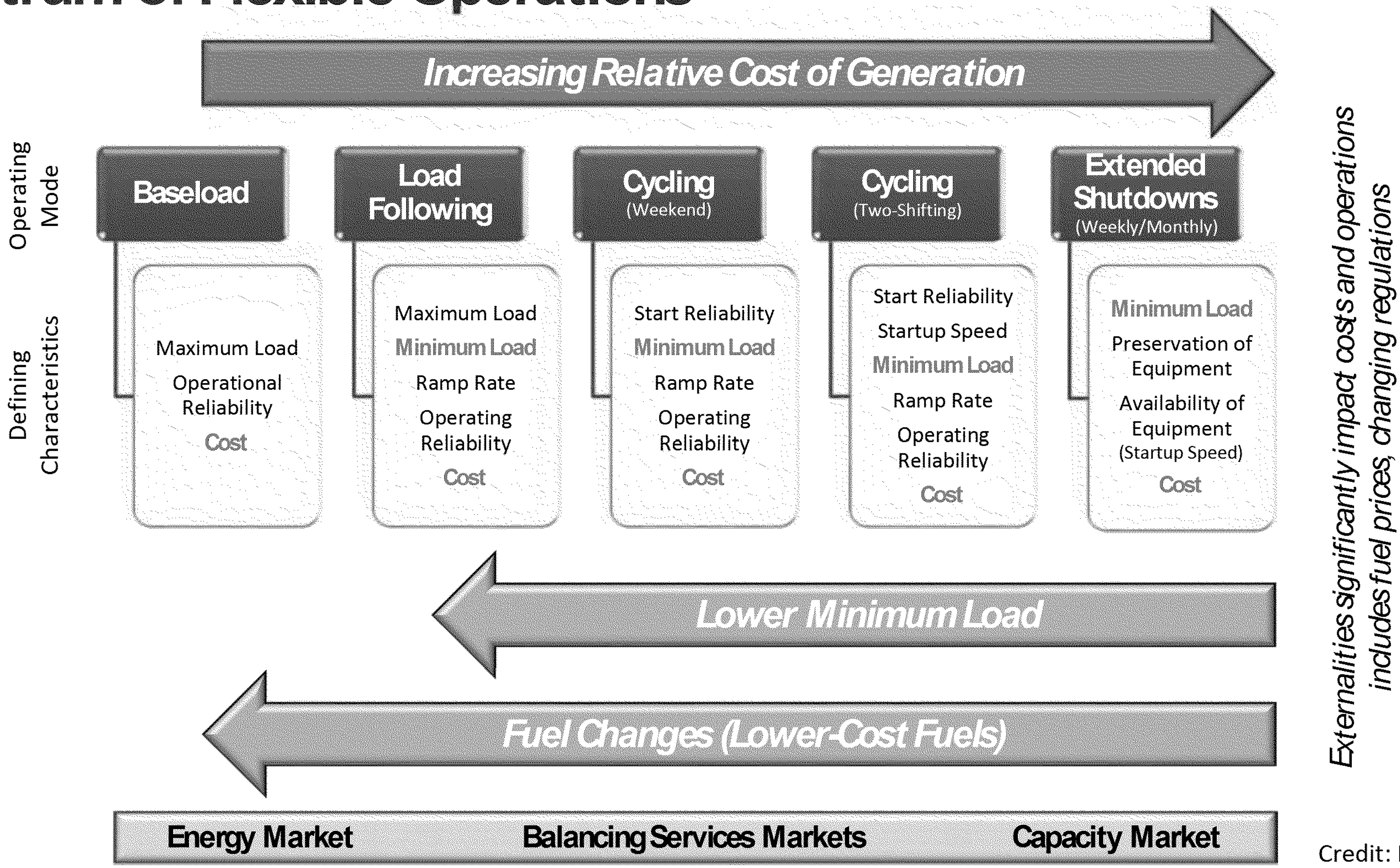
Motivations: Low Gas Prices, High Renewables, and Flexibility

- Value of dispatchable assets on the grid grows as the share of non-dispatchable resources increases
- Value prospects of minimum load operations for flexible generators
  - Avoid negative operating margins
  - Provide grid services (e.g., reserves)
  - Avoid frequent startups



This analysis focuses on the economics of individual asset flexibility instead of system flexibility

Spectrum of Flexible Operations



Credit: Mike Caravaggio

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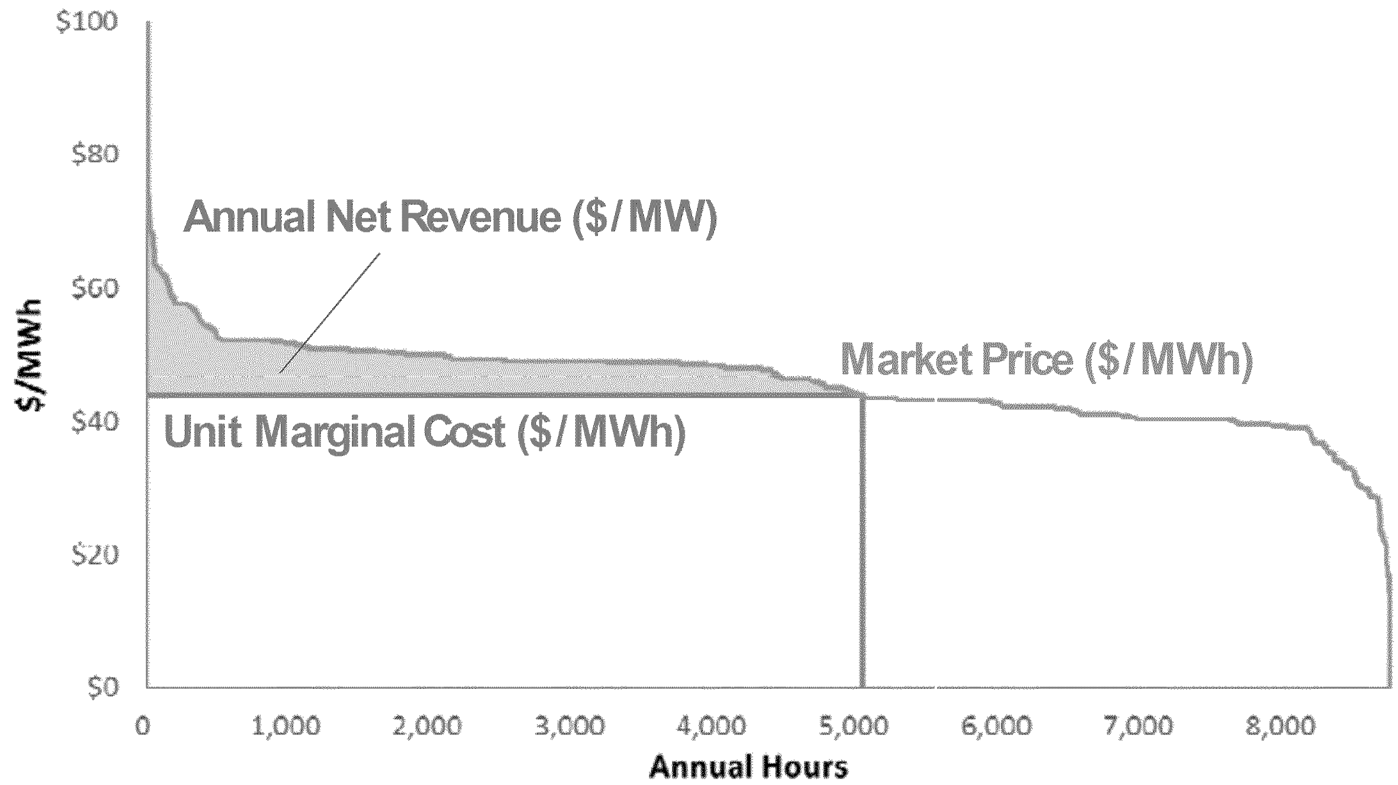
Research Questions: Economics of Flexible Operations

- How can enhanced operational flexibility (in this analysis, **lower minimum loads**) for coal and gas assets impact operations and profitability under large-scale renewable deployment?
- How does the economic value of this flexibility vary across different regions, asset types, and market environments (e.g., level of renewable deployment)?

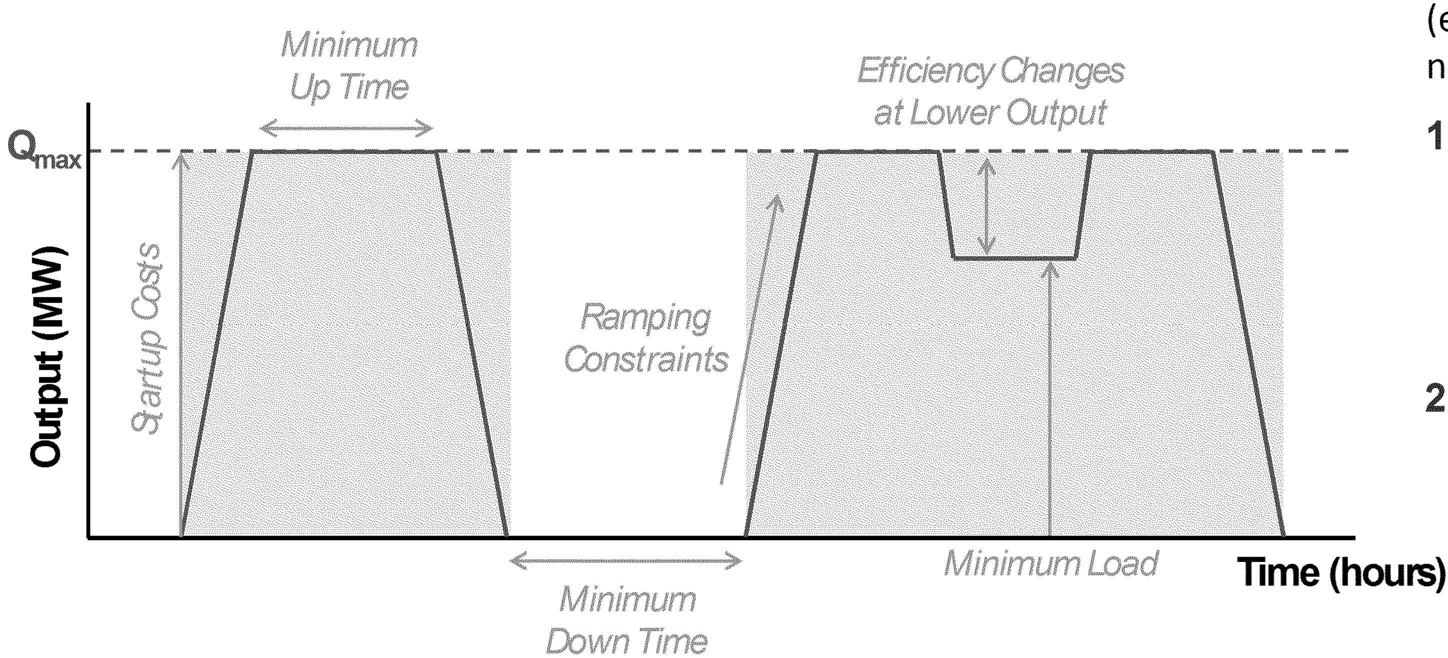
Goal is to evaluate the economic impact of improving technical parameters like minimum load to increase flexibility

Price Duration Curves Drive Net Revenues for Power Plants

Example without Commitment Costs and Constraints



Impacts of Commitment Costs and Constraints

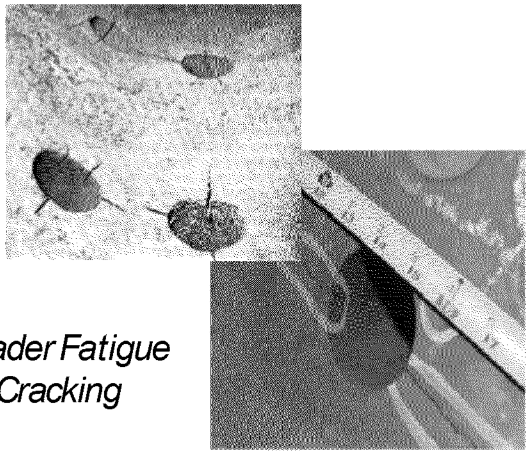


When operating margins for plants (e.g., spark spreads for gas units) turn negative, a plant can:

1. **Ramp down:** Stay online at minimum stable capacity, which forces the unit to absorb losses for generation but avoids shutdown and startup costs
2. **Shut down:** Turn off entirely, which avoids operating at a loss but with additional costs

Turn Down for What? Physical Impacts of Flexible Operations

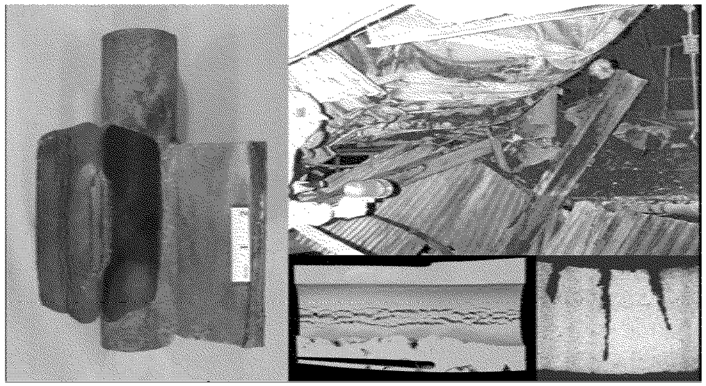
Thermal Fatigue Damage



Header Fatigue Cracking

- Predominate failure mode in boiler/turbine components subject to: frequent starts, fast ramping, etc.
- Caused by temperature mismatches between steam and metal surfaces

Corrosion Fatigue



Tube Failures

- On drum units, corrosion fatigue has been observed on riser tubes
- Involves combination of: manufacturing-induced bend stress, water chemistry fluctuations, etc.

Steam Turbine Impacts

Steam Chemistry: Offline Pitting

- Reliability areas impacted: differential growth, thermal and speed cycling, creep fatigue, steam chemistry effects, erosion and corrosion, low-load impacts on blade flutter

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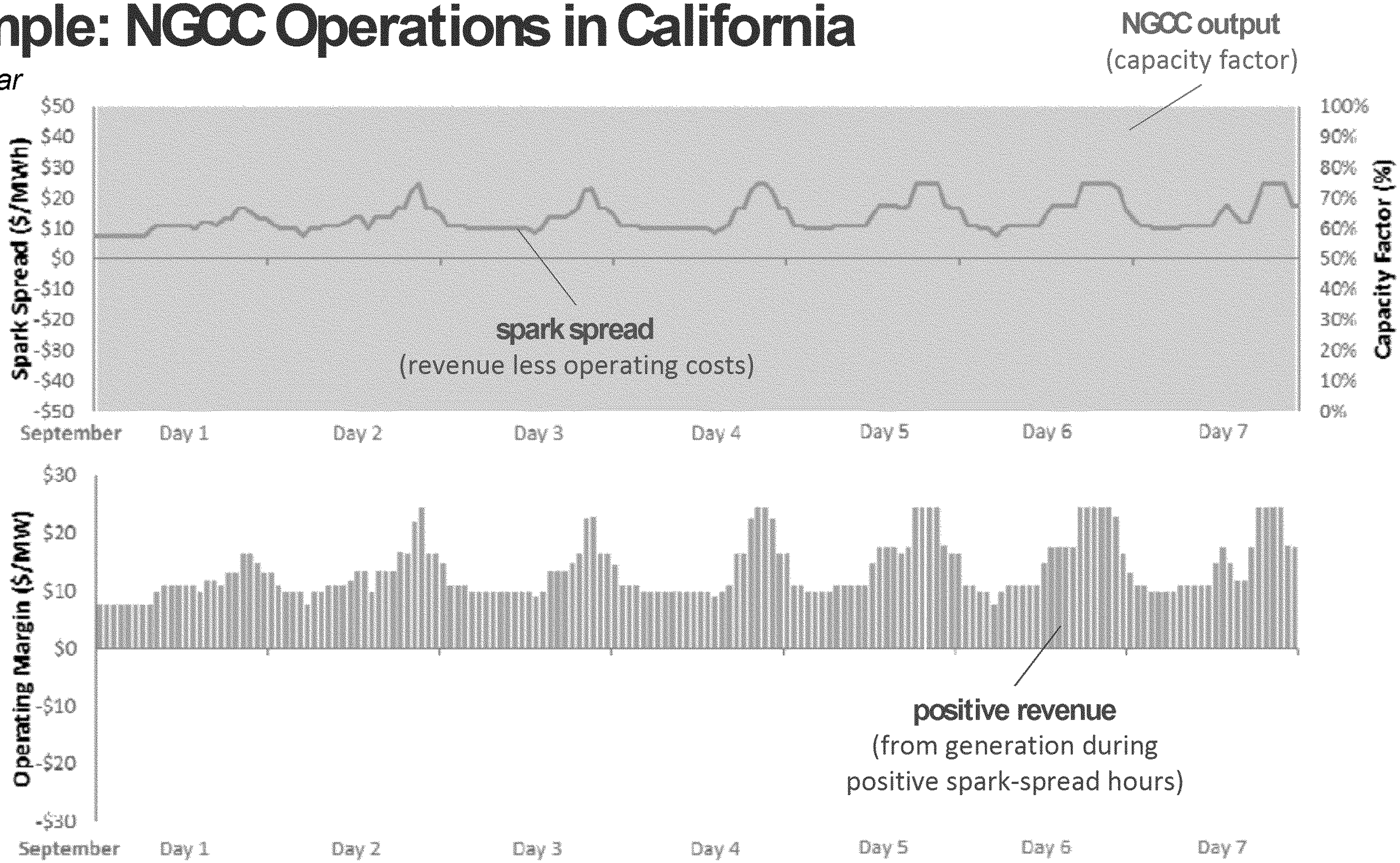
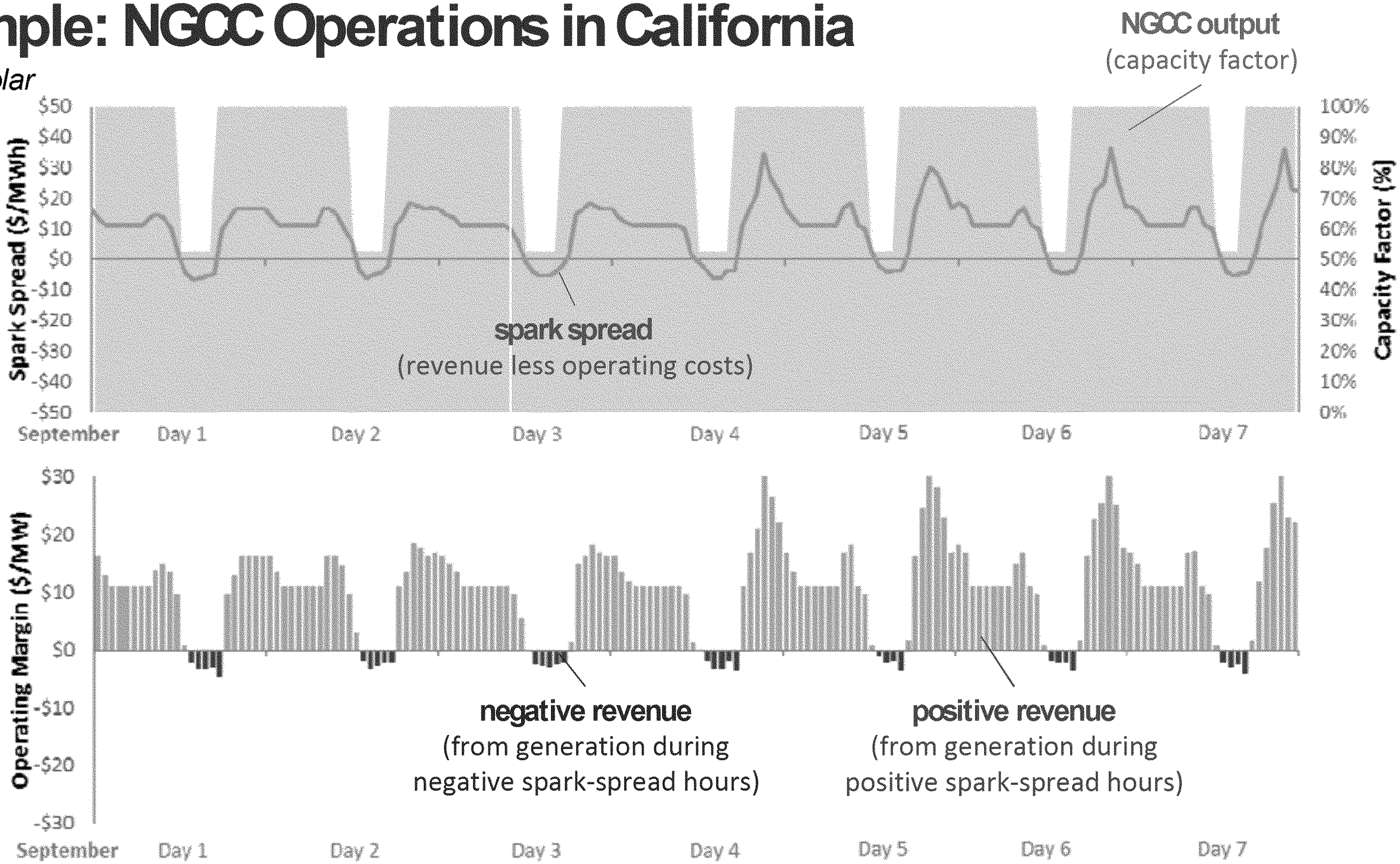
Example: NGCC Operations in California

0 GW Solar



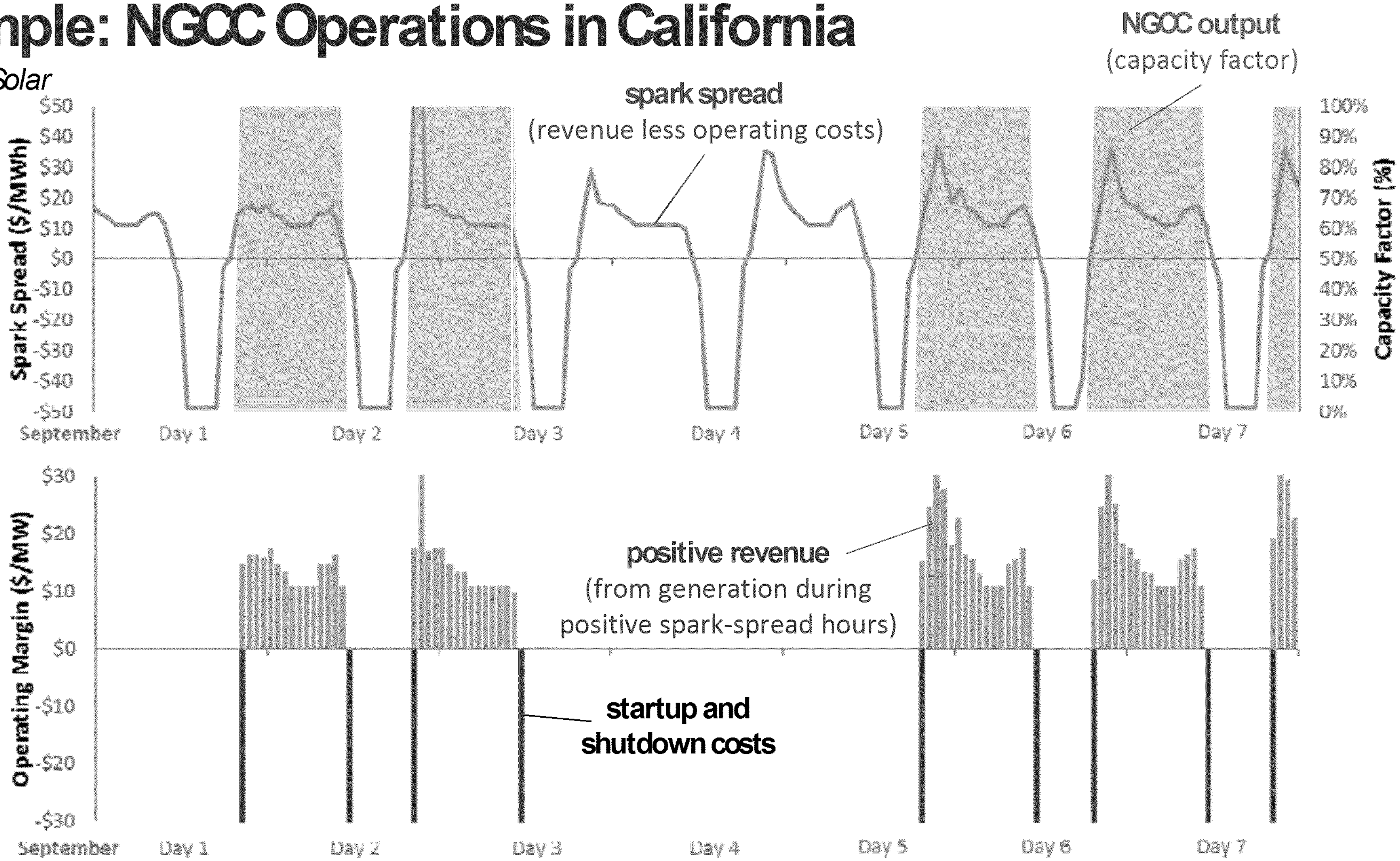
Example: NGCC Operations in California

40 GW Solar



Example: NGCC Operations in California

100 GW Solar



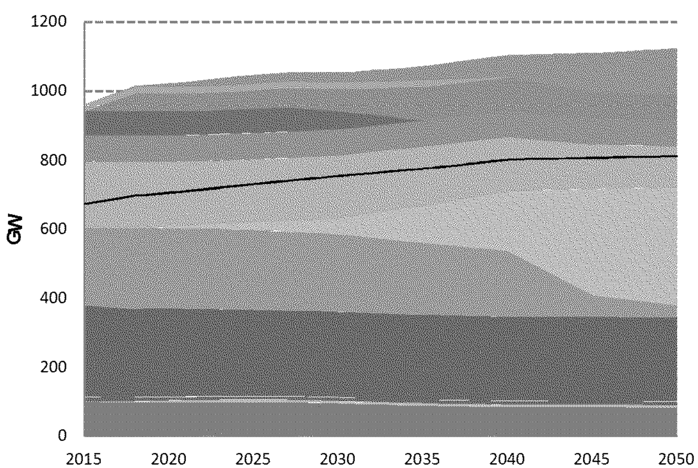
US-REGEN: EPRI's In-House Electric Sector Model

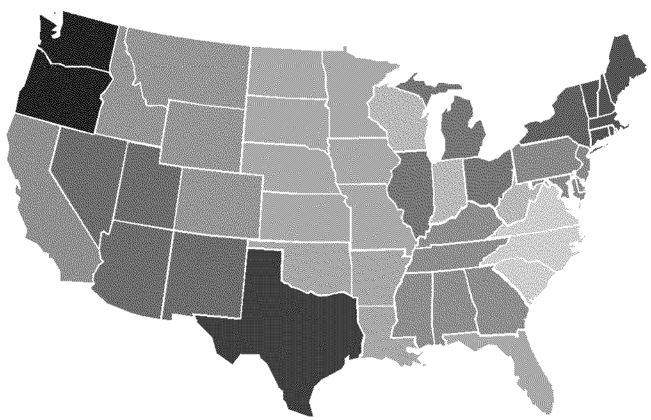
U.S. Regional Economy, GHG, and Energy

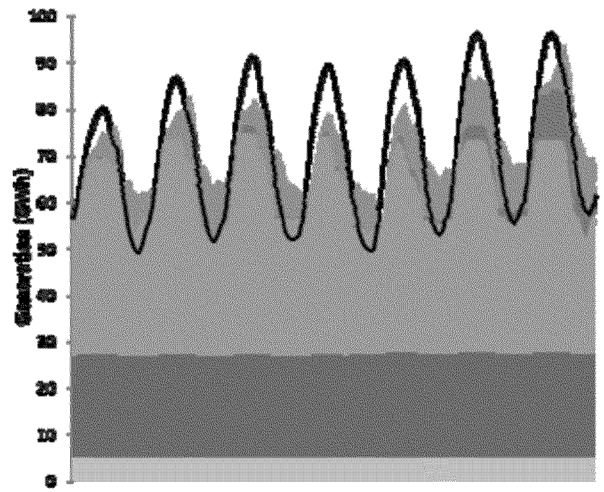
Capacity Expansion Economic Model, Long Horizon to 2050

Customizable State/Regional Resolution for Policy and Regulatory Analysis

Linked with Hourly Unit Commitment Model







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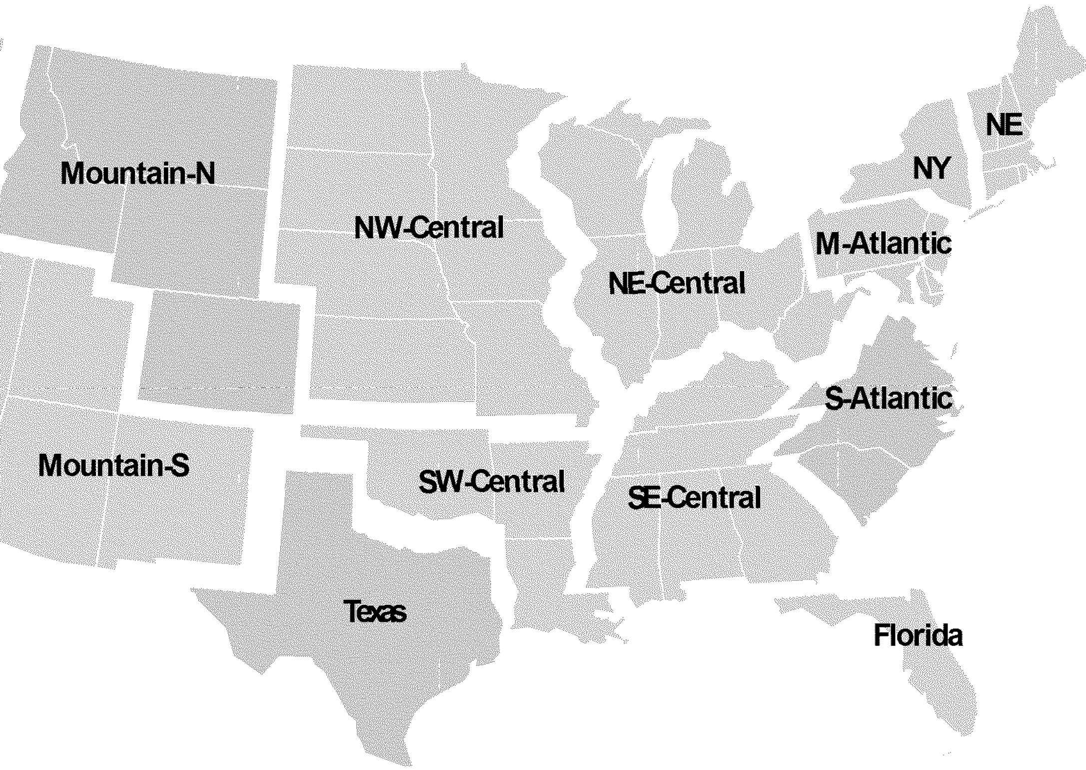
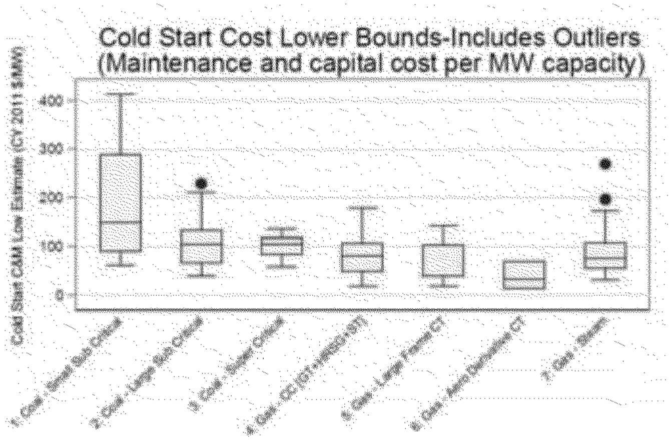
Scenario Description

- Focus on **four regions in 2035**
- Five policy scenarios
  1. **Reference** (current policies only)
  2. **CO_2 tax** ($16/t-$CO_2$ in 2035)
  3. **Solar mandate** (50% in-region demand)
  4. **Wind mandate** (50% in-region demand)
  5. **50/50 solar/wind mandate** (50% in-region demand)
- **Three asset types:** coal and NGCC (existing and new)
- Two parametric sensitivities
  - Lower minimum load
  - Startup costs


Mountain-N
NW-Central
NE-Central
NY
NE
M-Atlantic
S-Atlantic
Mountain-S
SW-Central
SE-Central
Texas
Florida

Model Parameters

Startup and Cycling Costs



- Using 25th and 75th percentiles for low/high values, but Intertek considers these "**lower bound costs**"
- By start type, technology, and cost category (O&M, fuel, and other)
- Source: NREL/Intertek (2012), "Power Plant Cycling Costs"

Minimum Load Levels

	Low	**High**
Coal	20%	50%
NGCC (New)	20%	50%
NGCC (Existing)	20%	50%

- Value of flexibility connected to initial ("High") and final ("Low") parameters for minimum load levels
- Using the same values enables apples-to-apples comparisons across asset types
- Sources: NREL/Intertek (2012), BNEF

Heat Rate

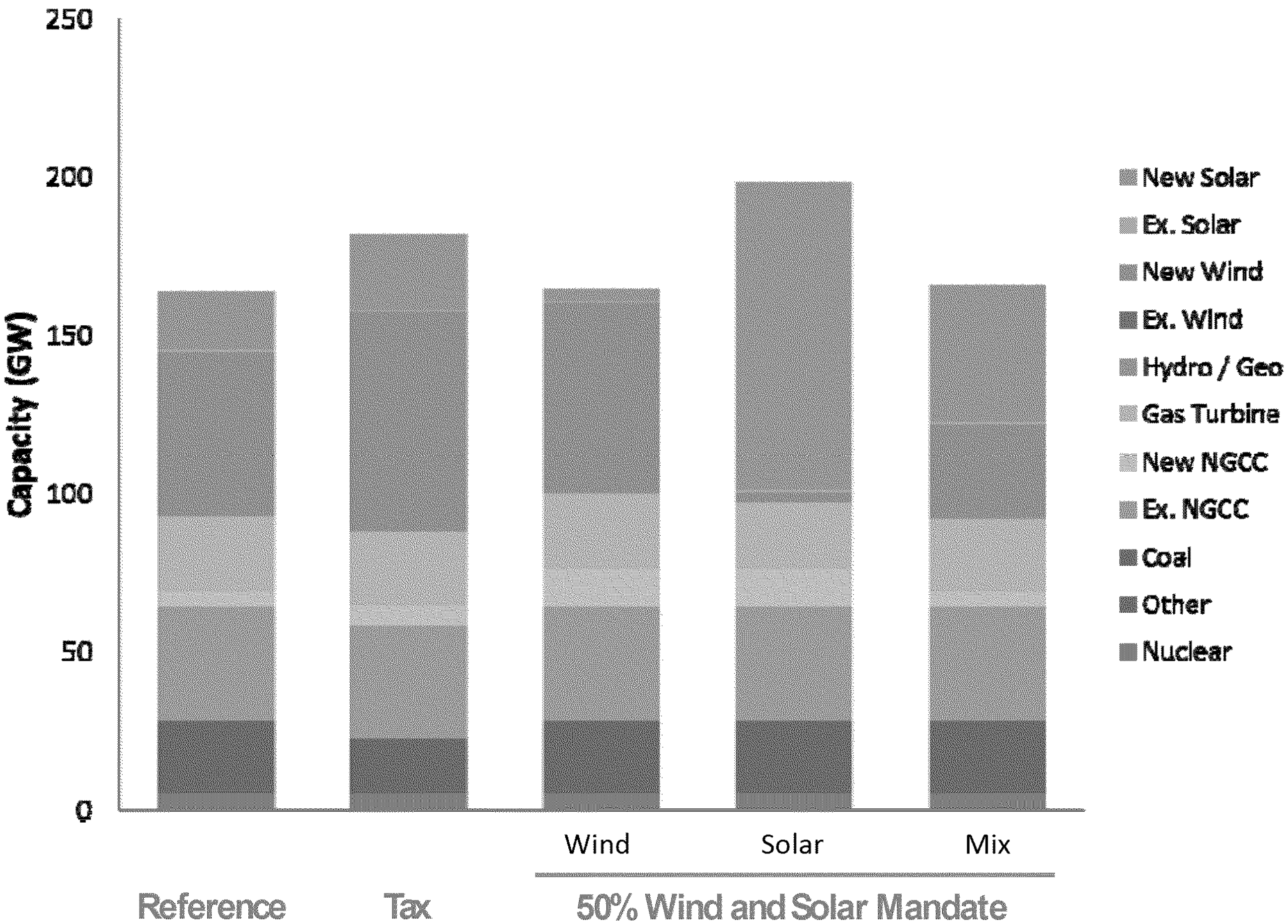
	Full (MMBtu/MWh)	**Penalty** (% Increase)
Coal	9.2	15%
NGCC (New)	6.8	20%
NGCC (Existing)	8.2	20%

- Using representative assumptions for existing supercritical coal, new NGCC, and existing NGCC
- Sources: ABB Velocity, EPRI

Detailed Regional Results

Enhanced Operational Flexibility and Cycling Impacts in Texas

Scenario Assumptions Drive Investments: 2035 Capacity in Texas



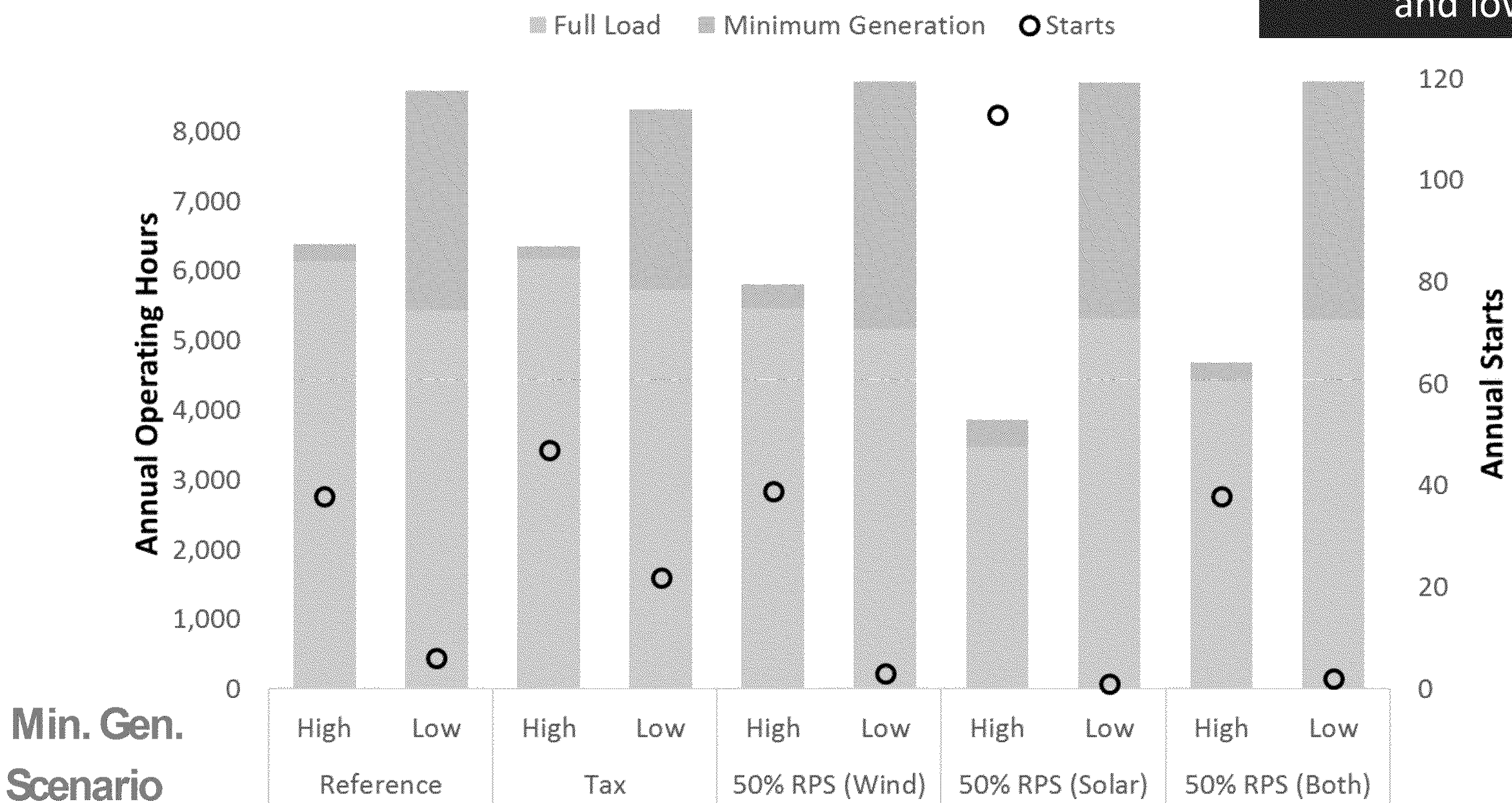
Observations

- Wind development is extensive in the reference scenario
- CO_2 tax forces some coal retirements but more significant changes in dispatch
- Under 50% RPS, lower capacity needs when portfolio of renewable technologies included
- Caveat: Changes in other regions under these scenarios, which are not shown here

Changes in Operations with Lower Minimums

Texas, NGCC (New)

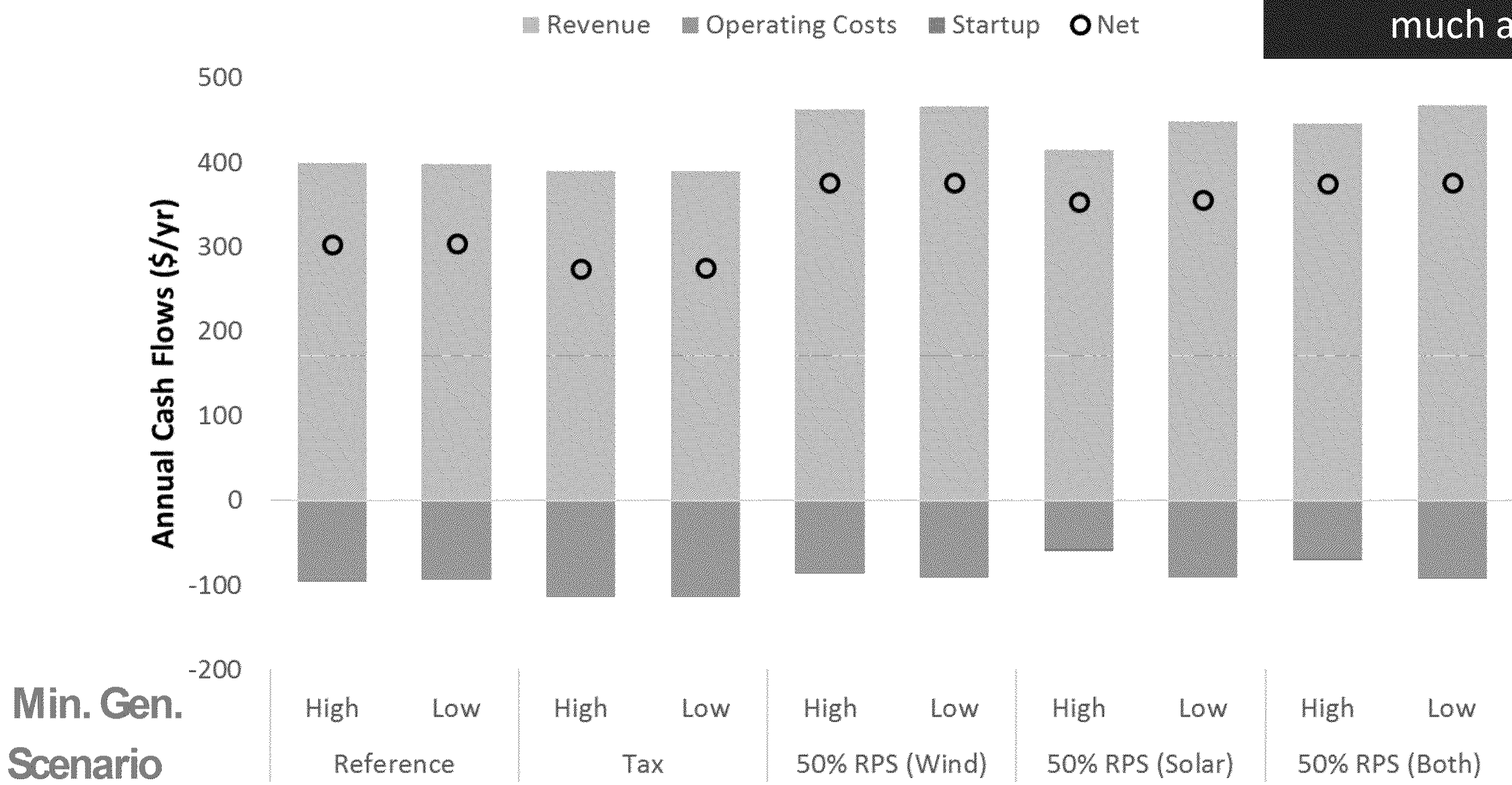
Higher capacity factors when NGCC units can avoid starts and lower losses



Changes in Operating Revenues with Lower Minimums

Texas, NGCC (New)

Total annual operating margins do not change as much as dispatch



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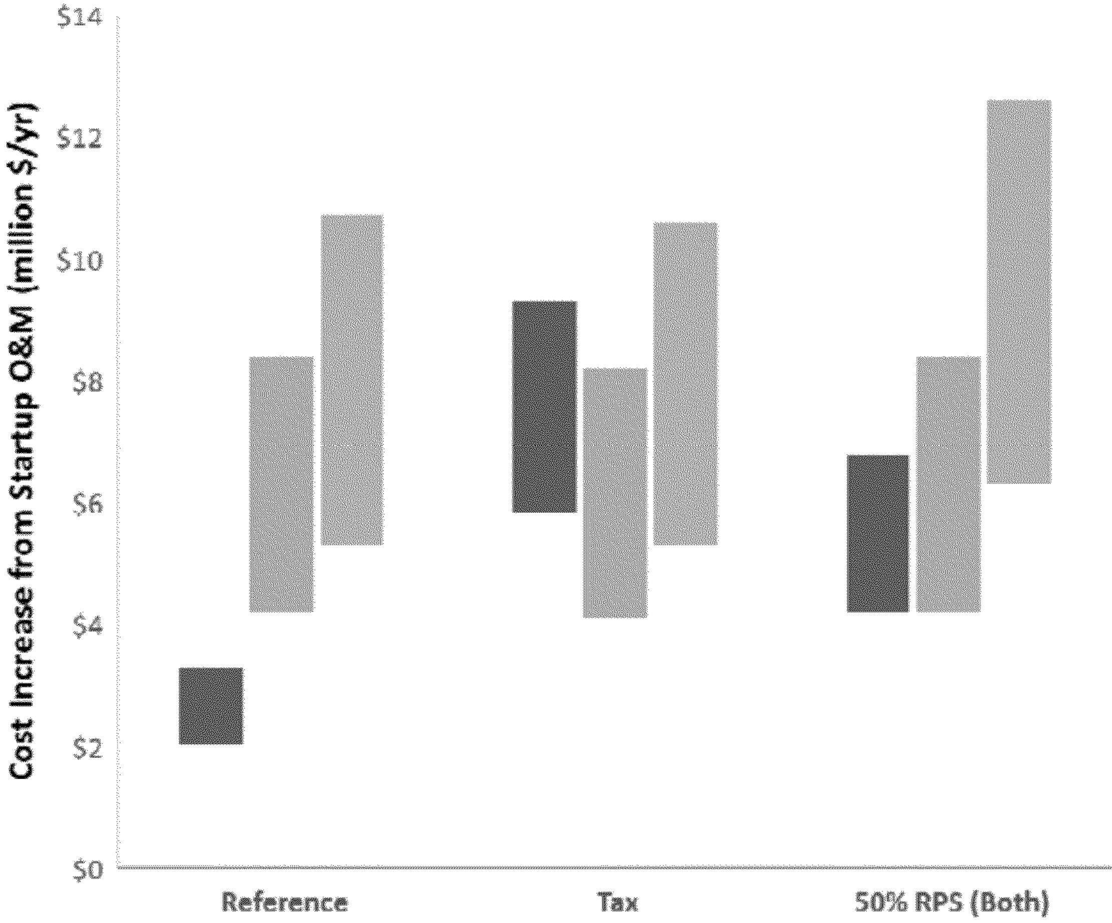
Long-Run Cost of Simple Dispatch

Texas



Coal
NGCC (Ex.)
NGCC (New)

Notes

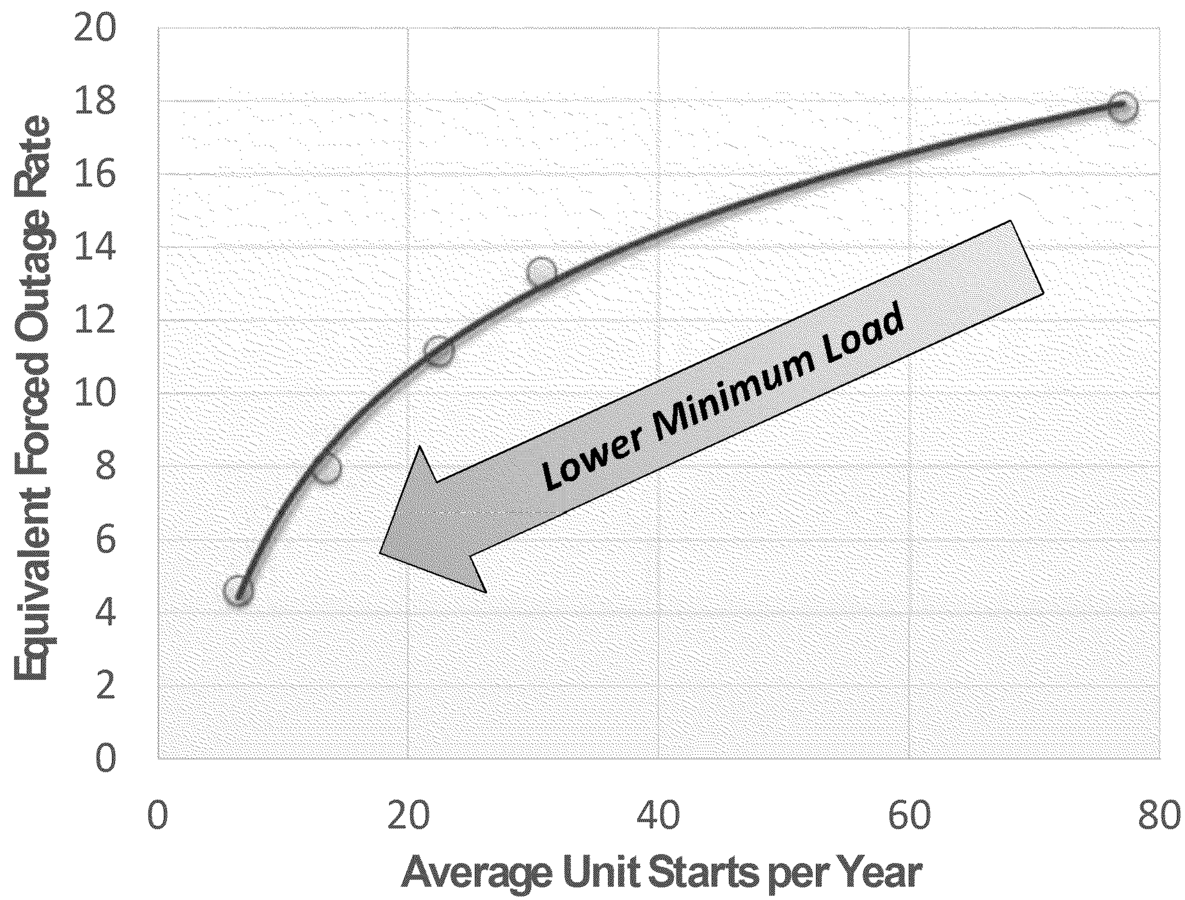
- Vertical axis = long-run O&M costs due to cycling if dispatch is based only on short-run marginal costs
  - Based on Intertek (2012)
  - Range shows 25th/75th %ile
- Costs track number of starts

Takeaways

- CO_2 tax scenarios increase cycling and costs for coal units
- Startups are lower for coal since in-the-money for many hours (opposite for existing NGCC)
- High renewable deployment drives greater system ramping/flexibility needs

Caveats

- Not including full range of possible O&M costs
- Not including possibility of early retirement
- Not including changes in outage rates



Lowering minimum load reduces startups, which reduces EFOR

Observations: Lower Minimum Loads in Texas

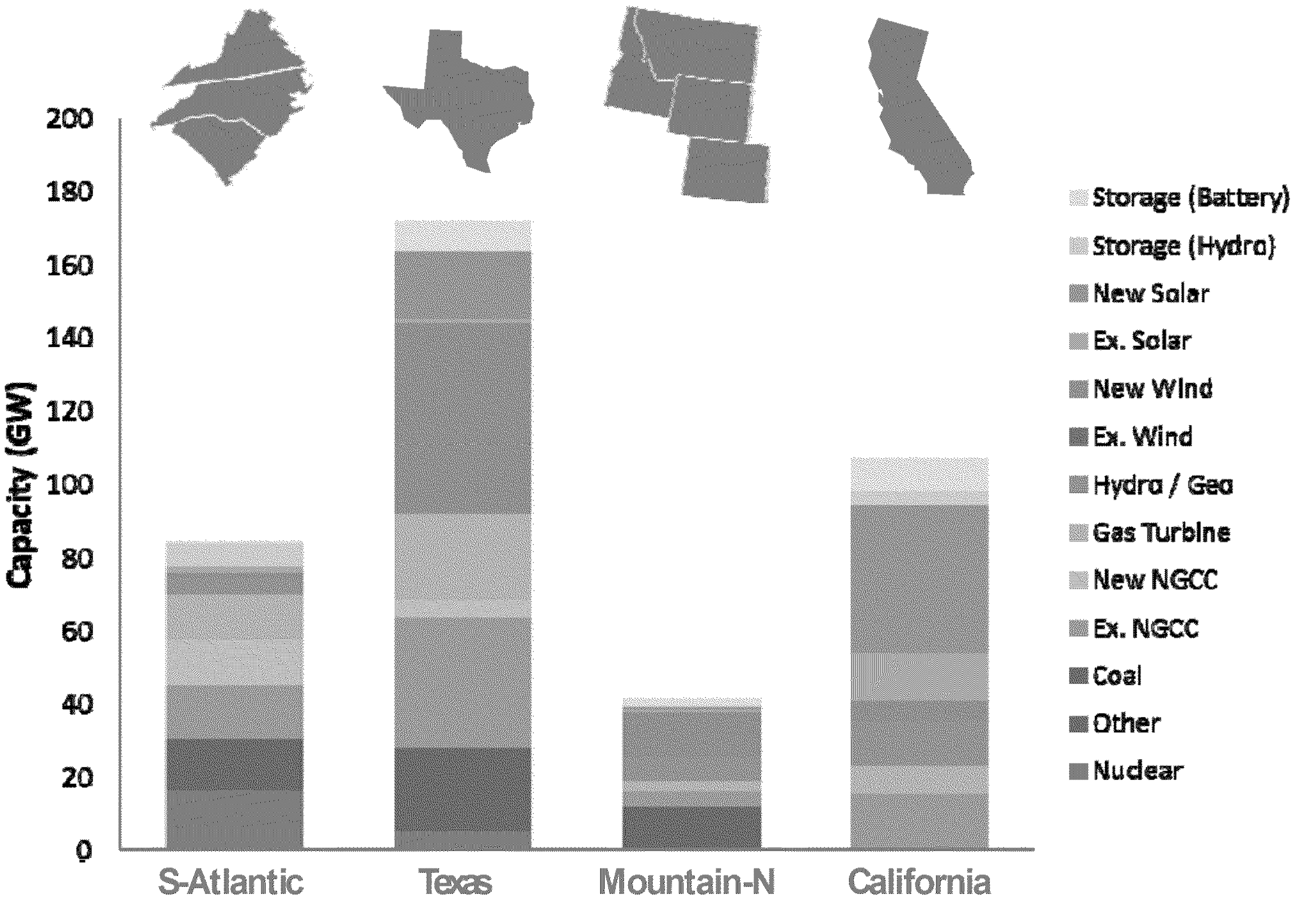
- Expected returns for coal- and gas-fired generators are shaped by future market and policy conditions
  - Operational characteristics are a second-order driver of profitability
  - Flexibility allows assets to adapt to bearish markets
- Plant flexibility impacts operations more than annual margins
  - Especially true for mid-merit units
  - Could impact long-run closures if cycling O&M is more costly than currently anticipated, especially since damage mechanisms give rise to "lumpy" costs
- Preparations for flexible operations can help regardless of which state-of-the-world obtains

Cross-Regional Comparison

How well do insights about flexible operations transfer to other regions?

Capacity and Minimum Generation Levels Vary across Regions

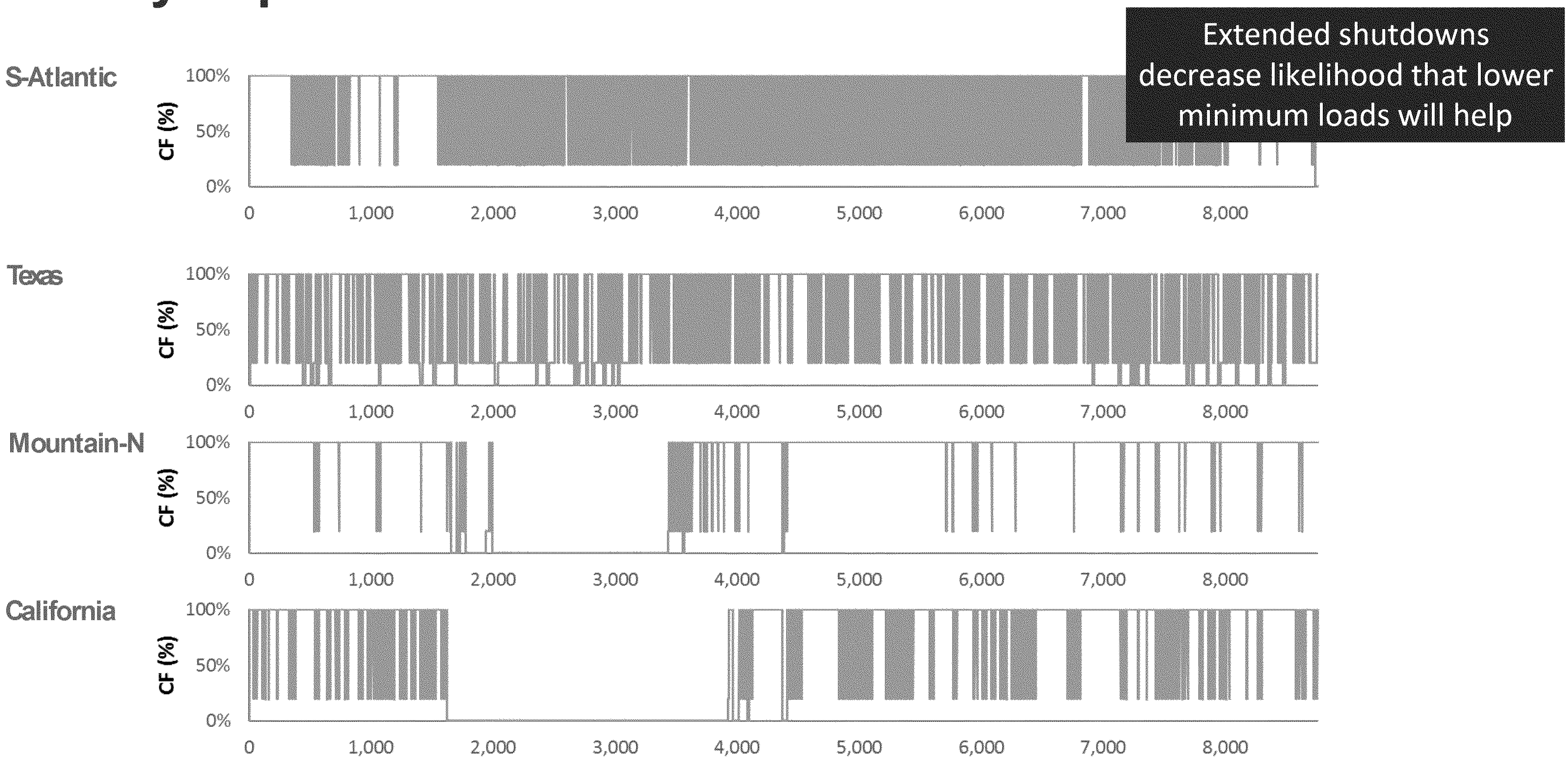
Reference Scenario in 2035



Observations

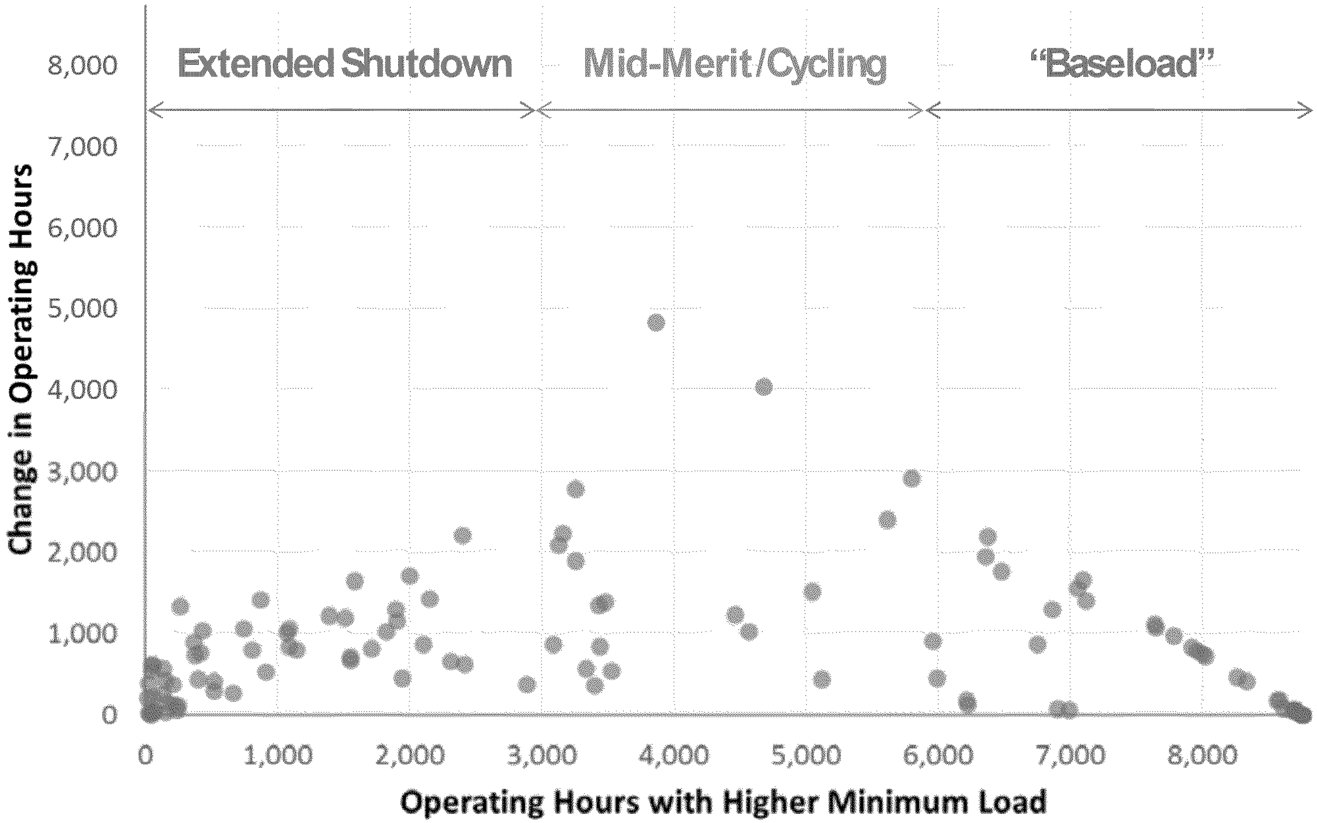
- Grid sizes and compositions vary significantly without policy
- Economics of wind are strong in Texas and Mountain-N even without policy support
- S-Atlantic has more inflexible generation (in absolute and relative terms) than other regions

Hourly Dispatch of New NGCC Unit under Reference Conditions



Changes in Operating Hours with Lower Minimum Load

All Regions, Scenarios, and Asset Classes



Mid-merit units benefit most from lower minimum loads

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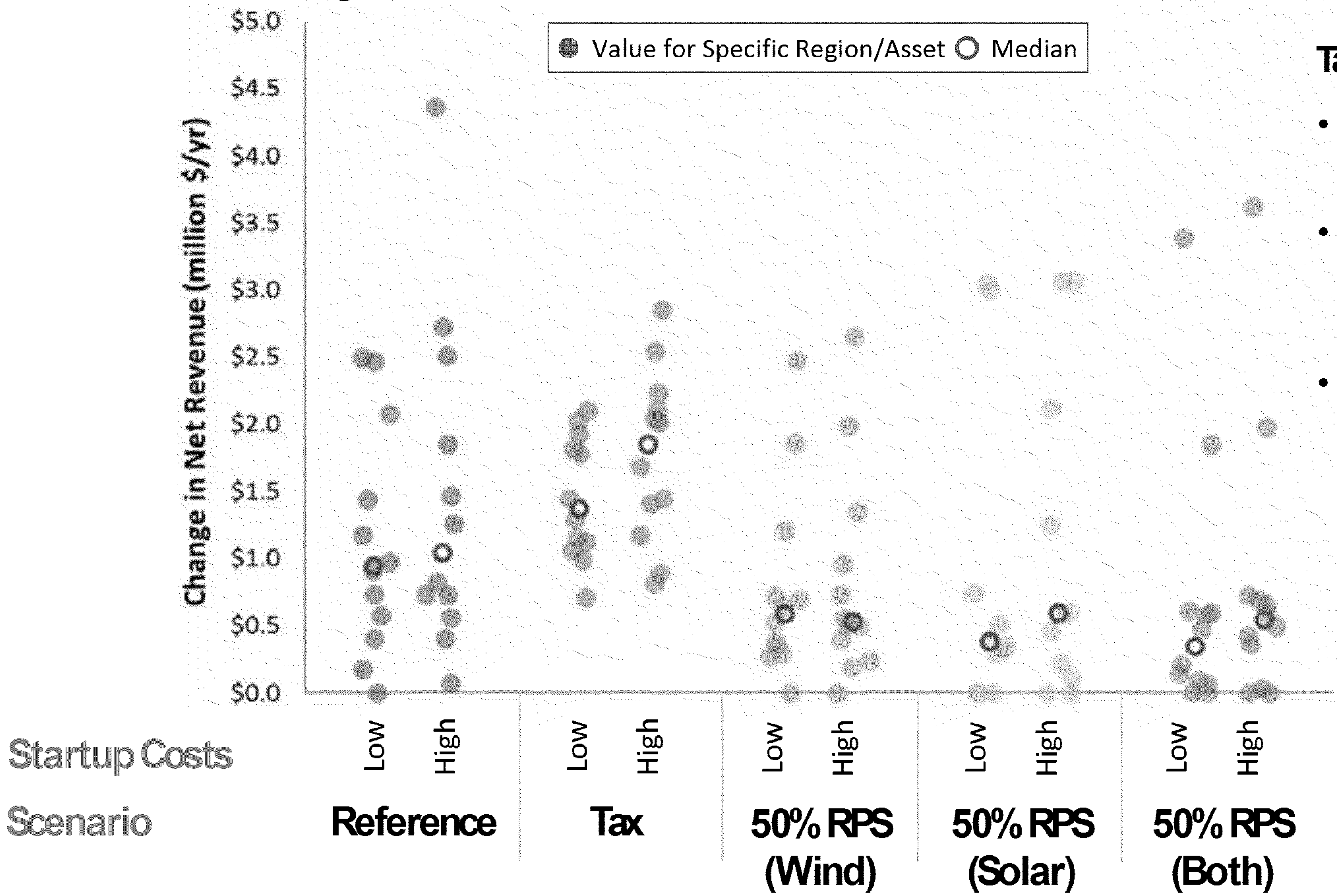
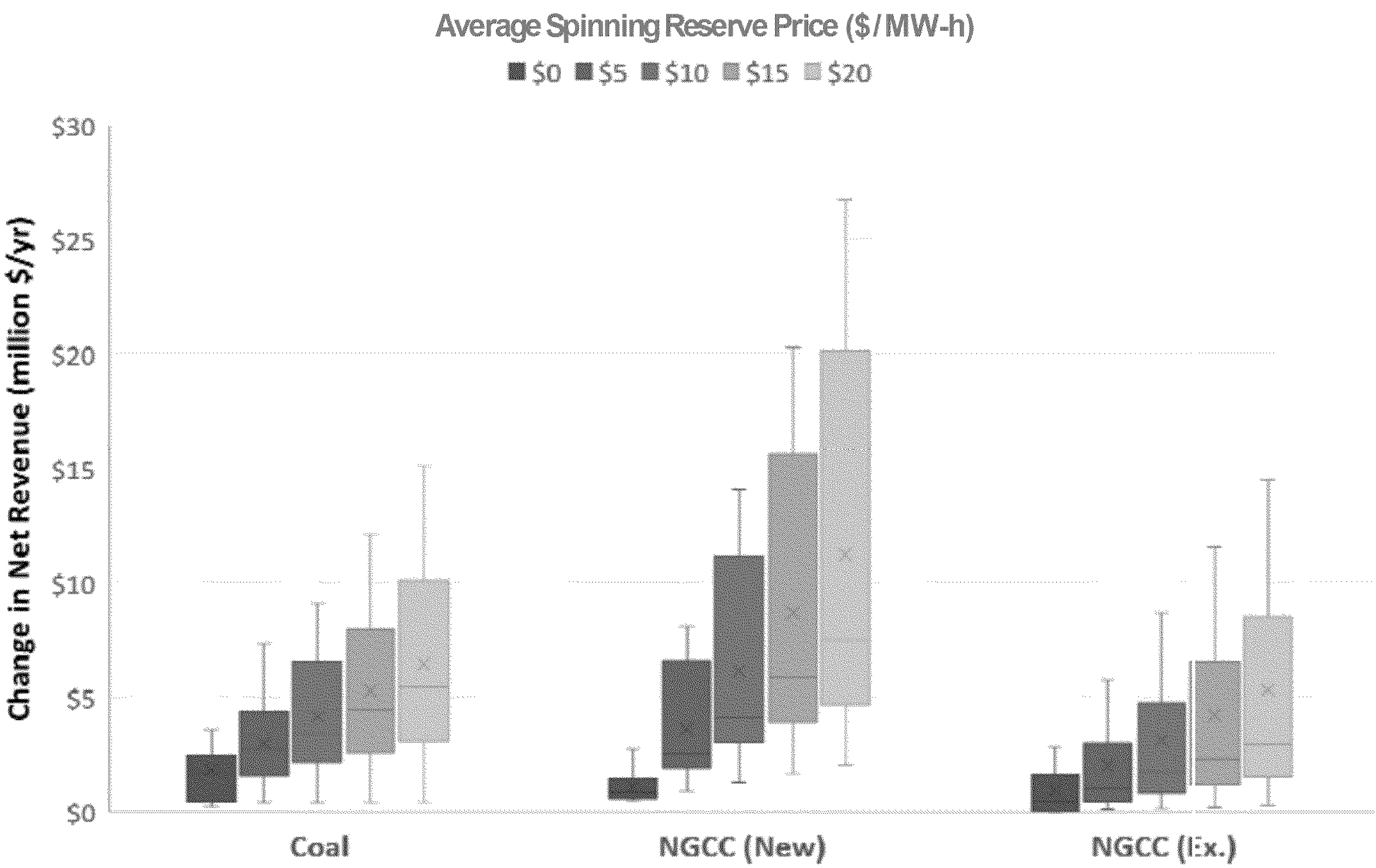
Profitability Increases with Lower Minimum Loads



Takeaways

- Flexibility can be valuable even without significant VRE buildout
- Lower minimum generation is most valuable (on average) under a CO_2 tax (e.g., coal as mid-merit)
- Under 50% RPS scenarios, net profitability impacts are similar, even though system costs vary
  - Seasonal/diurnal patterns differ, but offsetting effects
  - RPS often induces seasonal layups, which lower the value of flexibility

How Valuable Are Lower MinGen Levels with Reserve Revenues?



Takeaways

- NGCC benefits most from reserve revenues due to higher number of hours at minimum generation (i.e., with capacity headroom)
- Ancillary services revenues can boost economics of flex. ops., but markets are uncertain and "thin"
- System forecast errors become more important to track over time
  - Impact reserve needs/prices
  - Essential also for determining least-cost commitment schedule, especially if starts are costly

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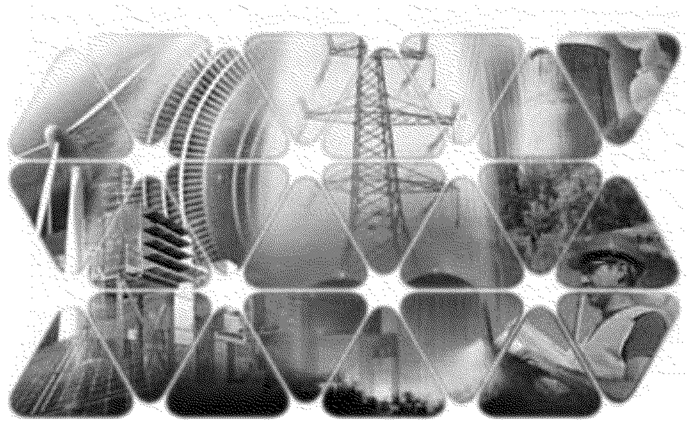
Takeaways

- Flexibility (e.g., through lower minimum loads) lowers costs
  - Profitability impacts accrue in the long term, even though the most significant operational impacts are related to short-run dispatch
  - Difficulty: Long-run cycling costs are uncertain!
- Lower minimums are most valuable when…
  - Policies rearrange merit order (e.g., CO_2 tax)
  - Mid-merit units (e.g., new NGCC) are considered
  - Regions/scenarios do not force seasonal layup
  - Units are more flexible than other comparable generators
- Discrepancy between system value of flexibility and incentives for generators to provide?
- Ancillary services revenues improve prospects for flexible operations, but their market outlook and depth are unknown



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John Bistline
Senior Technical Leader
650-855-8517
jbistline@epri.com

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