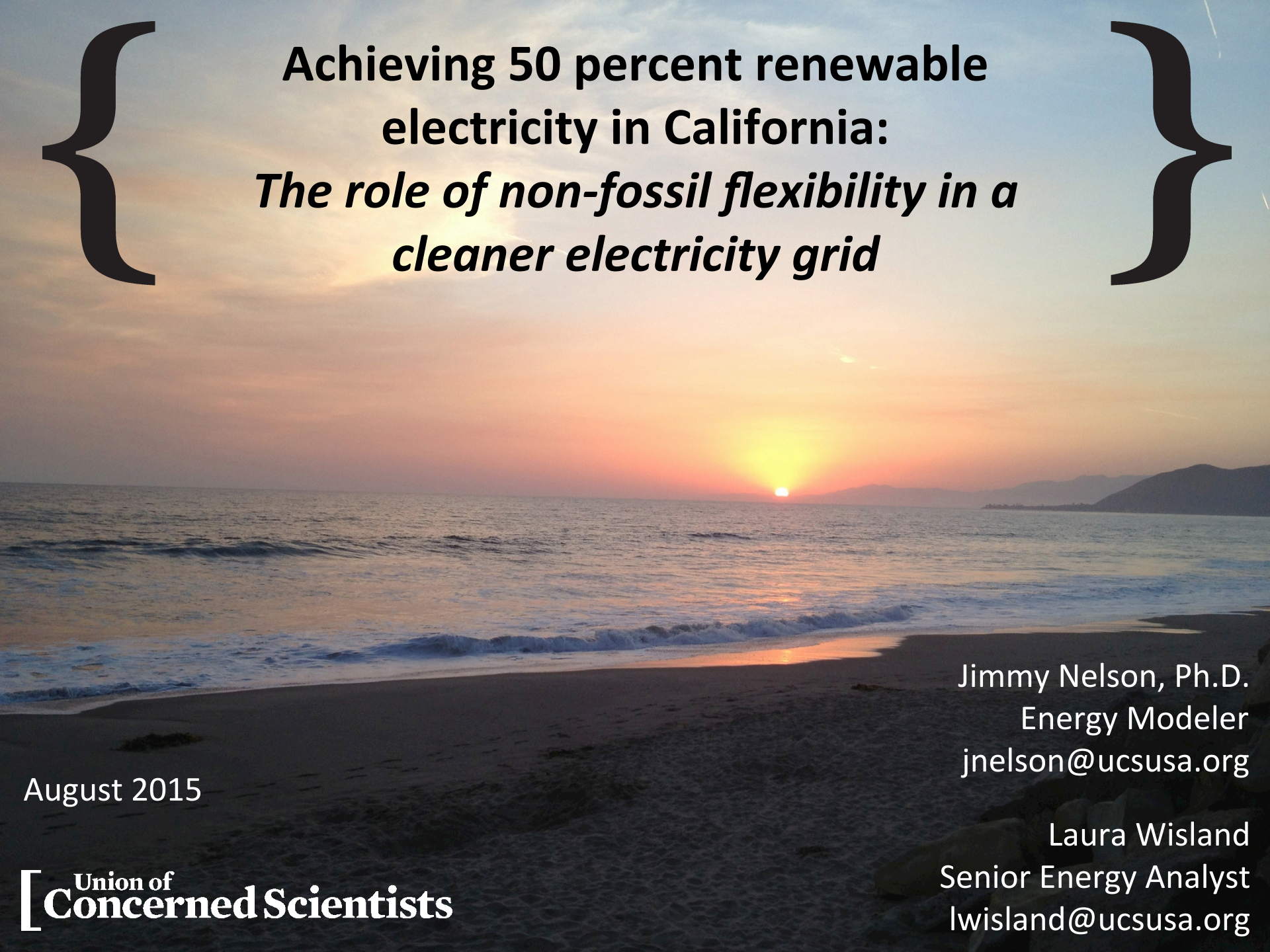

# Achieving 50 percent renewable electricity in California:
## *The role of non-fossil flexibility in a cleaner electricity grid*


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August 2015


Union of Concerned Scientists

Full report available at:
www.ucsusa.org/California50RPSanalysis

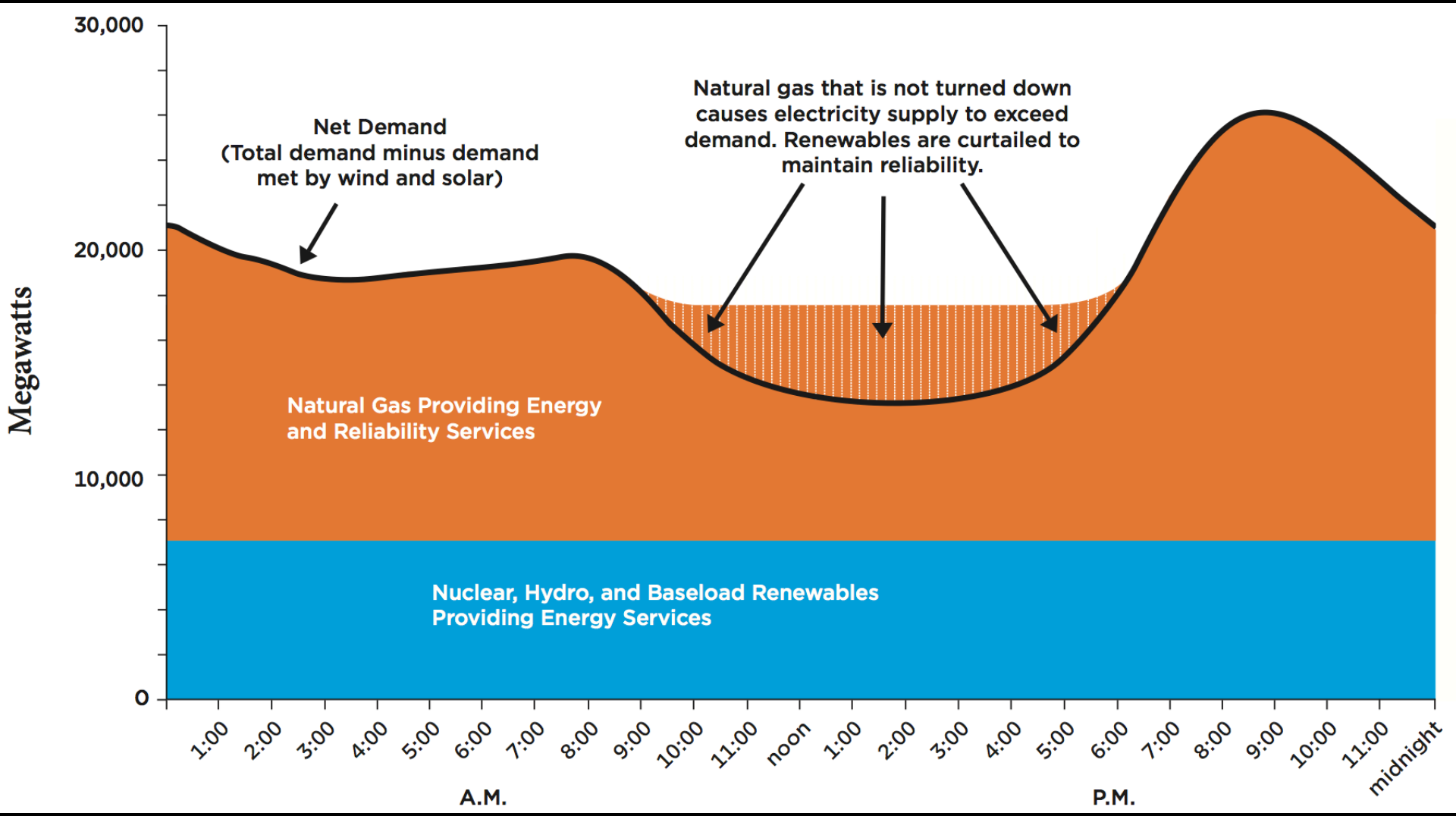
# "Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources"

Source: Bird, L., J. Cochran, and X. Wang. 2014. Wind and solar energy curtailment: Experience and practices in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-60983. Online at http://www.nrel.gov/docs/fy14osti/60983.pdf.

- Curtailment is a default option for maintaining reliability when an electricity grid relies more heavily on renewable sources of power
- Curtailment can be expensive because most renewables have low or zero marginal cost
- In limited quantities, curtailment can make important contributions to grid operational flexibility, reducing the need to make other investments in flexibility

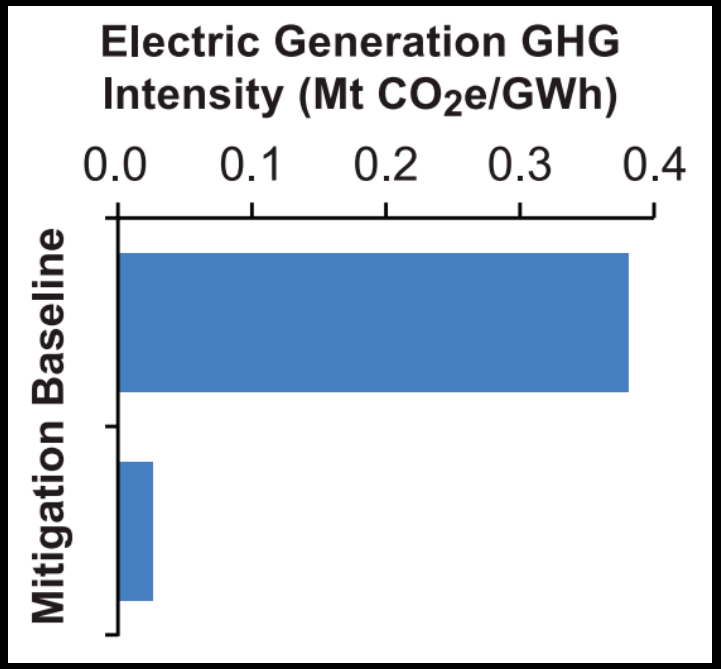
# Avoid coincident gas generation and renewable curtailment

# The UCS "Duck Chart"




Fact Sheet: Renewables and Reliability, Union of Concerned Scientists, March 2015.
Available at: http://www.ucsusa.org/sites/default/files/attach/2015/03/california-renewables-and-reliability.pdf

It would be very difficult to meet long-term climate goals if gas is online when renewables are being curtailed




Williams, J.H., *et al*., 2012. The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity. *Science* 335, 2012, 53-59.

# Modeling

# Acknowledgements

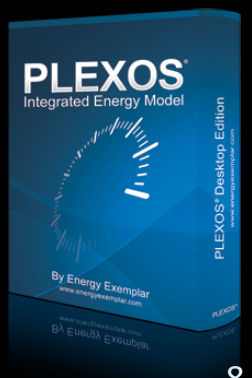

- Ryan Jones, Arne Olson, and Energy and Environmental Economics (E3)
  - Hourly renewable, reserve, outage, and demand data
  - Production cost model framework
  - Discussions
- UCS for support, fellowship, and discussions
- NREL for discussions
- Energy Exemplar / PLEXOS for software support
- Report reviewers


Energy+Environmental Economics

Union of Concerned Scientists

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY exemplar



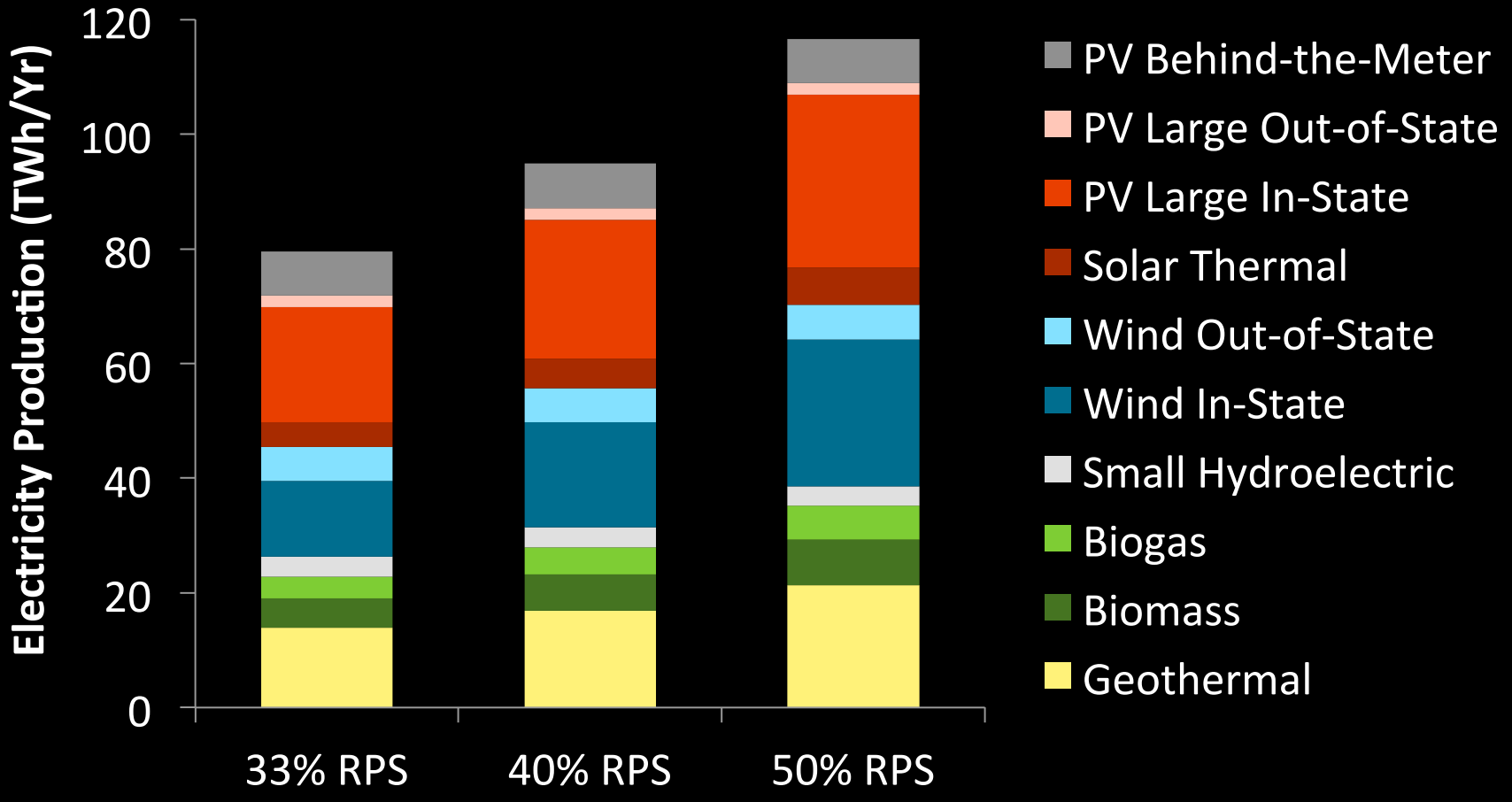
# Scope of analysis

- Renewables Portfolio Standard (RPS) target:
  - 33%, 40%, ***50%***
- Geographic scope: the California Independent System Operator (CAISO) footprint
  - ~80% of California
- Timeframe: 2024
  - Economy-wide decarbonization might necessitate very quick renewable deployment
  - Results relevant to 2030 50% RPS policy discussion
- Modeling tool: PLEXOS production cost model
  - Focuses on electricity operations
  - NOT an investment model

# What our analysis does and does not address

| Our analysis does: | Our analysis does not: |
|---|---|
| Focus on the year 2024 | Simulate years other than 2024 |
| Use industry standard software to simulate the CAISO electricity system | Simulate other sectors of the economy |
| Include electricity demand from 2 million electric vehicles within the CAISO footprint | Determine an optimal amount of vehicle electrification |
| Include a diverse portfolio of renewables | Optimize a portfolio of renewables or focus on a single renewable technology |
| Simulate detailed grid operations and constraints on generators and resources inside the CAISO footprint | Simulate detailed grid operations and constraints on generators and resources outside the CAISO footprint |
| Include generation requirements in specific regions inside the CAISO footprint | Model transmission constraints inside the CAISO footprint |
| Explore a variety of ways to reduce renewable curtailment | Find an optimal amount of renewable curtailment or grid flexibility |
| Quantify renewable curtailment, production costs, and GHG emissions from electricity production | Quantify capital and fixed costs of renewable generators or additional grid flexibility |
| Quantify shortfalls in generation capacity and reserves | Perform an analysis of system capacity need or loss of load expectation |

# A diverse portfolio of renewables is simulated

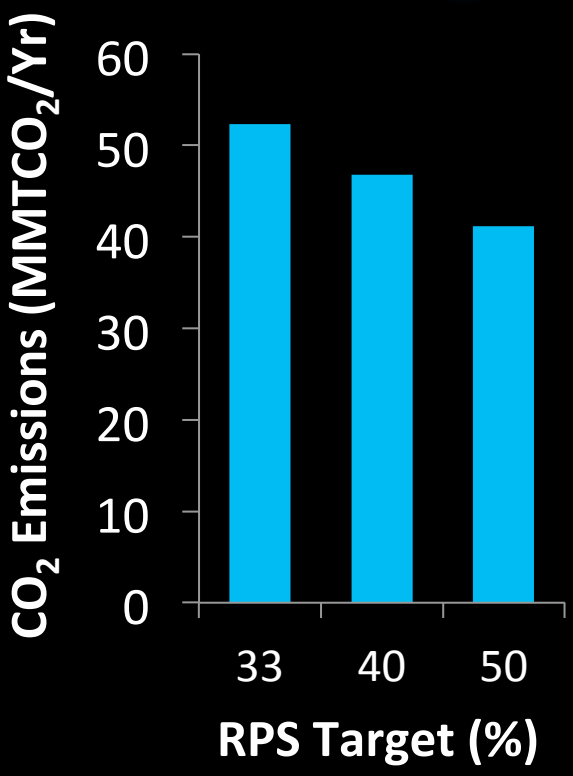



- Heavily weighted towards in-state renewables
- Behind-the-meter photovoltaics (PV) don't directly count towards RPS

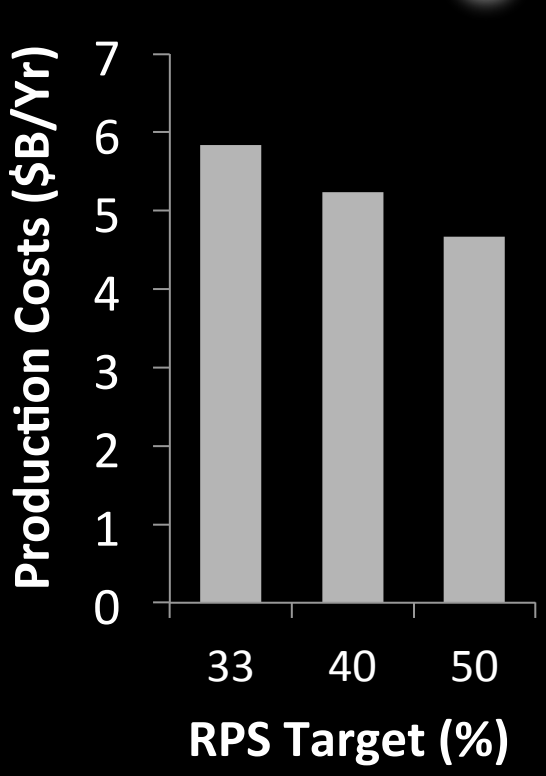
# As the RPS is increased…

[without additional operational flexibility]

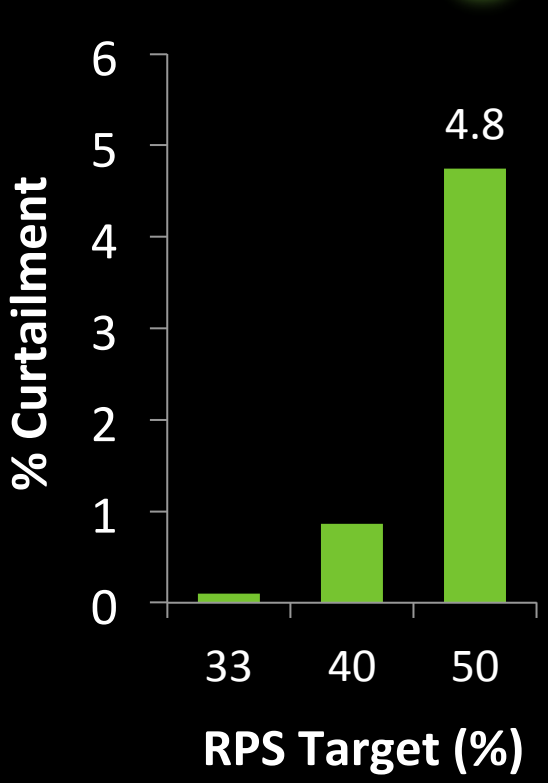
GHG Emissions




Production Costs

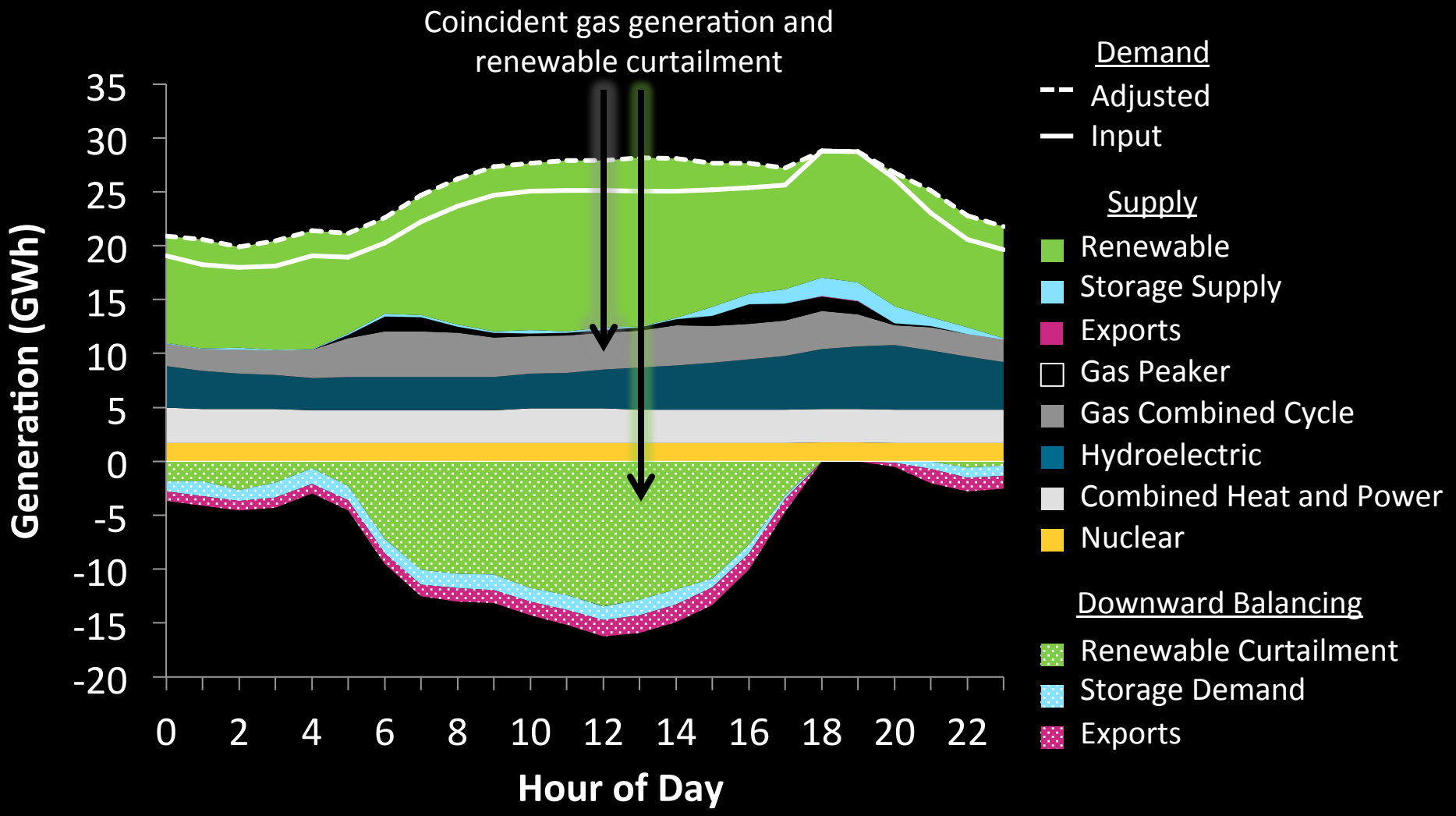



Renewable Curtailment



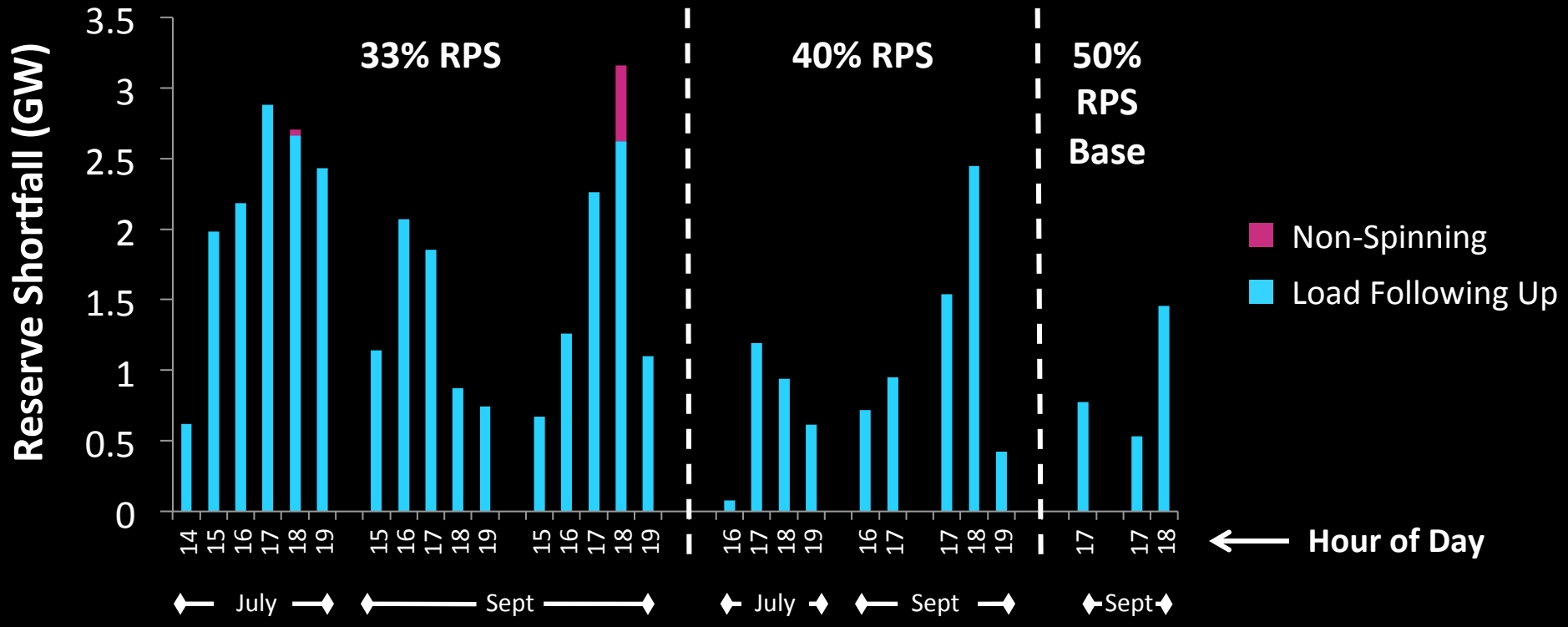

Note: production costs do not include capital and maintenance costs, and are therefore only one important part of the total electricity cost

# Operational constraints keep gas online during hours that experience renewable curtailment




Example day depicted here is a near worst-case weekend day in May

# Renewables can provide some electricity during times of greatest need for system capacity

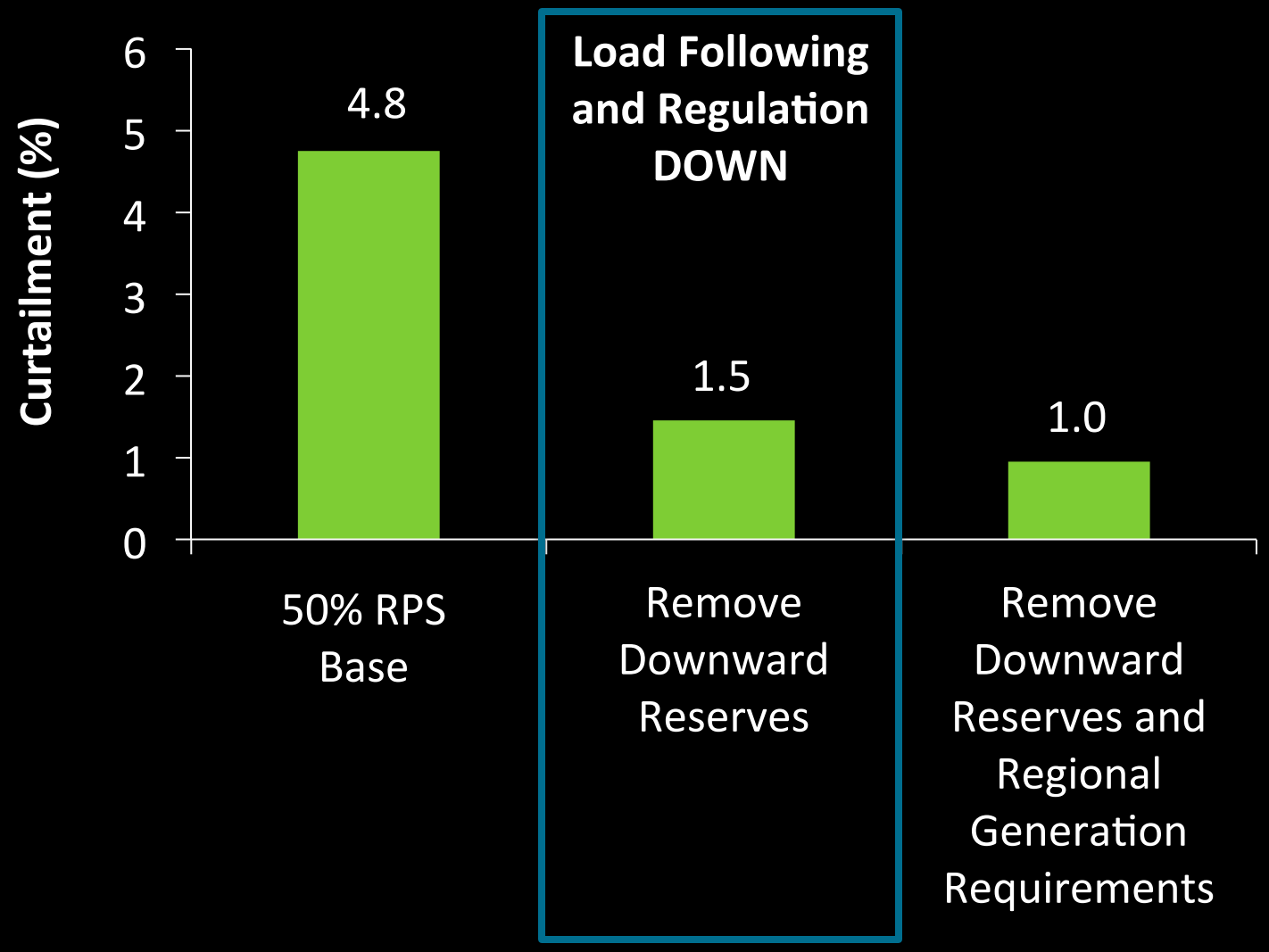



- However, even at a 50 percent RPS, renewables cannot produce enough power to ensure a reliable electricity system during some peak periods, resulting in reserve shortfalls
- Our study suggests that the projected 2024 CAISO fleet of natural gas power plants will be important in ensuring that the grid has enough capacity to meet demand during peak periods

# Reliability requirements cause renewable curtailment

# Essential reliability services needed in grid operations

[But some reliability requirements cause curtailment at a 50% RPS]



# Load following bridges between hourly and five minute schedules

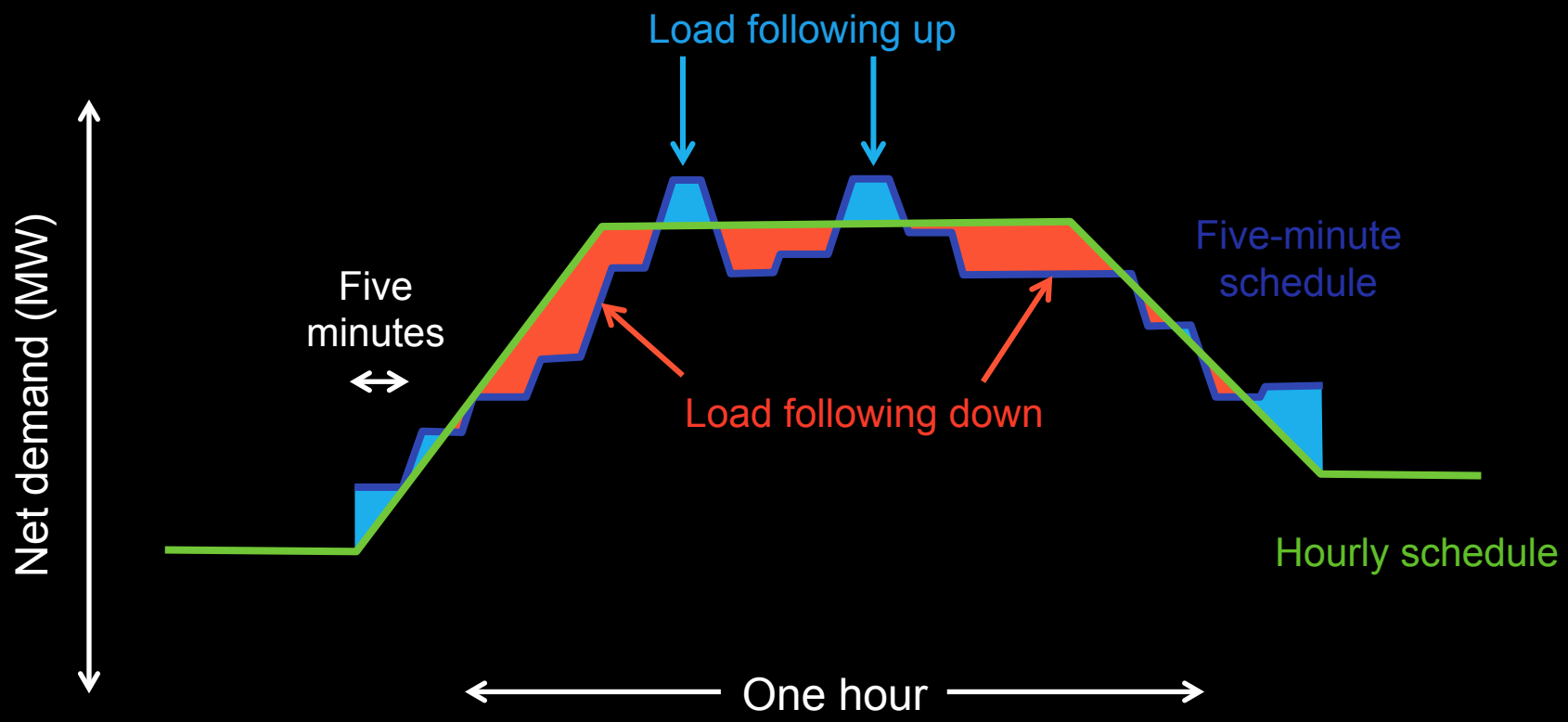



Figure based on:
Makarov, Y. V., *et al*., 2009. Operational Impacts of Wind Generation on California Power Systems. *IEEE Transactions on Power Systems* 24 (2), 2009, 1039-1050.

# Regulation bridges between five minute schedules and actual generation

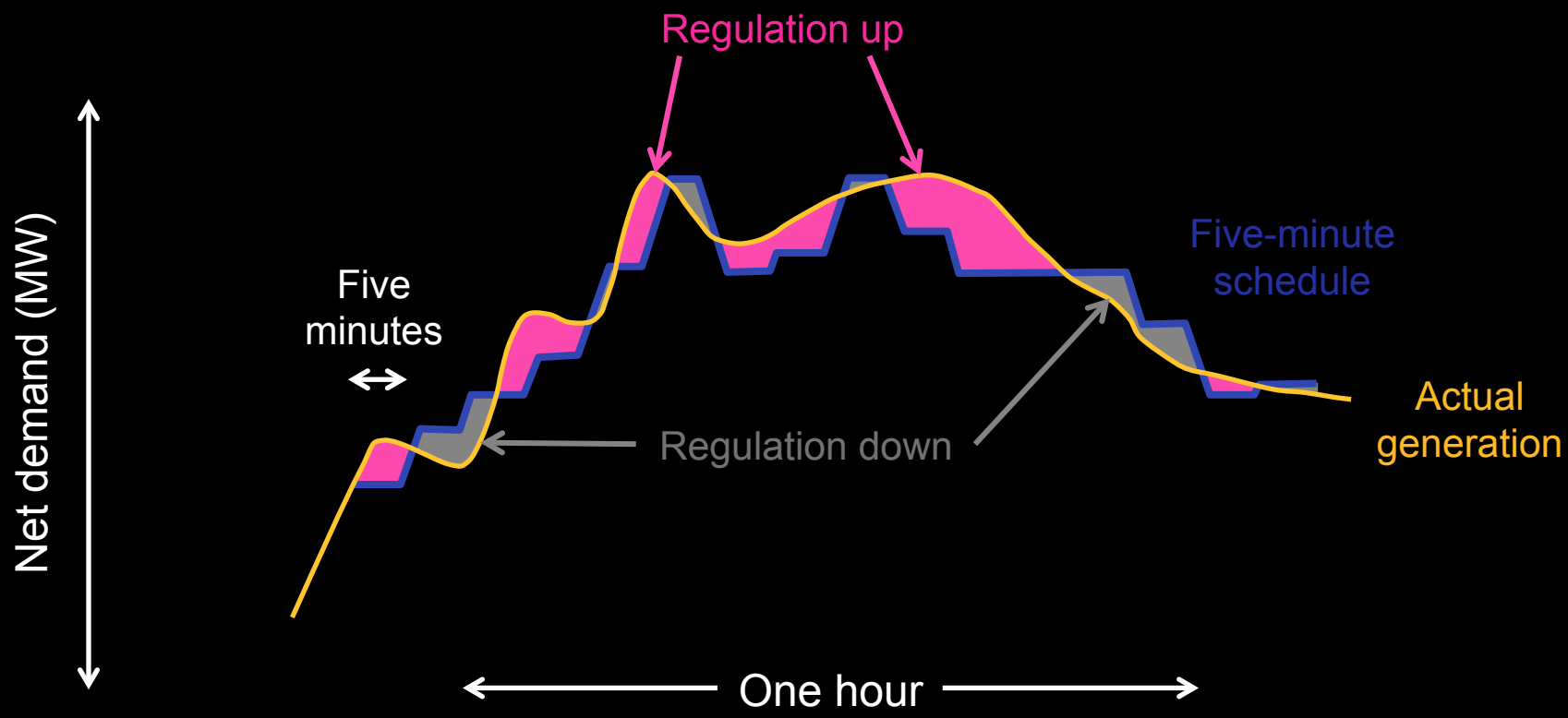



Figure based on:
Makarov, Y. V., *et al*., 2009. Operational Impacts of Wind Generation on California Power Systems. *IEEE Transactions on Power Systems* 24 (2), 2009, 1039-1050.

# Regional generation requirements are a proxy for many essential reliability services

These reliability considerations could cause coincident renewable curtailment and gas generation:

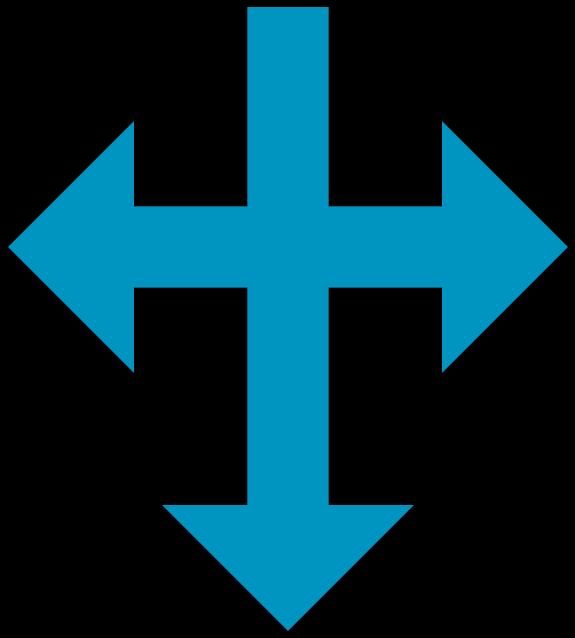
- ✧ voltage support and reactive power
- ✧ inertia and primary frequency response/governor response
- ✧ local and system-wide requirements for operating reserves
- ✧ transmission congestion
- ✧ transmission contingencies

Grid planners and operators should encourage non-fossil resources (including renewable generators) to provide essential reliability services

# Increasing operational flexibility at a 50% RPS: What works and what doesn't

# We modeled three different flexibility strategies

[1] Operate renewables more flexibly

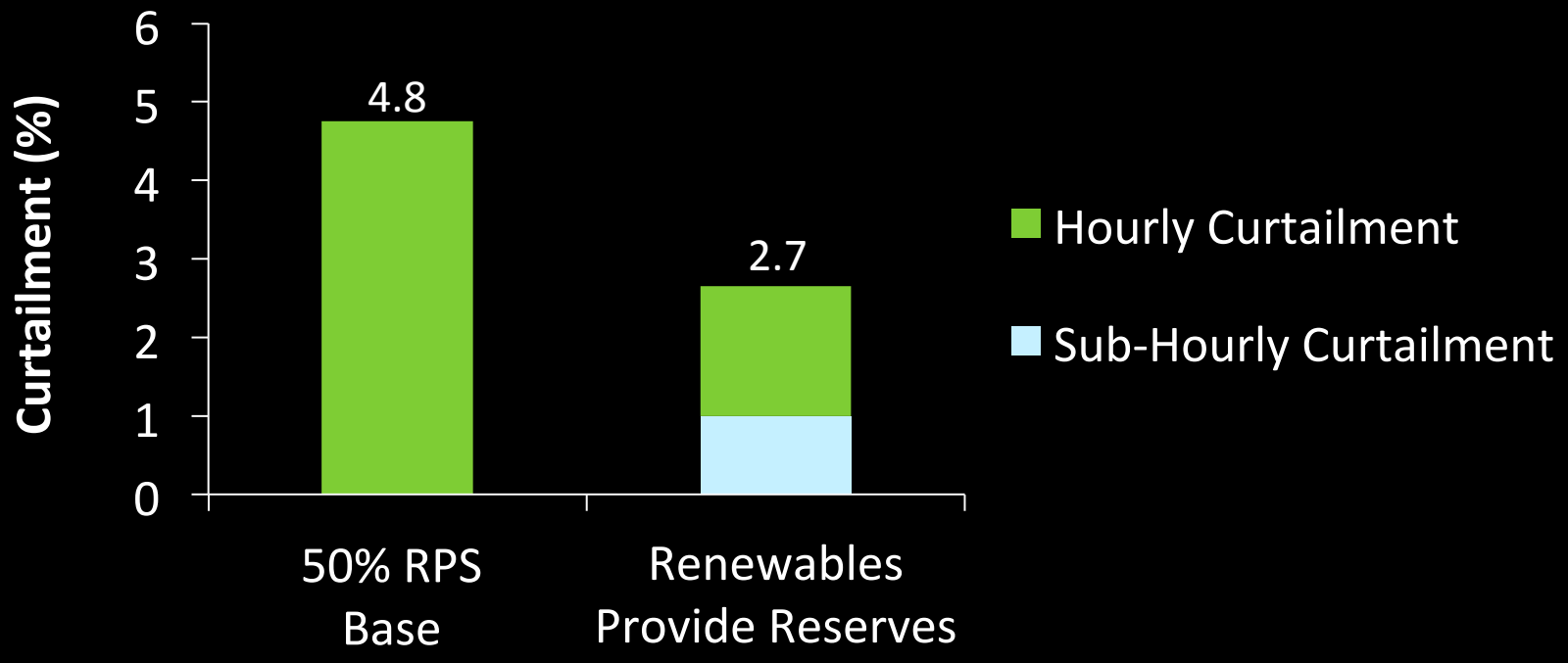


[2] Increase natural gas power plant fleet flexibility

[3] Add non-generation flexibility:
Storage
Advanced Demand Response
Exports

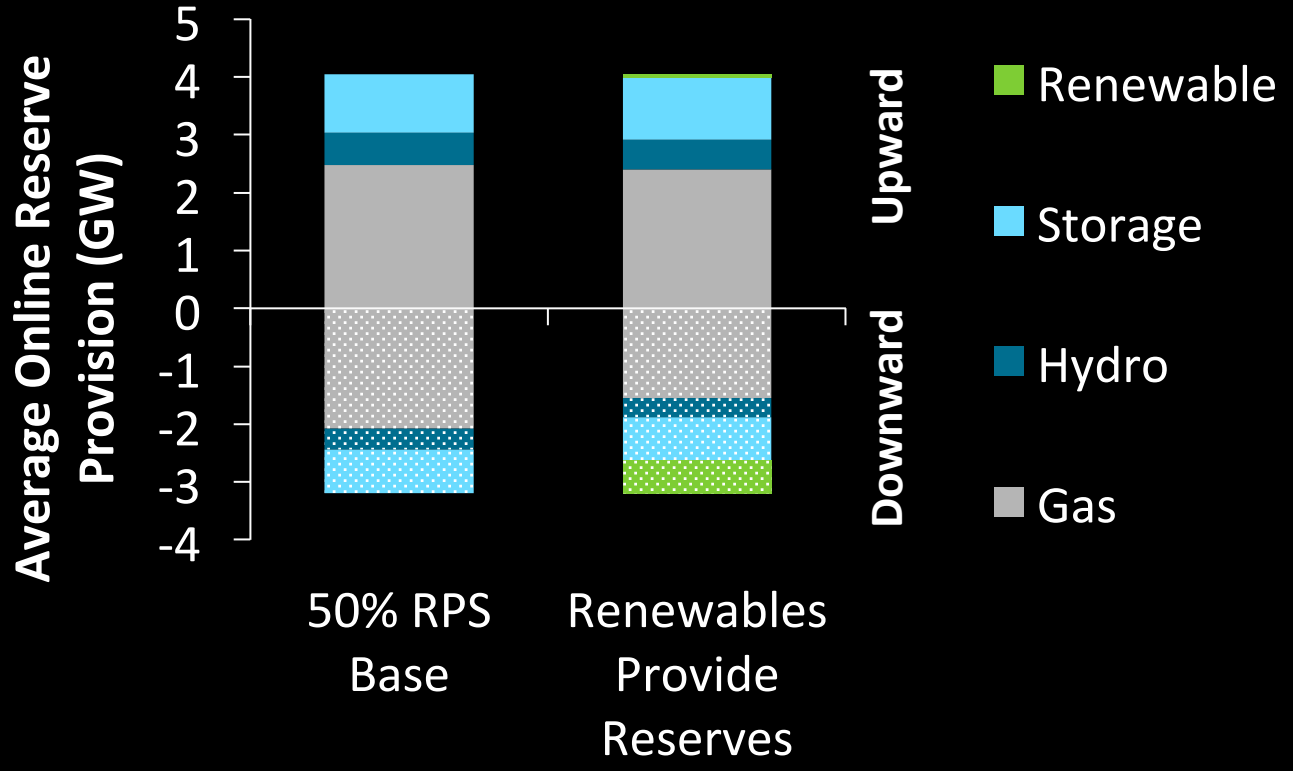
# Strategy [1]: Operating renewables flexibly is particularly effective

- Curtailment: nimble is much better than blocky
- Renewables should be incentivized to participate in CAISO markets and to install or utilize control equipment



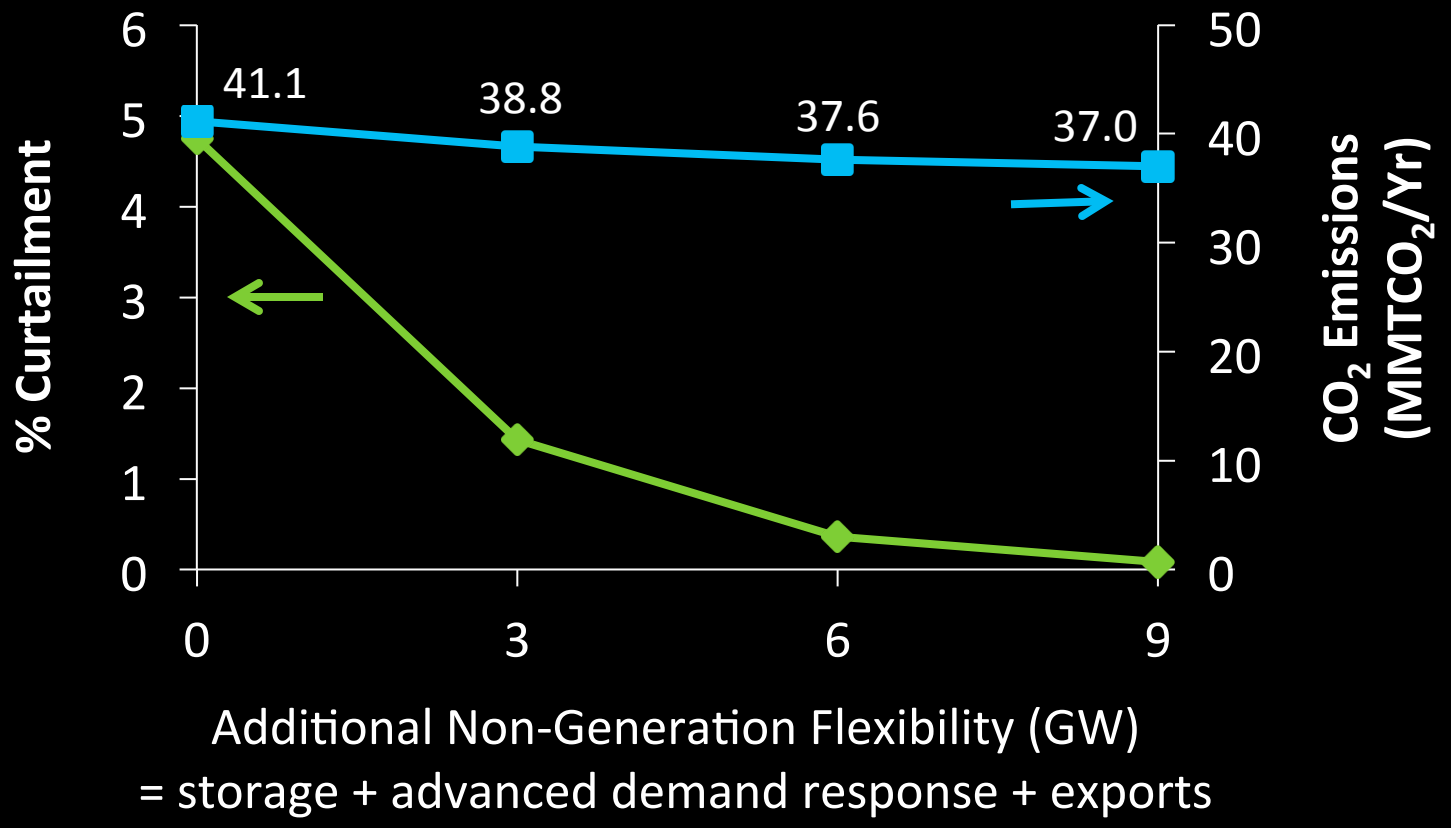
# Renewables frequently provide downward reserves

- Renewables don't have to be pre-curtailed to provide downward reserves



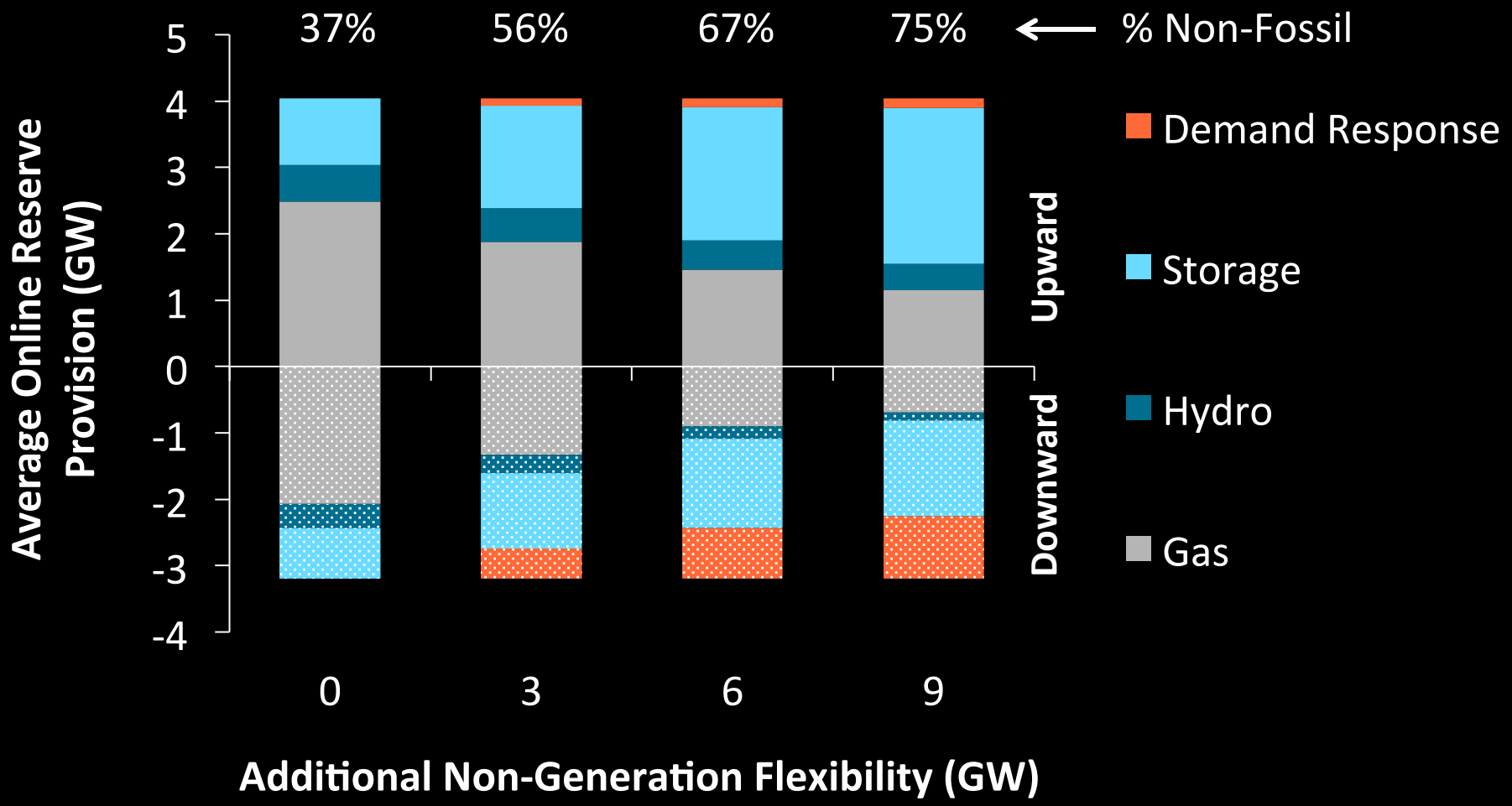

Online reserves: Load following, regulation, and spinning

# Strategy [2]: Non-generation flexibility reduces curtailment and GHG emissions




- More analysis needed on cost tradeoffs

# Reserves from non-fossil resources are valuable




- Downward reserves are particularly valuable

# Strategy [3]: Gas power plant flexibility has important limits

- Providing some reliability services with gas requires electricity production, which "crowds out" renewables

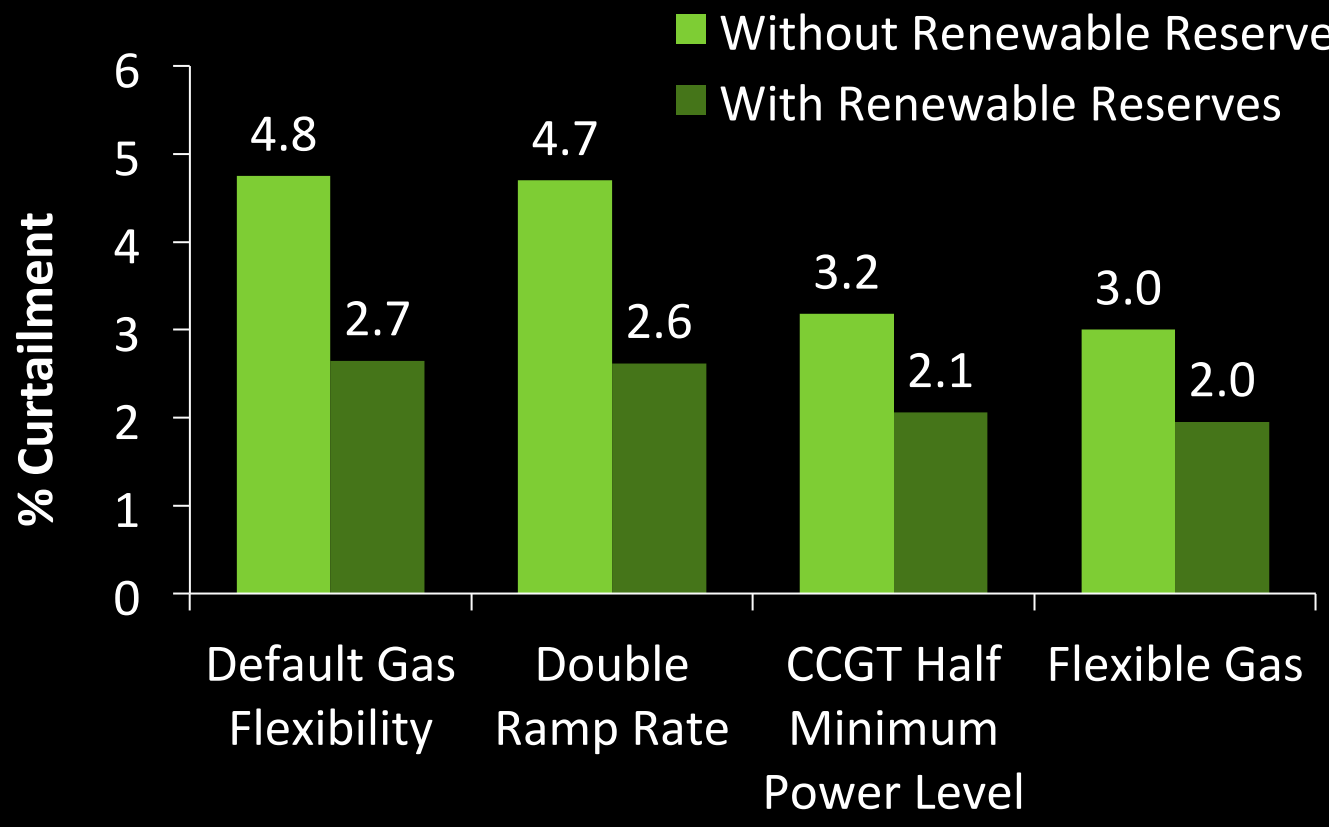

Gas fleet changes in the Flexible Gas run:

- Double ramp rate
- Half minimum power level
- 1 hour start and stop times
- 2 hour minimum uptime and downtime

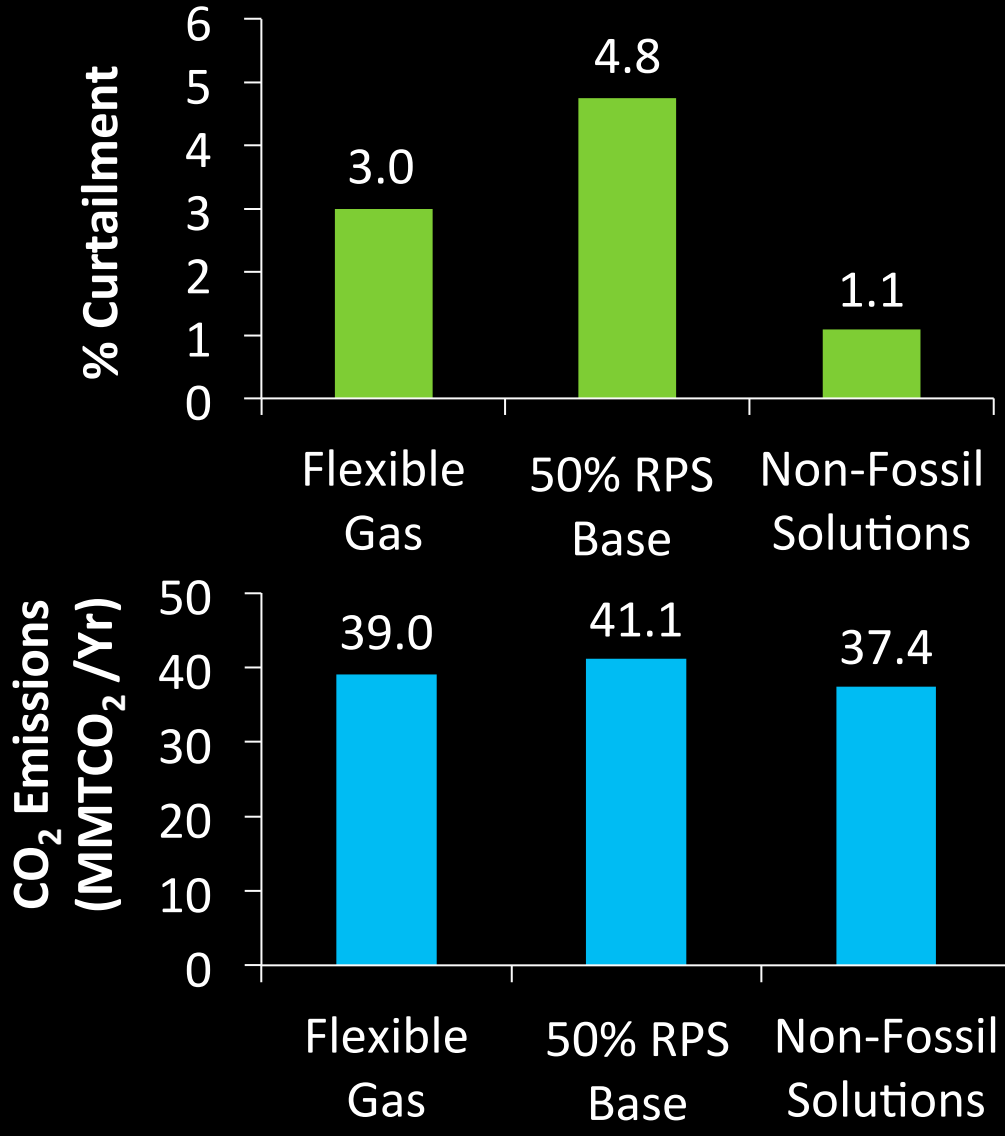
- Duck Chart: "belly" is much more important than the "neck"

# Renewable flexibility competes with gas flexibility

- When renewables can provide reserves, the amount of operational flexibility on the grid increases. Consequently, the amount of curtailment that can be avoided by increasing the flexibility of natural gas power plants decreases



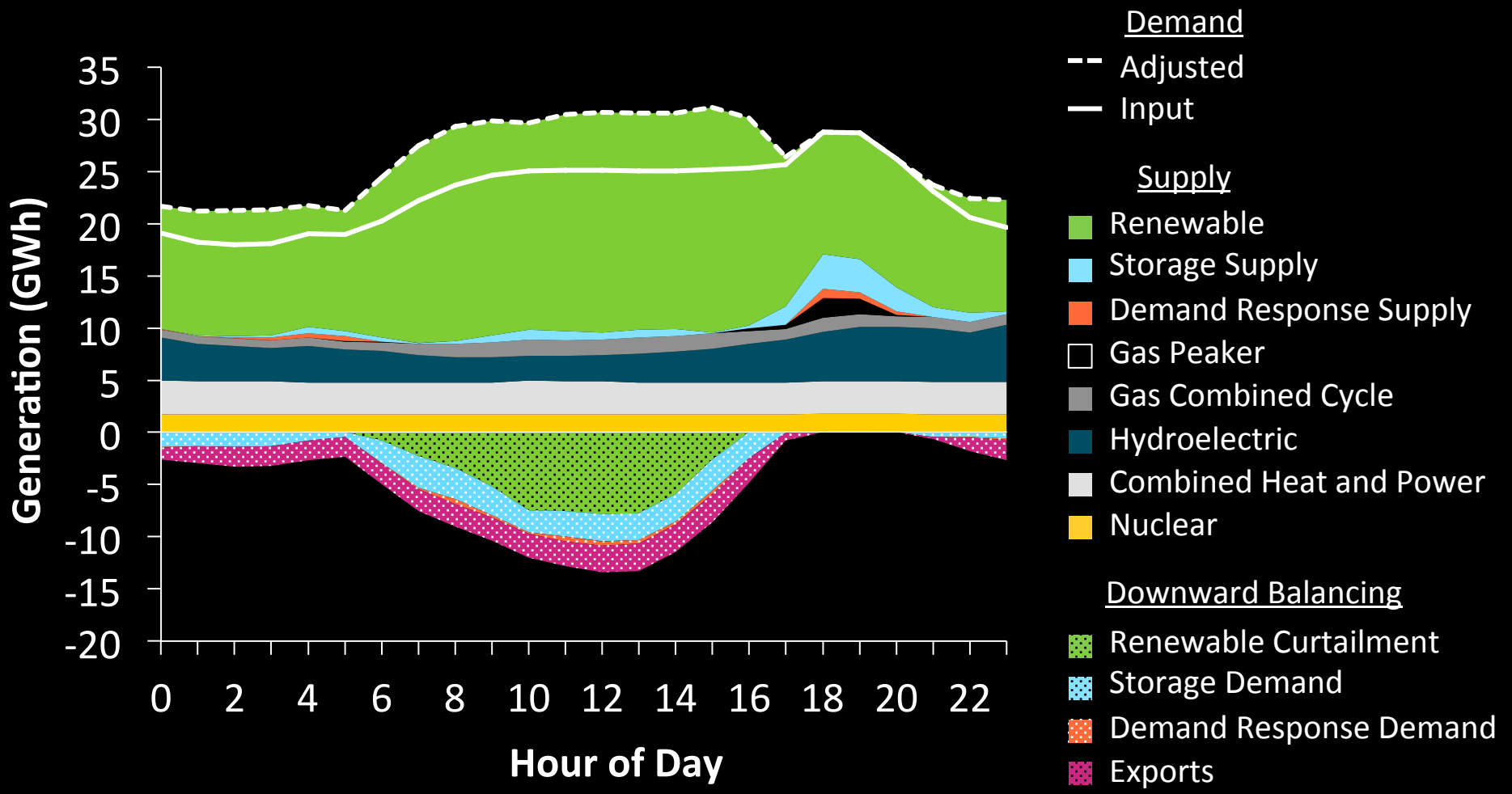
# Operational flexibility: Non-fossil can go further than gas




Non-Fossil Solutions:

- Renewables can provide reserves
- 1 GW additional electricity storage
- 1 GW advanced demand response
- 1 GW net exports allowed

# Non-fossil solutions can turn gas down or off when ample renewable energy is available

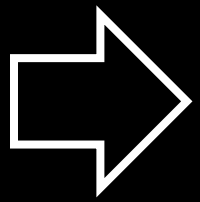



Example day depicted here is a near worst-case weekend day in May

# At a 50% RPS, renewables should help to integrate themselves by being dispatchable during critical times

33% RPS

50% RPS



Renewable
**curtailment**

Renewable
***dispatchability***

# Key findings

- Increasing the RPS from 33% to 50% reduces electricity GHG emissions by 22 - 27%
- Coincident gas generation and renewable curtailment should be avoided
- Reliability requirements cause renewable curtailment
- Operating renewables flexibly is particularly effective
- Non-generation flexibility can reduce GHG emissions
- Natural gas power plant flexibility has important limits