



Meeting Challenges to California's Long-term Electric Sector Decarbonization

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Workshop on Electricity Market Design Under Long-Term Decarbonization

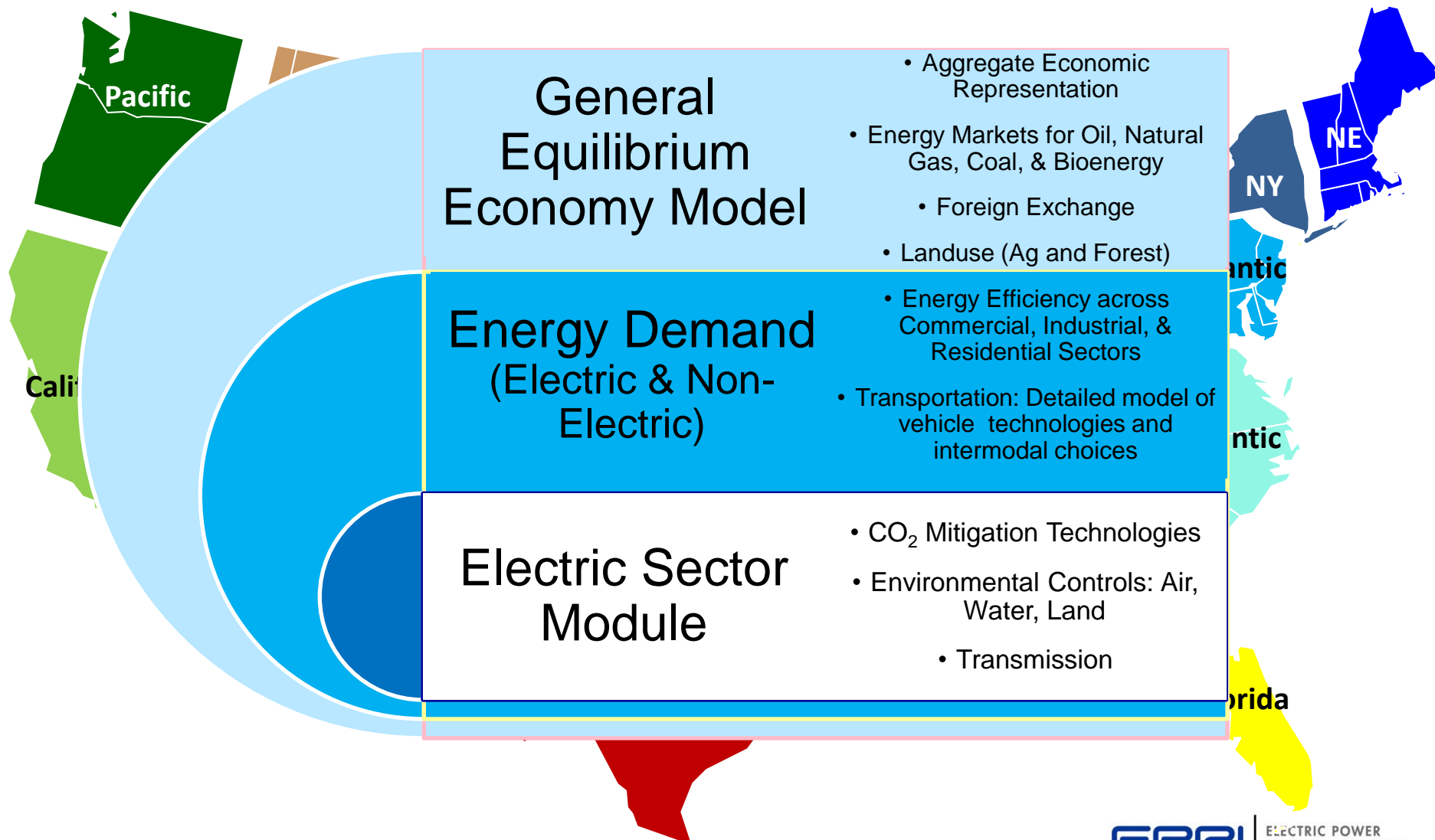
Paris, France

October 8, 2014

Ongoing EPRI Application of REGEN to California's Long-term Decarbonization Goal

- California Governor's Executive Order seeks to cut economy-wide GHG's in California to 80% below 1990 levels by 2050
 - Makes CA a good case-study for future regulations elsewhere
- Raises question of how can the California's electric sector support meeting this goal and what will it cost?
 - Can electric sector decarbonize?
 - What will it cost?
- Integrated US-REGEN energy-economy simulations of CA provide analytically rigorous assessments of the costs and sensitivities to key policy, market, and technological uncertainties
- Results are a first step toward understanding how to achieve aggressive CO2 reductions and what are the costs

US-REGEN Model Overview

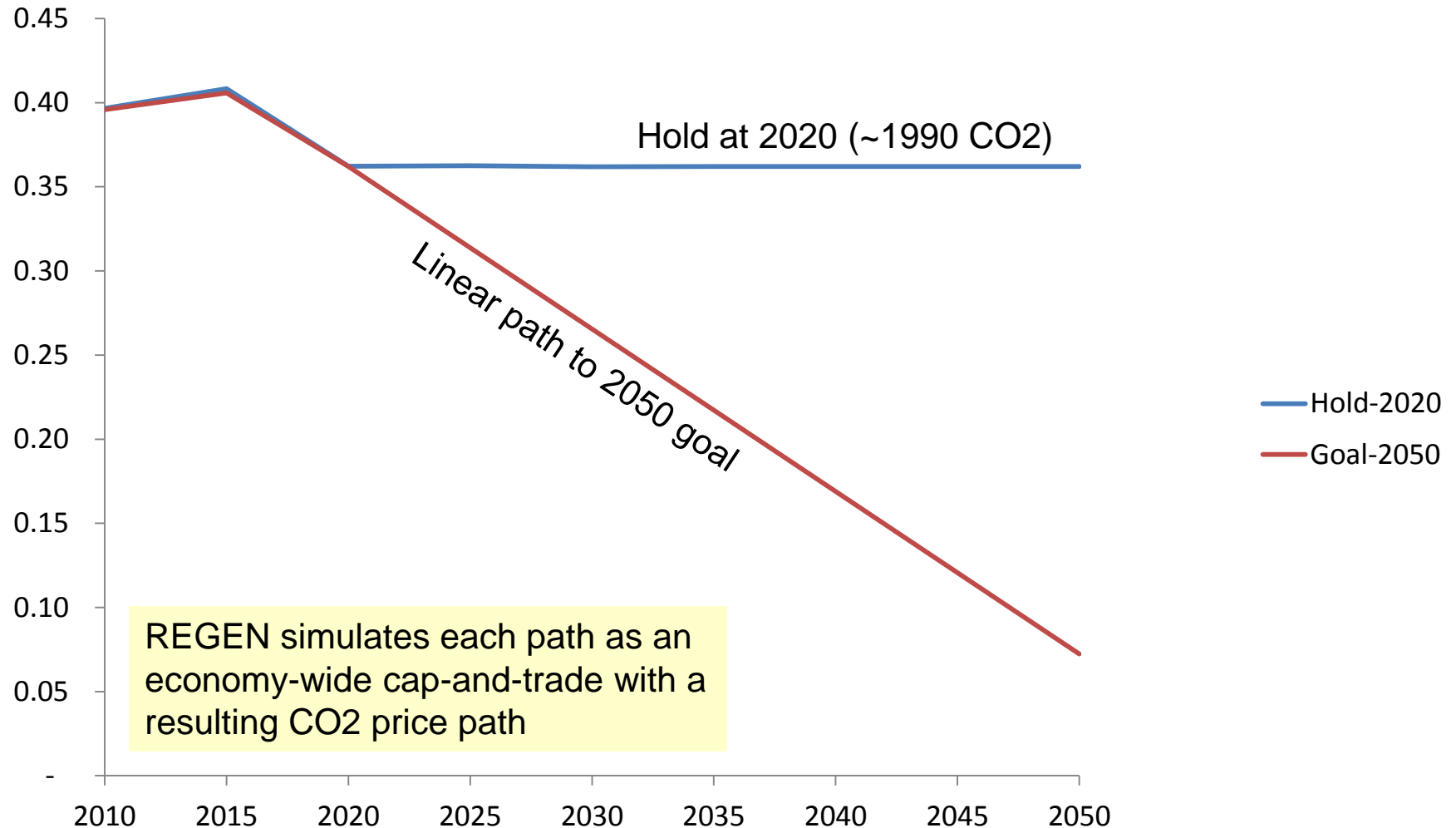


Important Assumptions – Electric Sector

- No new nuclear or CCS in CA, but some available in US
- Wind, solar, and storage only scalable in-state non-emitting generation options (geothermal, biomass supply limited)
- Hourly wind and solar profiles from EPRI's AWS Truepower database (2010 meteorology)
- AEO 2014 natural gas price path to 2040, then flat
- CA restricts imports of out-of-state power to zero
 - to prevent CO₂ leakage by out-of-state generation
 - CA can export power, and add transmission if economic
 - Restrictions on power imports unnecessary in scenarios with a US CO₂ cap (not shown here)

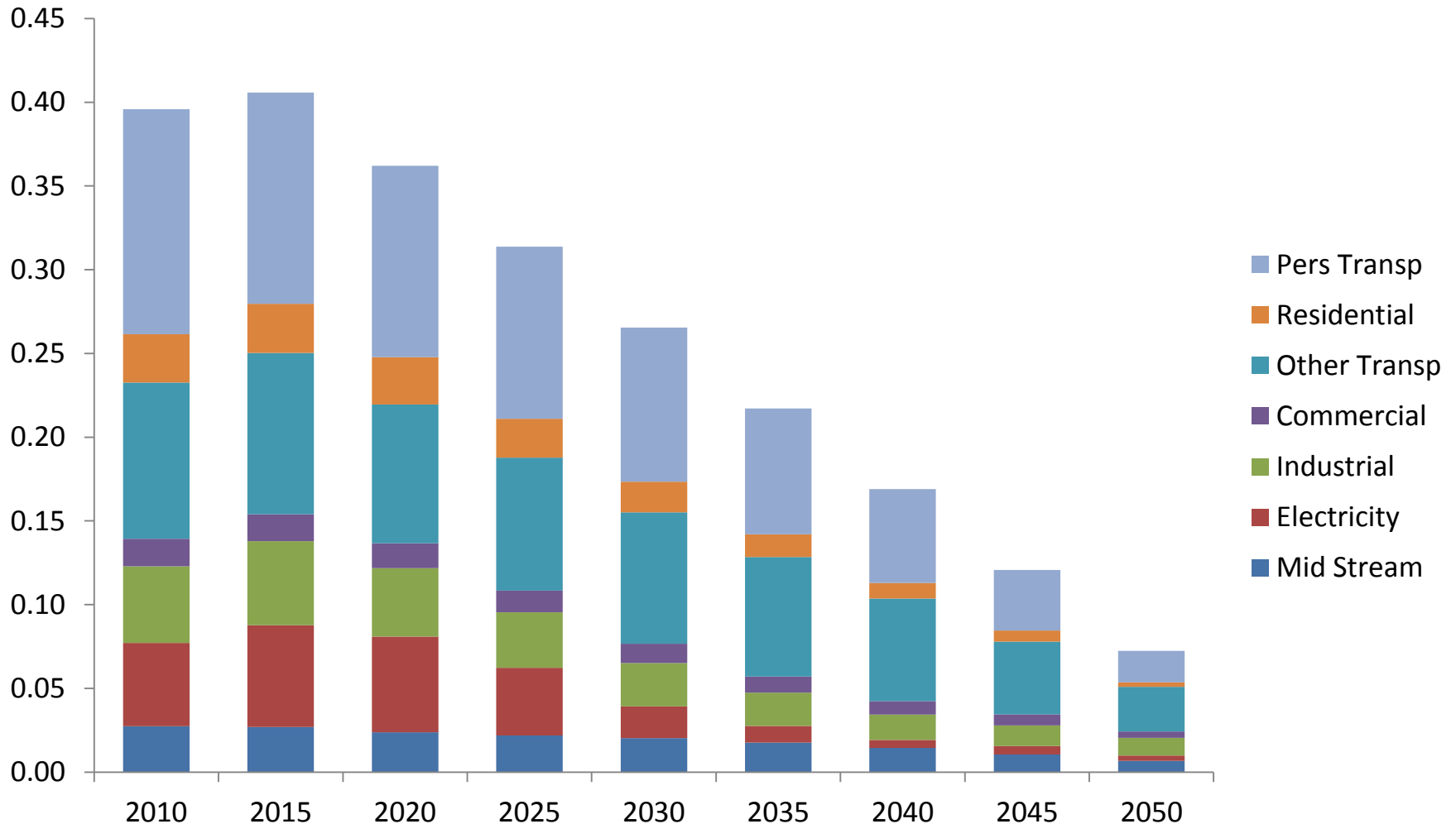
Two CA Economy-Wide CO₂ Paths Analyzed

Total California CO₂ Emissions by Scenario (billion mt)



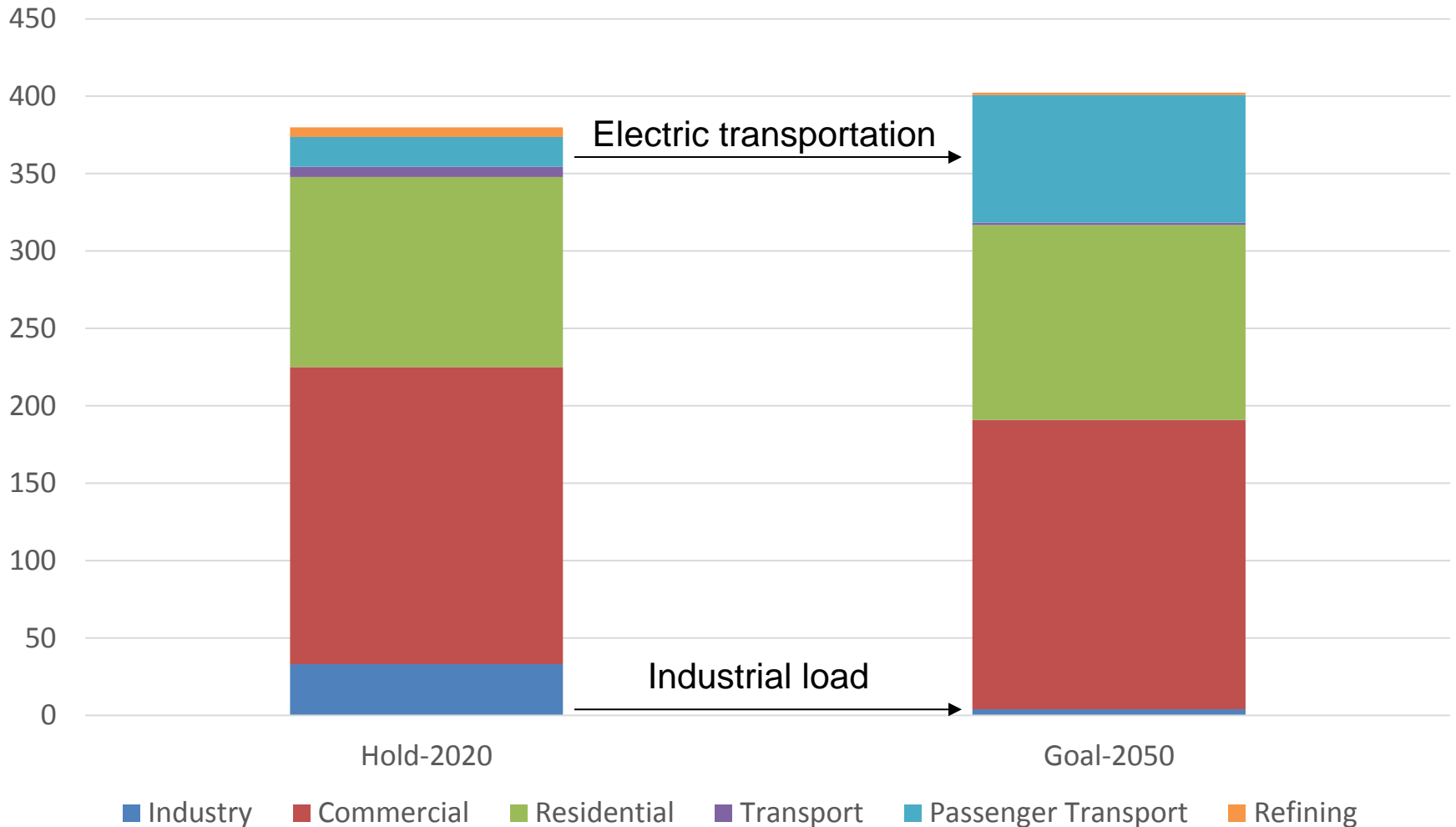
California CO2 by Economic Sector on One Possible Path to Meeting 2050 Goal

California Goal-2050 Scenario CO2 by Economic Sector (bmt)

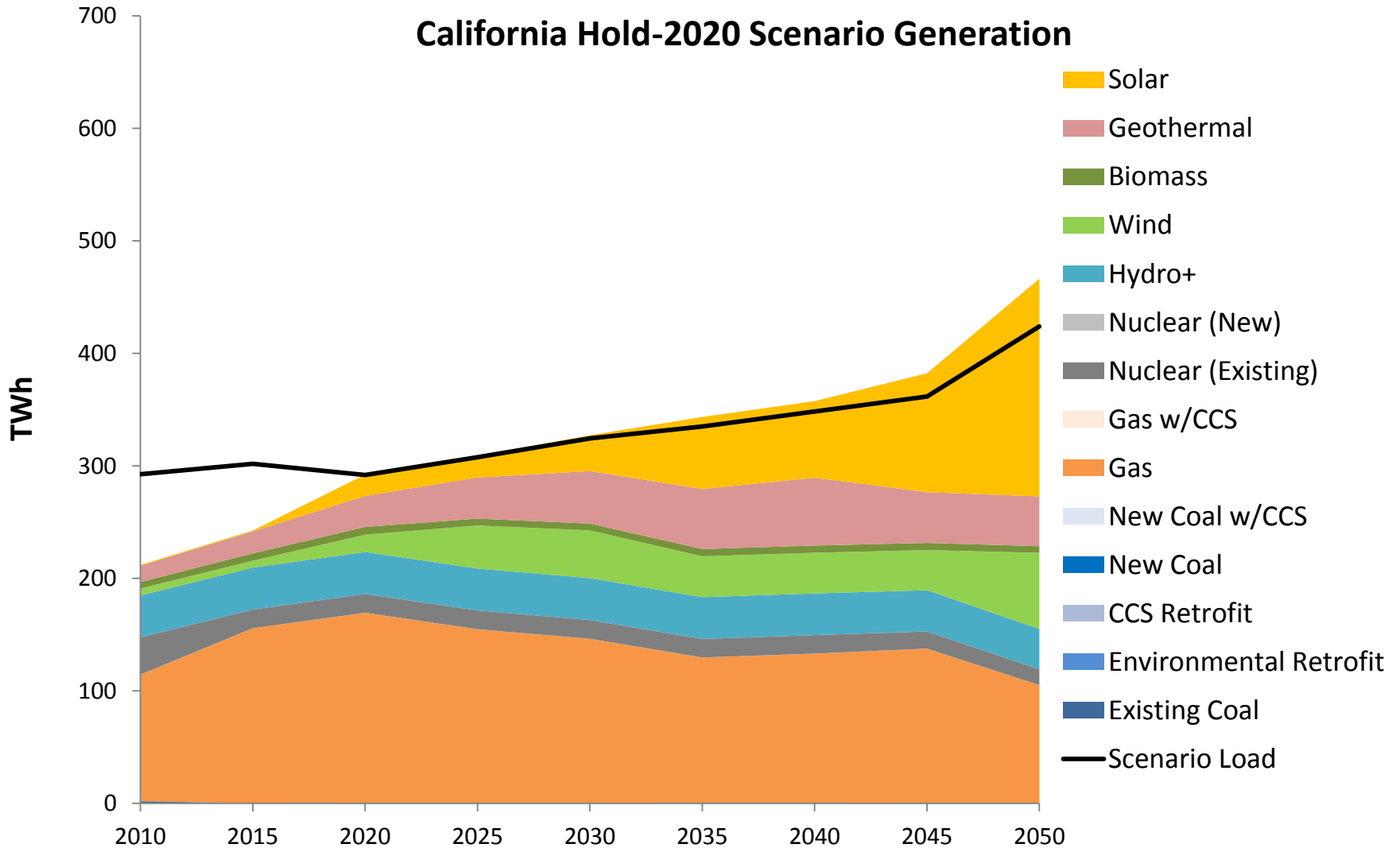


How Meeting 2050 Goal May Change Mix of Electric Load

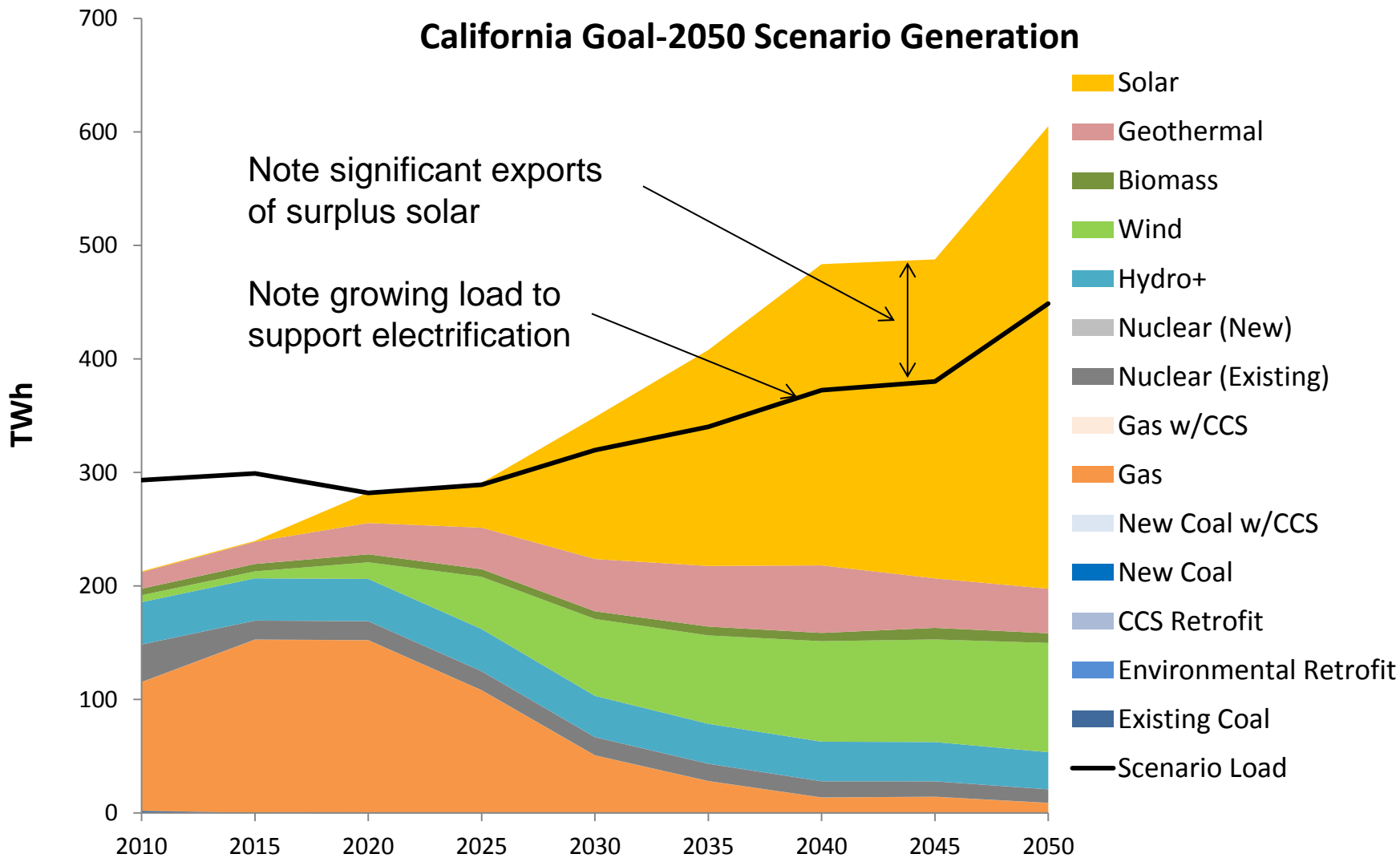
California Sectoral Electricity Use (TWh) in 2050



Generation for Hold-2020 Scenario (Reference)

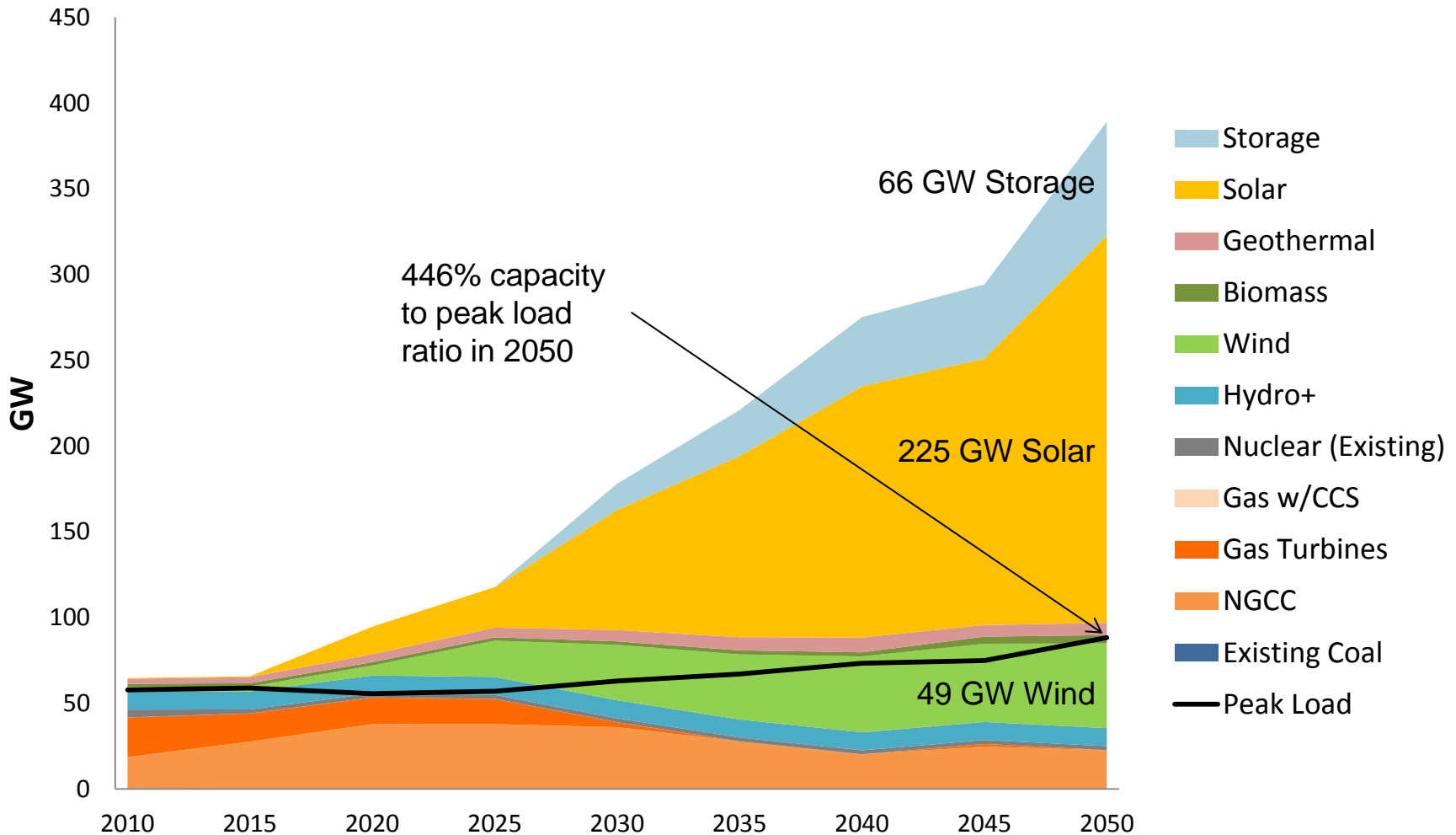


California's Electric Generation Mix Ultimately Dominated by Solar (Goal-2050 Scenario)



Decarbonizing Requires Substantial Investment in Renewable Energy and Storage

California Goal-2050 Scenario Installed Capacity



Observations on Decarbonizing the CA Electric Sector

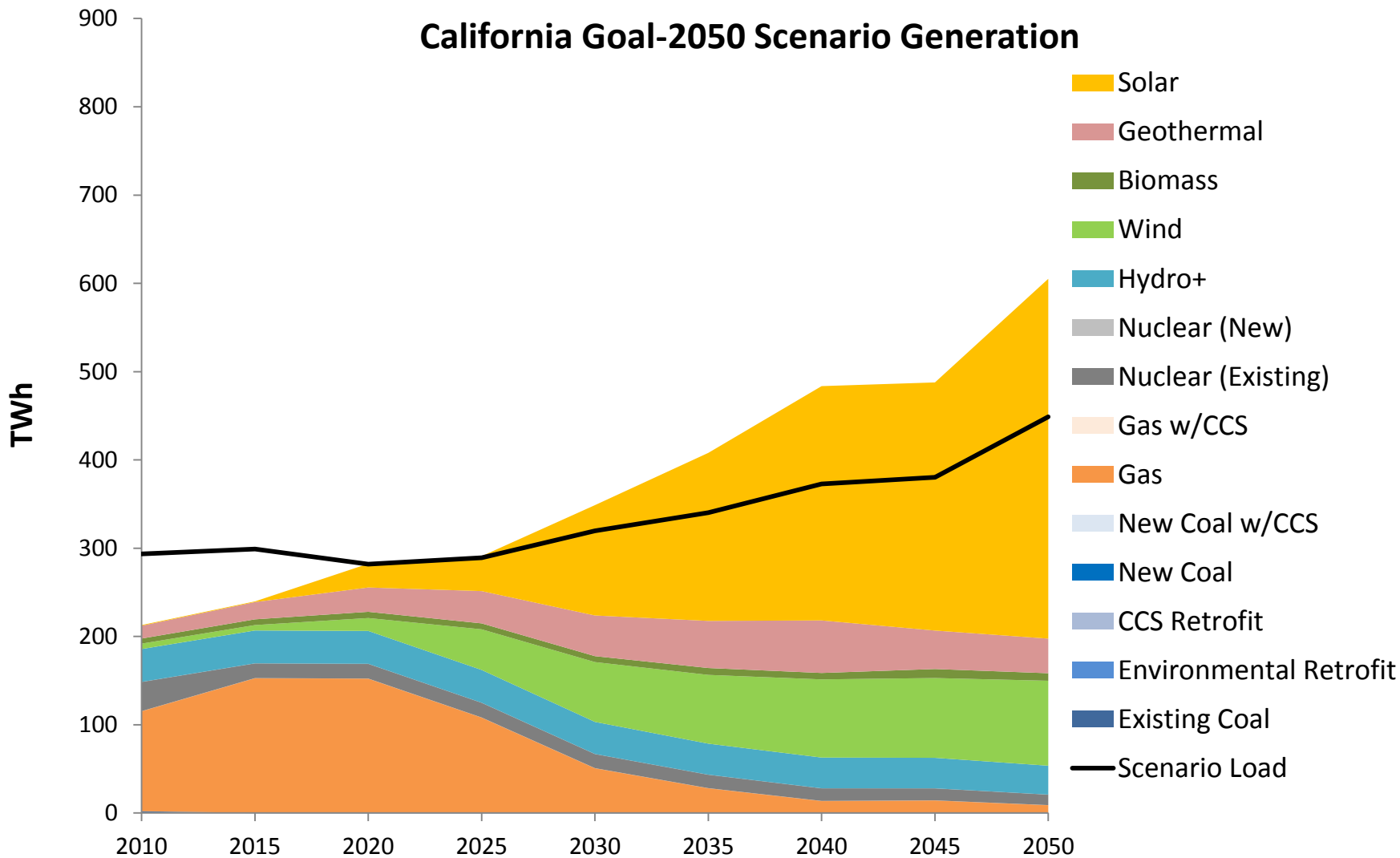
- To support 2050 goal electric sector must be near CO₂-free
- Without nuclear and gas CCS only options are wind and solar (geothermal and bioenergy count, but supply limited)
- Given that wind and solar aren't dispatchable, and can go to zero output simultaneously, need storage to meet load
- Analysis assumes pumped storage with 10-hour reservoirs at \$2,700/kW (currently much lower cost than batteries)
- Also end up with surplus wind and solar
- REGEN finds the minimum-cost mix of generation, storage, new transmission investments needed to cover load in all hours and comply with CO₂ limits
- For California's renewable resource endowment there is more solar than wind (we run out of wind in most scenarios)
- Being able to export surplus solar out-of-state, or import out-of-state wind lowers costs markedly

Sensitivity Scenario Tests Implications of Limiting Exports, Letting CA Add Nuclear

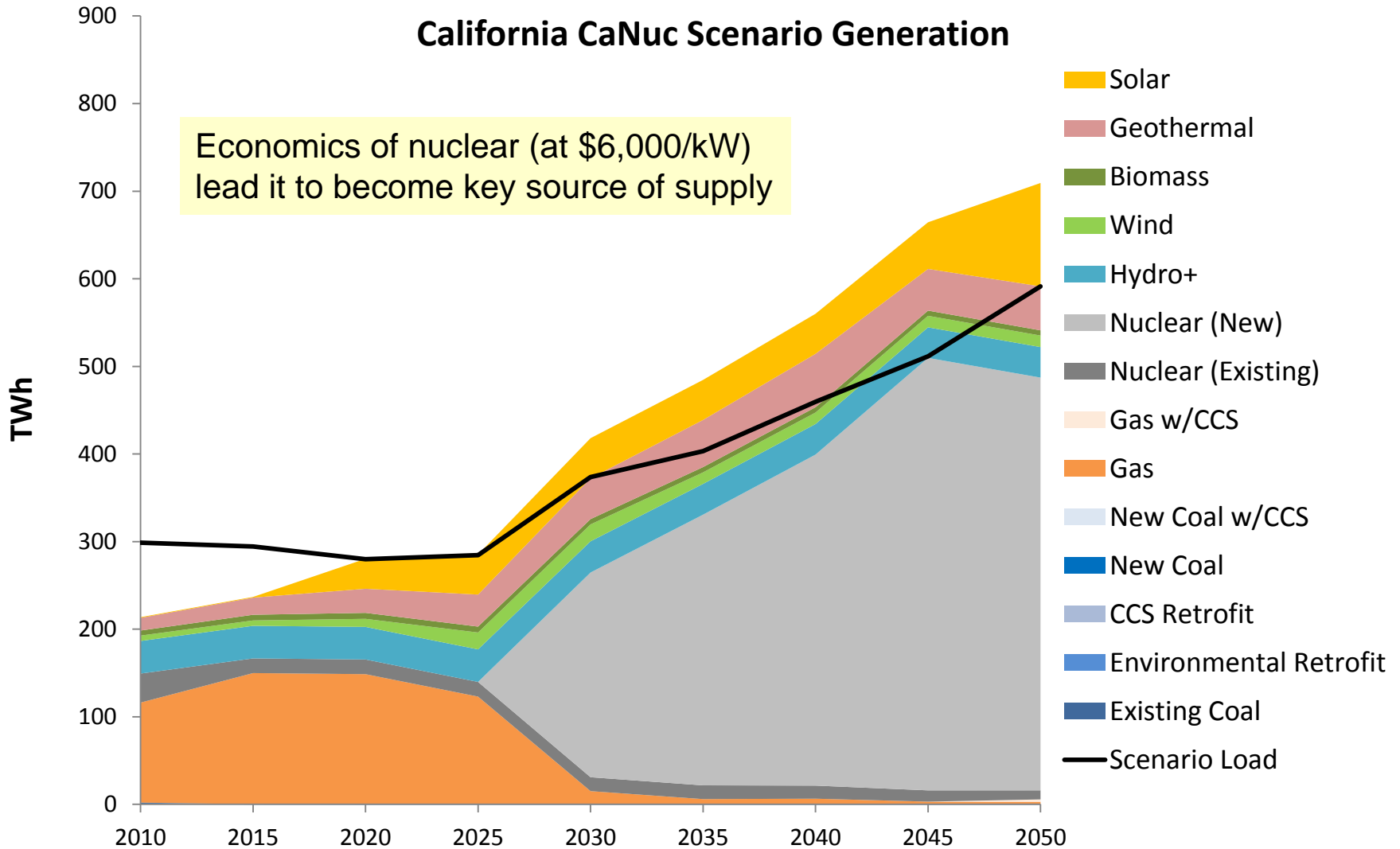
- Nuclear additions in CA currently not allowed due to legislative restrictions associated with national spent fuel storage
- CCS Gas also uncertain (technology and regulation)
- Sensitivity case intended to explore implications of being able to add new nuclear and gas CCS in CA
 - Nuclear capital cost ~\$6,000/kW and ~\$10,000
 - No limit on additions starting in 2030
- This is not a forecast

Goal-2050

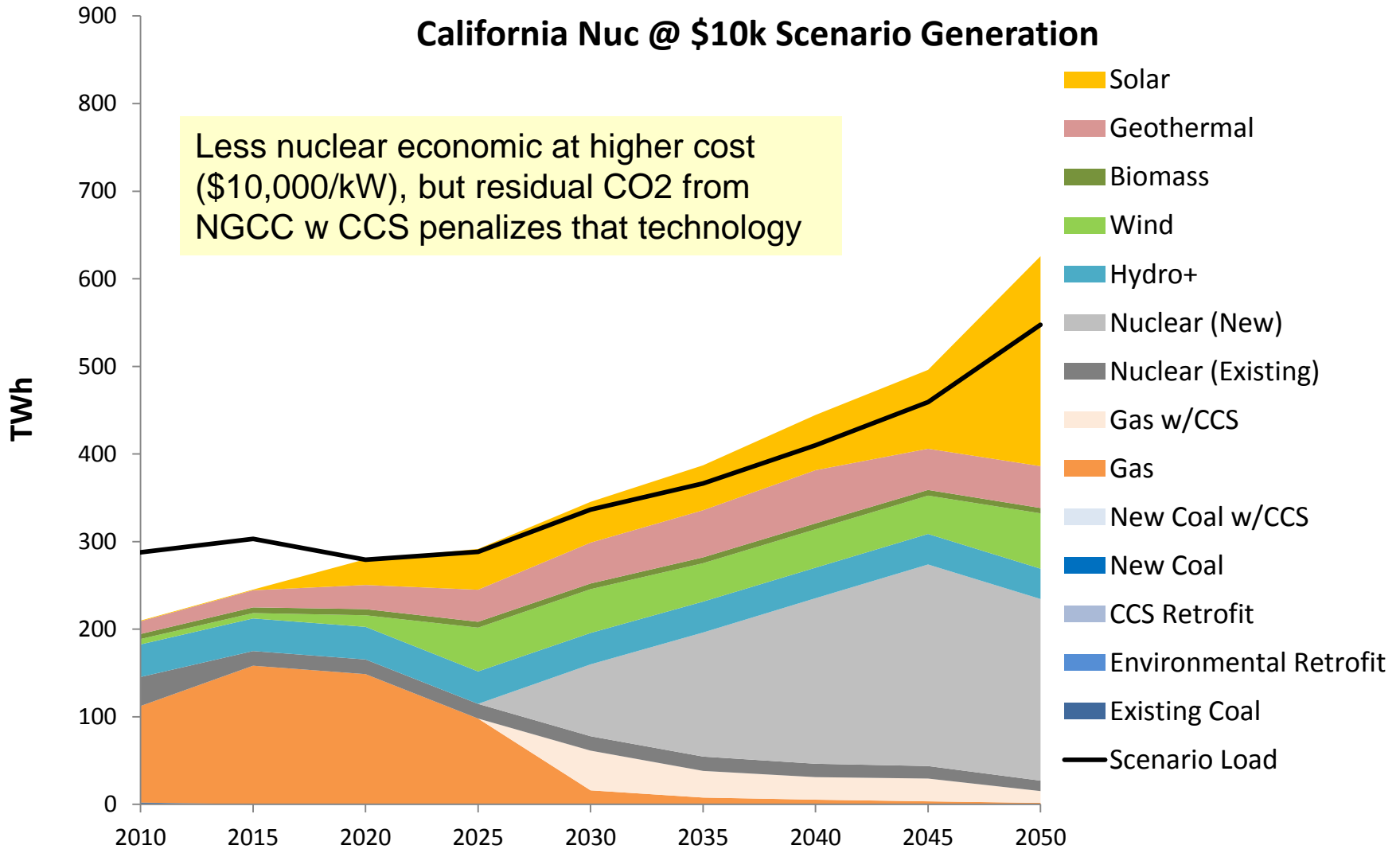
California Goal-2050 Scenario Generation



Evolution of Generation Mix – New CA Nuclear Scenario

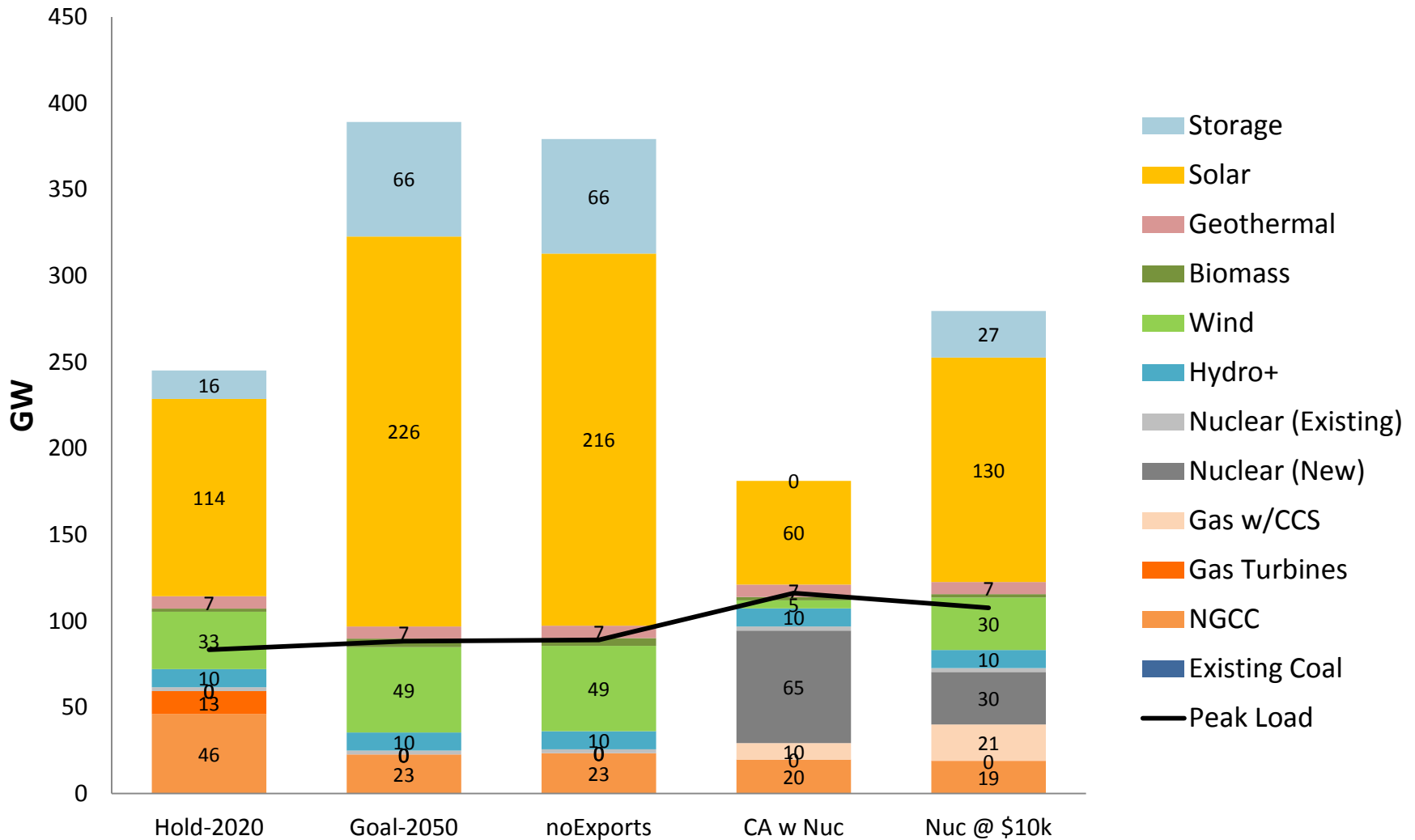


Evolution of Generation Mix – High-Cost New CA Nuclear Scenario



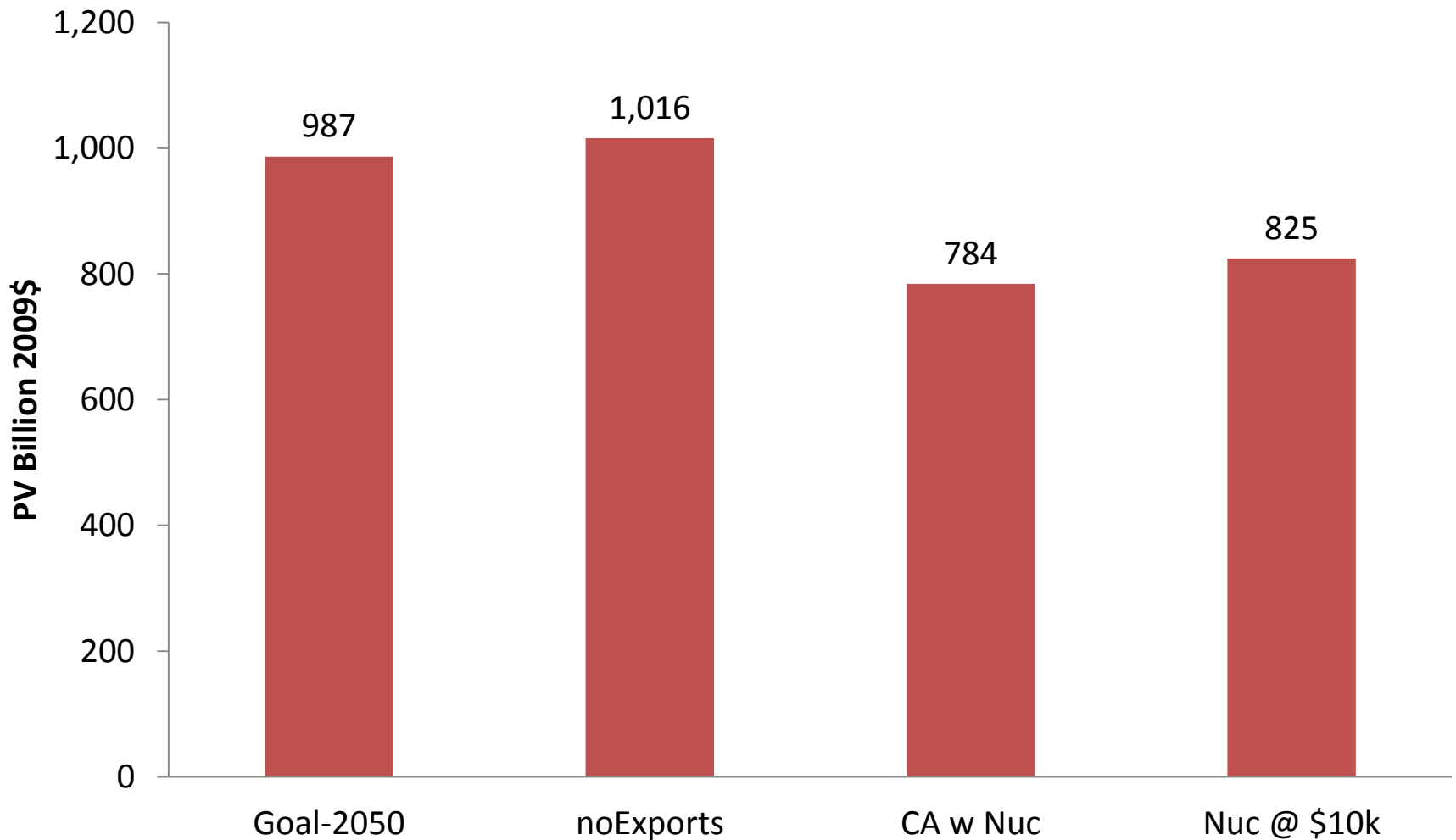
California Capacity in 2050 (note peak load responding to differences in power prices)

California Installed Capacity in 2050



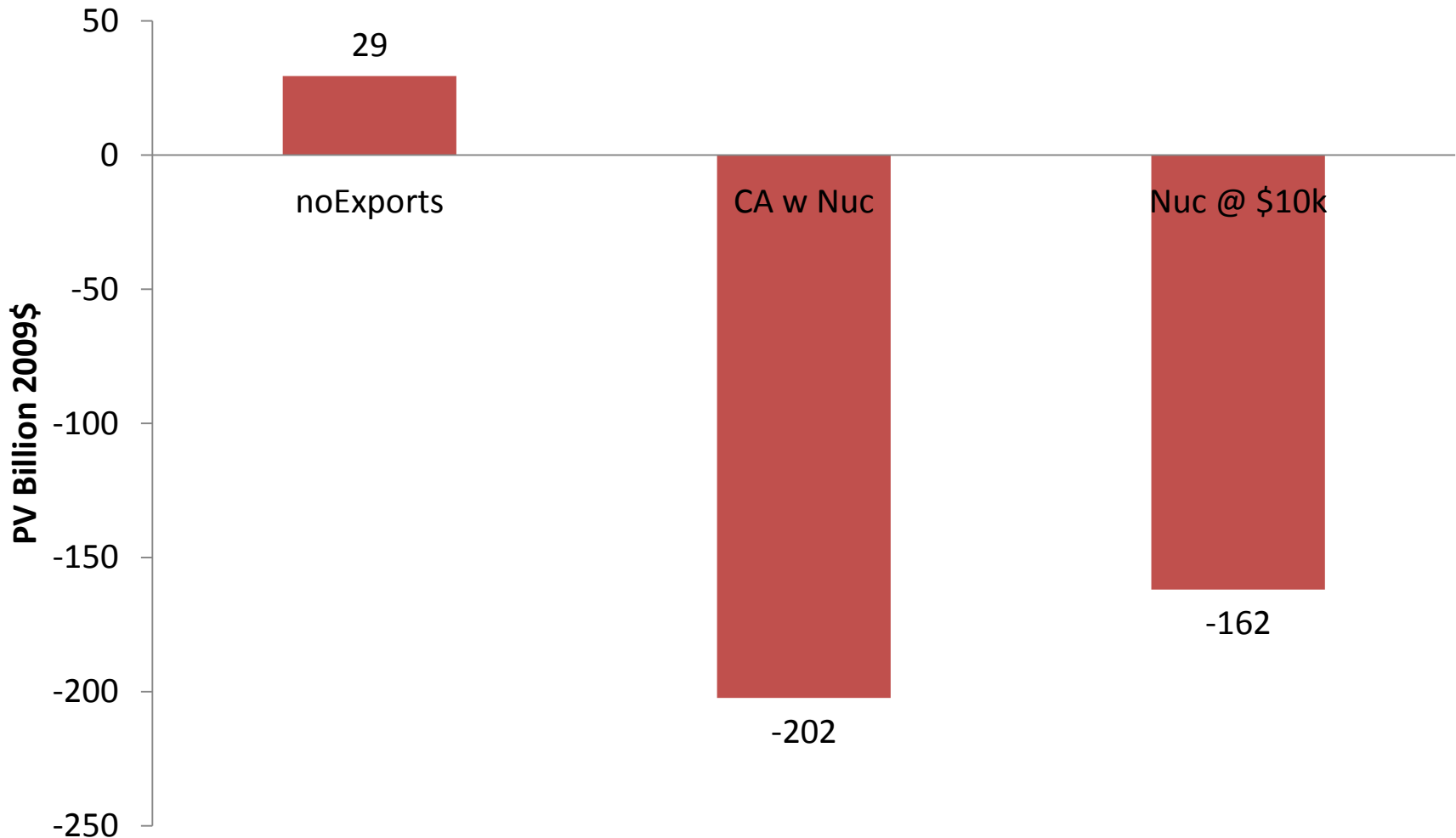
GDP Losses Compared to Hold-2020 Scenario (approximately 6% of PV of State GDP)

GDP Loss 2020 - 2050 (California)



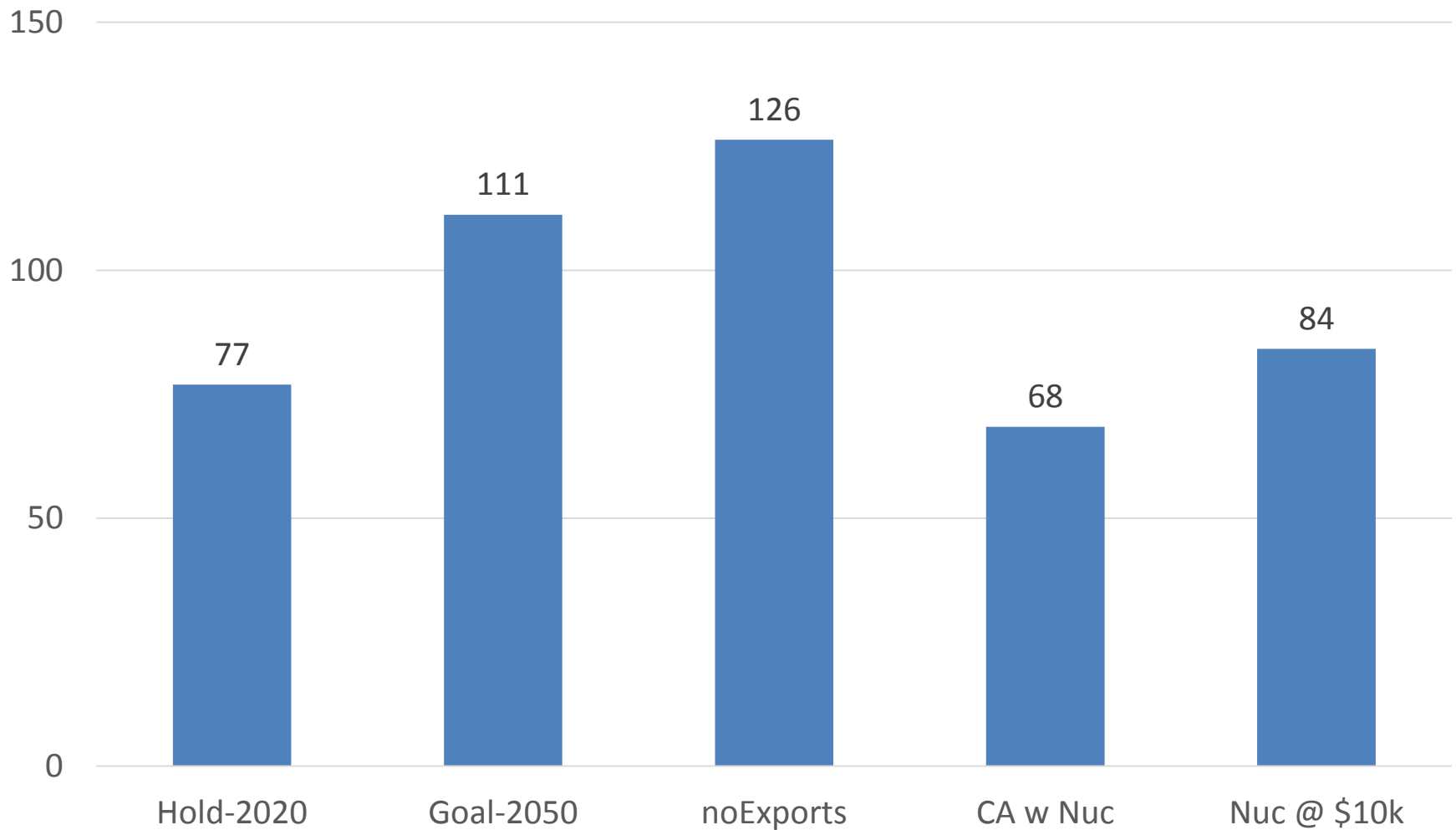
Option to Add New Nuclear Worth \$160-\$200B in Lower GDP Impacts

Incremental Sensitivity-Case GDP Loss 2020 - 2050 (California)



Wholesale Power Prices Sensitive to Policy and Technology

Average Price of Wholesale Power 2021-2050 (\$/MWh)



Note that prices include capacity value

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Caveats

- Analysis is intended to support insights and is not a forecast
- Electric system modeling assures overall supply-demand balance across all time periods but does not cover investment and operational challenges associated with power system transmission and operation (e.g., system stability and voltage management, sub-hourly supply adequacy, in-state transmission flows)
- Analysis based on today's technologies, and their potential for incremental development, but hard to anticipate the unanticipated: technology developments may have a significant roles by 2050

Observations on Challenges of Decarbonizing CA's Electricity

- Simulations show how CA can achieve a decarbonized electric sector largely based on solar, wind and storage
- Greatest reliance is on solar
- Costs are large by absolute levels, but a fraction of GDP
- Costs are higher if CA cannot export surplus solar/wind
- Costs lower if CA is able to add new nuclear generation, even at a cost of \$10,000/kW



Together...Shaping the Future of Electricity