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EVALUATING INVESTMENT IN GENERATION, TRANSMISSION, AND STORAGE UNDER CLIMATE CHANGE AND INTERMITTENCY CONSTRAINTS

Professor **Daniel Kammen**

Energy & Resources Group & Goldman School of Public Policy
Director, Renewable and Appropriate Energy Laboratory
Director, Transportation Sustainability Research Center
http://rael.berkeley.edu | http://tsrc.berkeley.edu

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Outline

- The SWITCH model: http://rael.berkeley.edu/switch
- Energy operation and planning decisions to 2030 and 2050

Motivation

- It is difficult to project what the economy and the electricity system should look like under stringent decarbonization constraints

A "*model result deserving special attention is the expanded role of electricity, which increases from 15% to 55% of end-use energy, essentially switching places with petroleum products*" (Williams *et al*., 2012).

"*Without zero-emissions load balancing (ZELB), a 100% renewable portfolio will have more emissions than any other electricity portfolio, about 30% more than a nuclear power portfolio. Without ZELB, natural gas or even coal plus CCS has fewer emissions than renewables*" (California's Energy Future, 2011).

High-level research questions

- How to keep costs low?
- What role should intermittent renewable sources play relative to other low-carbon technologies?
- How much of a constraint is intermittency in the 2050 timeframe?

Complex Power Systems: High Temporal and Spatial Resolution Modeling

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ENERGY POLICY

High-resolution modeling of the western North American power system demonstrates low-cost and low-carbon futures

James Nelson [a,b], Josiah Johnston [a,b], Ana Mileva [a,b], Matthias Fripp [c], Ian Hoffman [a,b,d], Autumn Petros-Good [a,b], Christian Blanco [a], Daniel M. Kammen [a,b,e,*]

[a] *Renewable and Appropriate Energy Laboratory, University of California, Berkeley, CA 94720-3050, United States*
[b] *Energy and Resources Group, University of California, Berkeley, CA 94720-3050, United States*
[c] *Environmental Change Institute, Oxford University, South Parks Road, Oxford, OX1 3QY, UK*
[d] *Electricity Markets and Policy Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, United States*
[e] *Goldman School of Public Policy, University of California, Berkeley, CA 94720-3050, United States*

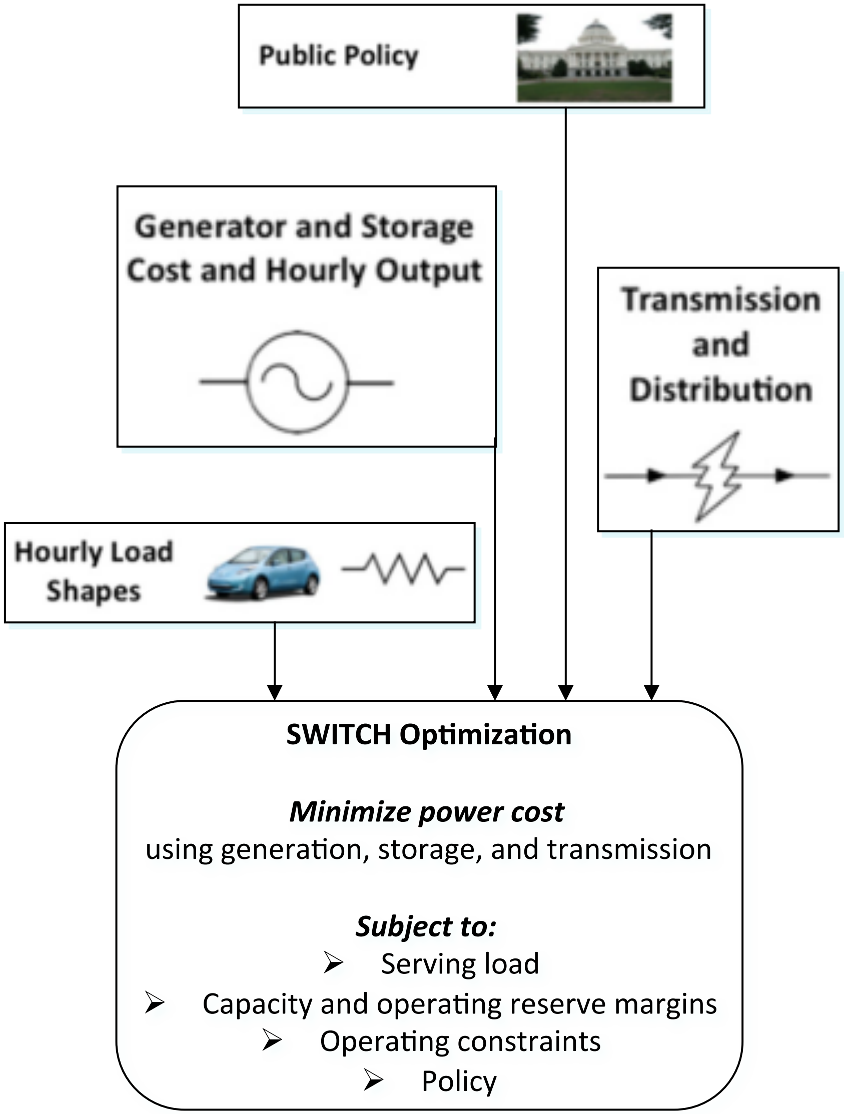
http://rael.berkeley.edu/**switch**

SWITCH Modeling Objectives to Support California Energy Planning

- SWITCH is a CEC-supported modeling program
  - Guido Franco & Joe O'Hagan – CEC Program Officers
- High-spatial and temporal resolution modeling of CA and WECC energy supply, T&D and end-use opportunities to meet cost, reliability and environmental objectives
- Next objectives include:
  - High-solar energy scenarios (pending detailed natural gas supply curves, added complexity of storage options)
  - Environmental impacts of energy siting and operation
  - Scenarios under carbon quantity and cost constraints
  - Inter-model comparisons and validation studies

The SWITCH Model

- Mixed-integer linear program
- The goal is to ensure :
  - Reliability
  - Policy goals
  - Low-cost
- Can choose to install and operate numerous generation and storage technologies as well as transmission lines
- Time-synchronized hourly load and generation profiles intermittent renewables
- Generator, transmission, and storage investment every 4 or 10 years
- Generator, transmission, and storage dispatch hourly
  - 144 dispatch hours per investment period
  - 576 dispatch hours per model run
- 50 load areas in the WECC



Credits:
- Fripp, Matthias, Optimal investment in wind and solar power in California. Doctoral Dissertation, University of California, Berkeley, 2008.
- Nelson, James, *et al*., High-resolution modeling of the western North American power system demonstrates low-cost and low-carbon futures, *Energy Policy*, Volume 43, April 2012, Pages 436-447.

The SWITCH-WECC Model (*Energy Policy*, 2012)

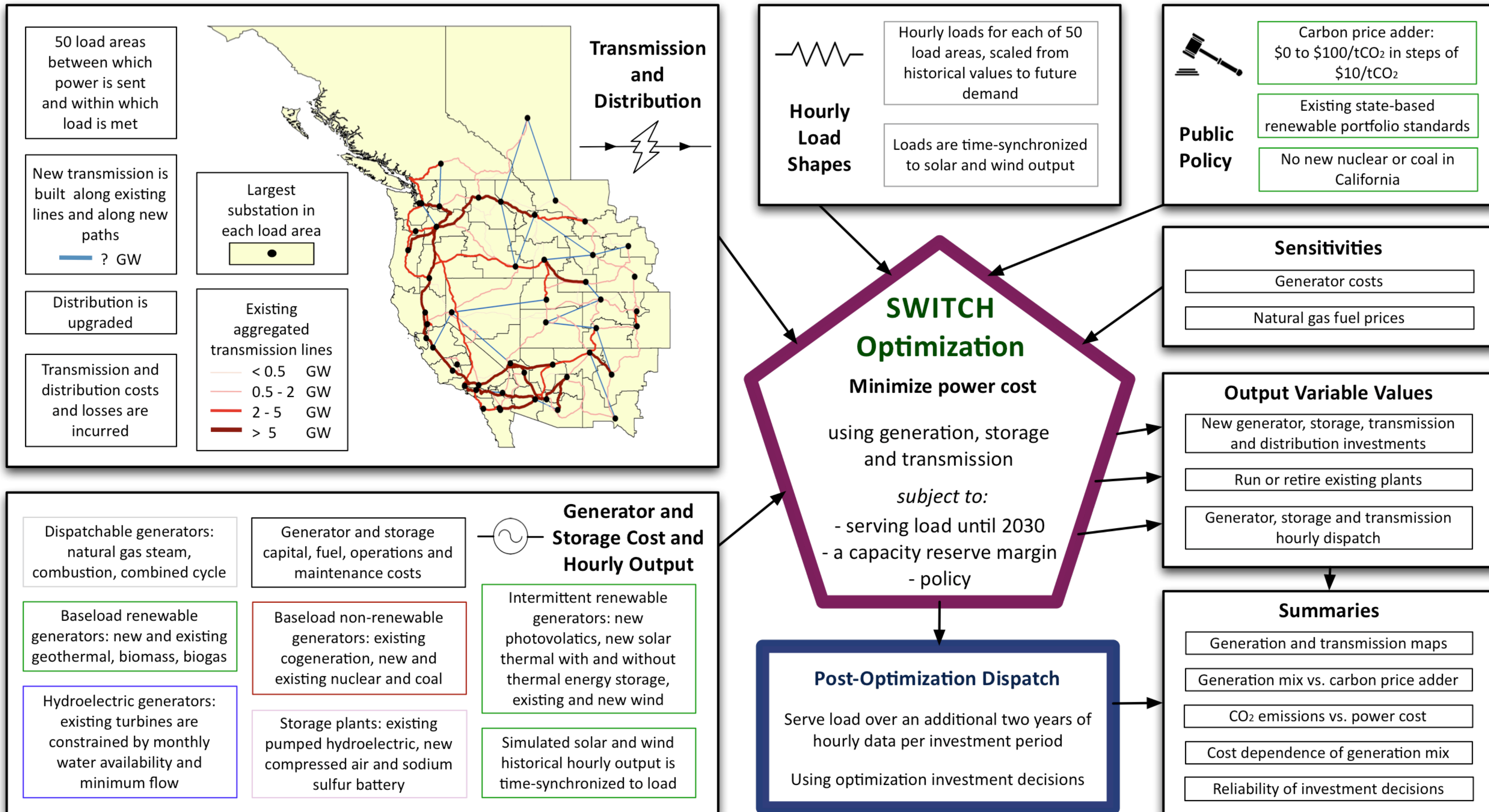
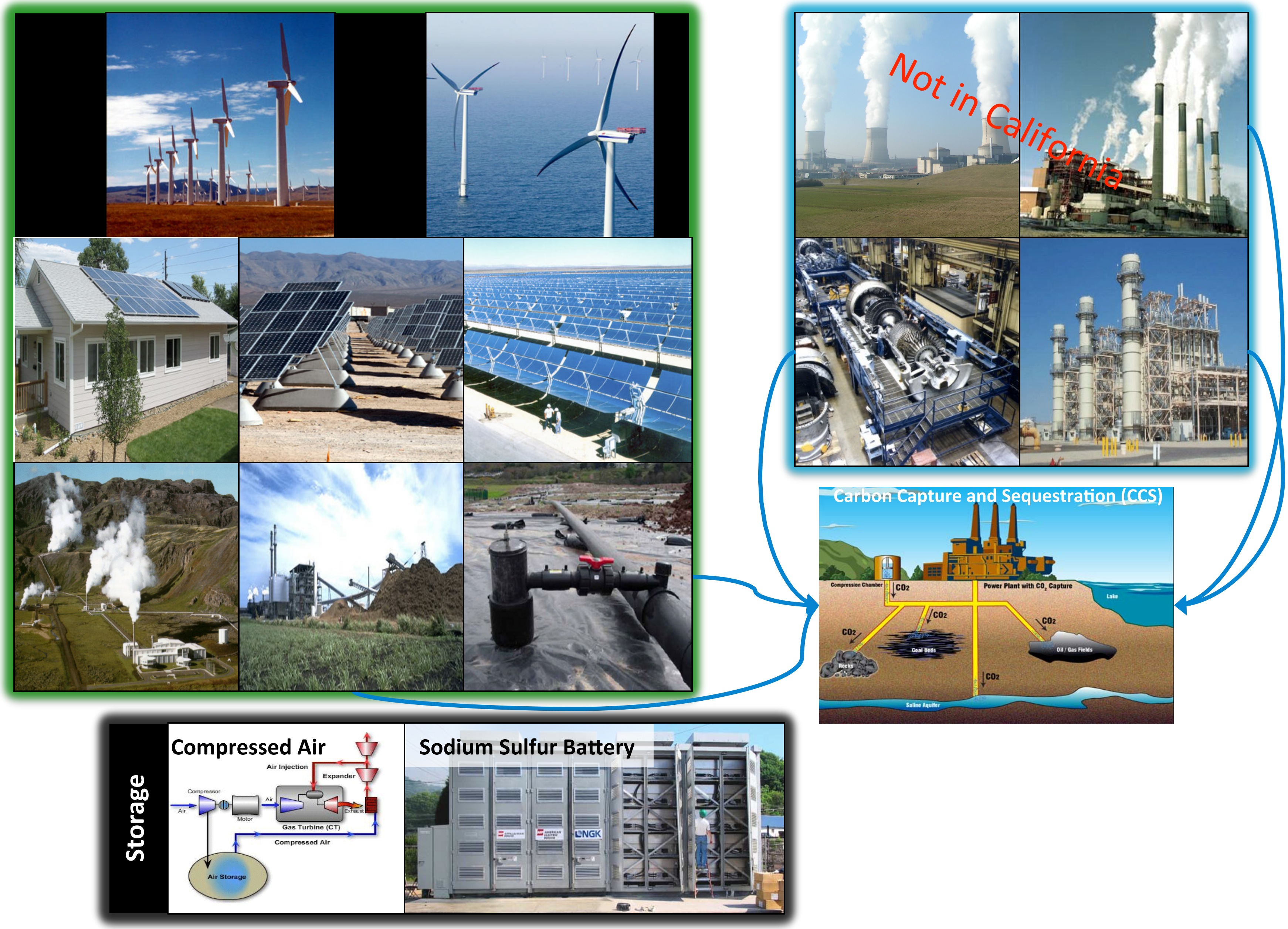
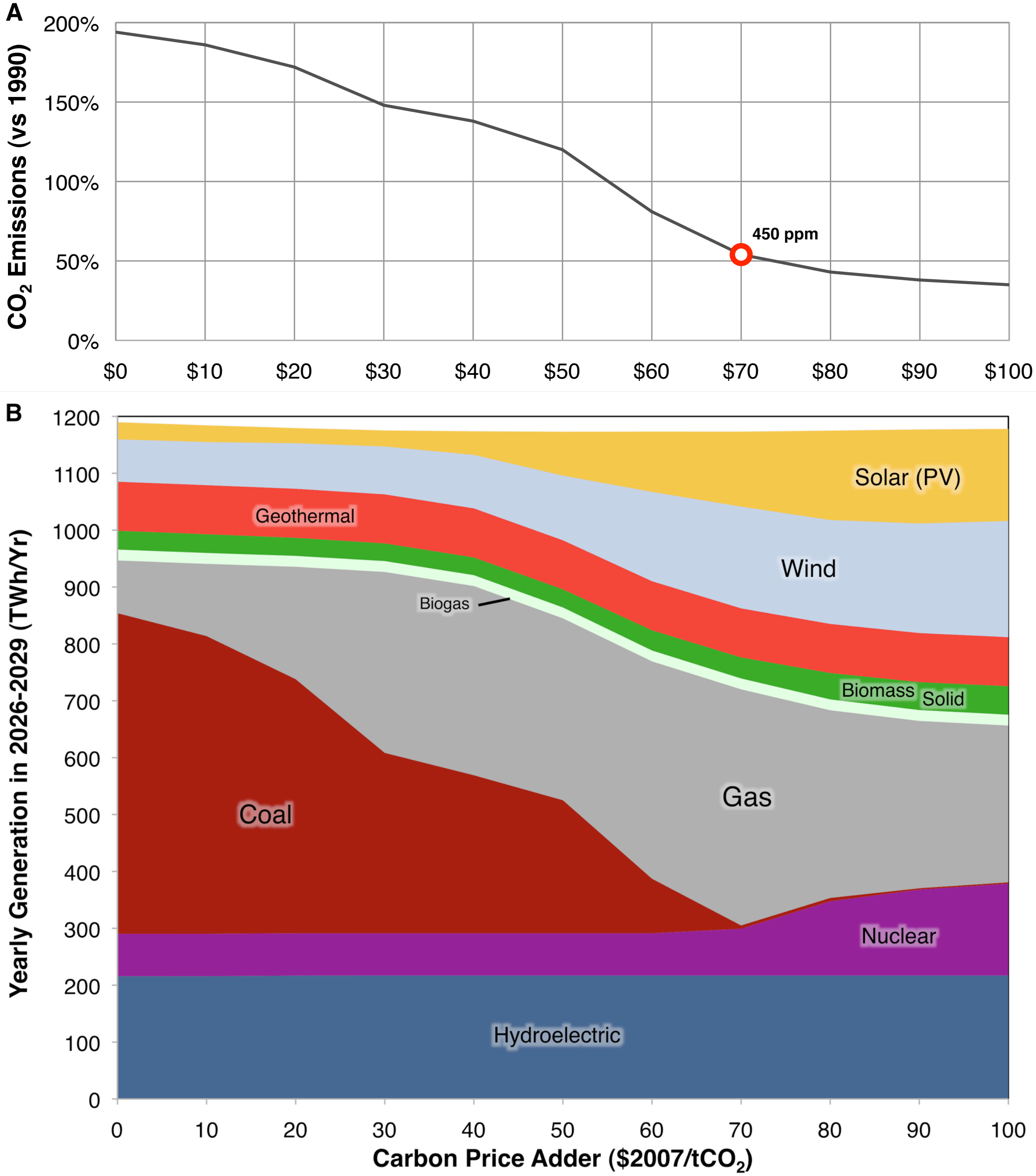


Figure 1. *Optimization and data framework of the western North American SWITCH model.*

New Generation & Storage Options in SWITCH



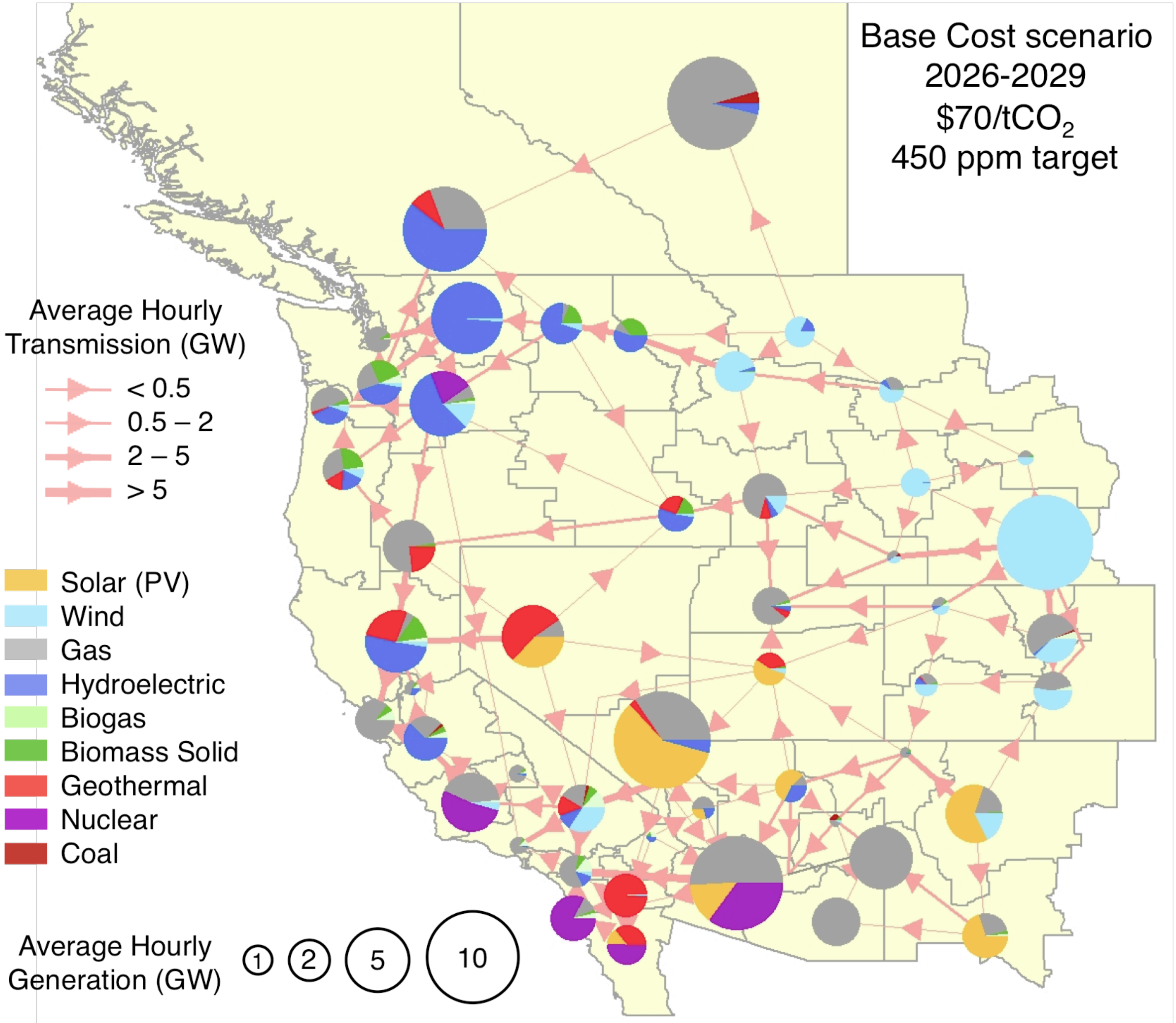
The SWITCH-WECC Model (*Energy Policy*, 2012)



WECC: Western Electricity Coordinating Council

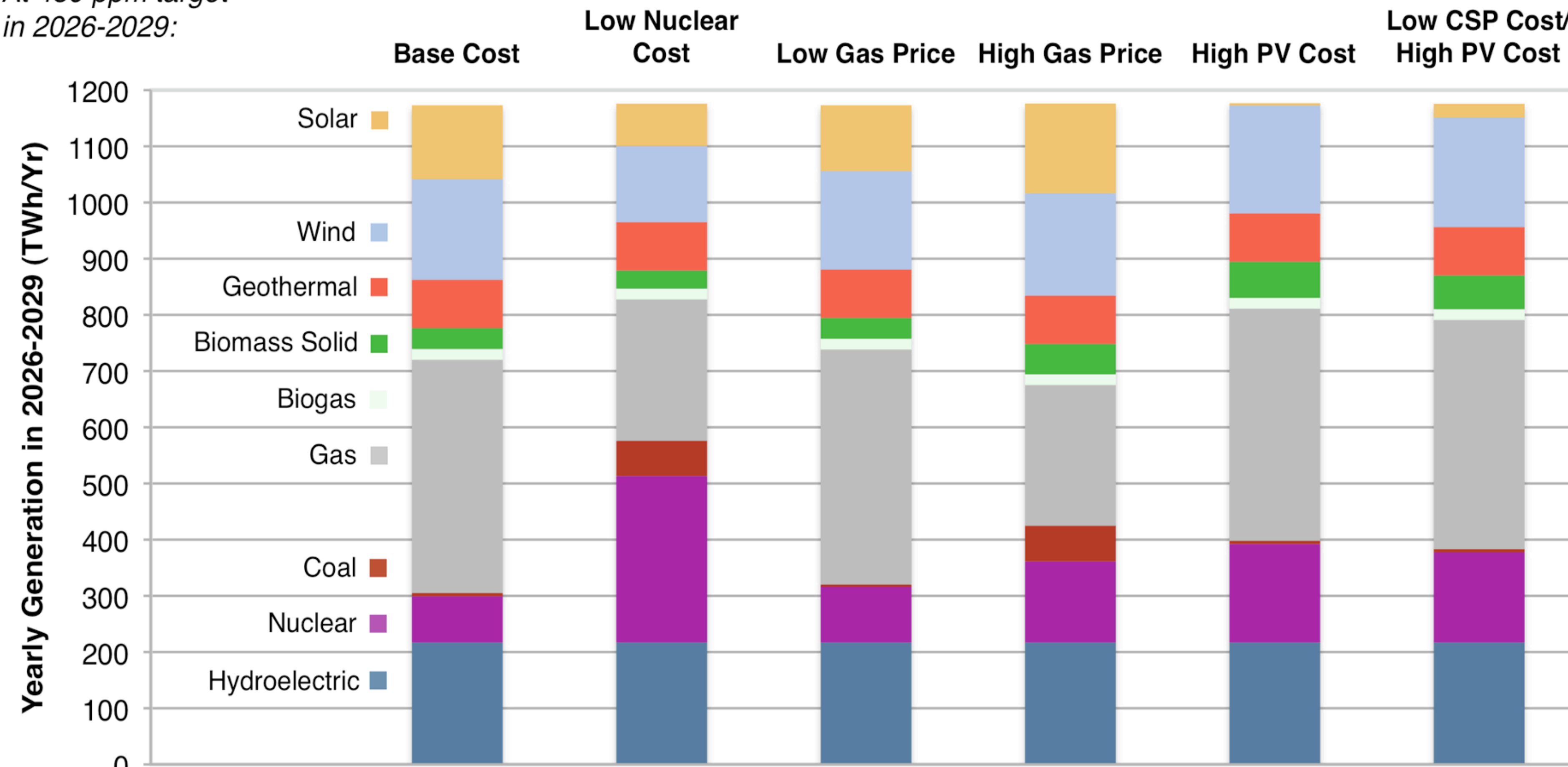
Base Cost scenario CO_2 emissions relative to 1990 emission levels (A) and yearly power generation by fuel (B) in 2026-2029 as a function of carbon price adder. As shown in panel A, the climate stabilization target of 450 ppm is reached at a carbon price adder of \$70/tCO_2.

The SWITCH-WECC Model (*Energy Policy*, 2012)



Average generation by fuel within each load area and average transmission flow between load areas in 2026-2029 at 54% of 1990 emissions for the Base Cost scenario. This scenario corresponds to a $70/ tCO$_2$ carbon price adder. Transmission lines are modeled along existing transmission paths, but are depicted here as straight lines for clarity. The Rocky Mountains run along the eastern edge of the map, whereas the Desert Southwest is located in the south of the map.

At 450 ppm target in 2026-2029:



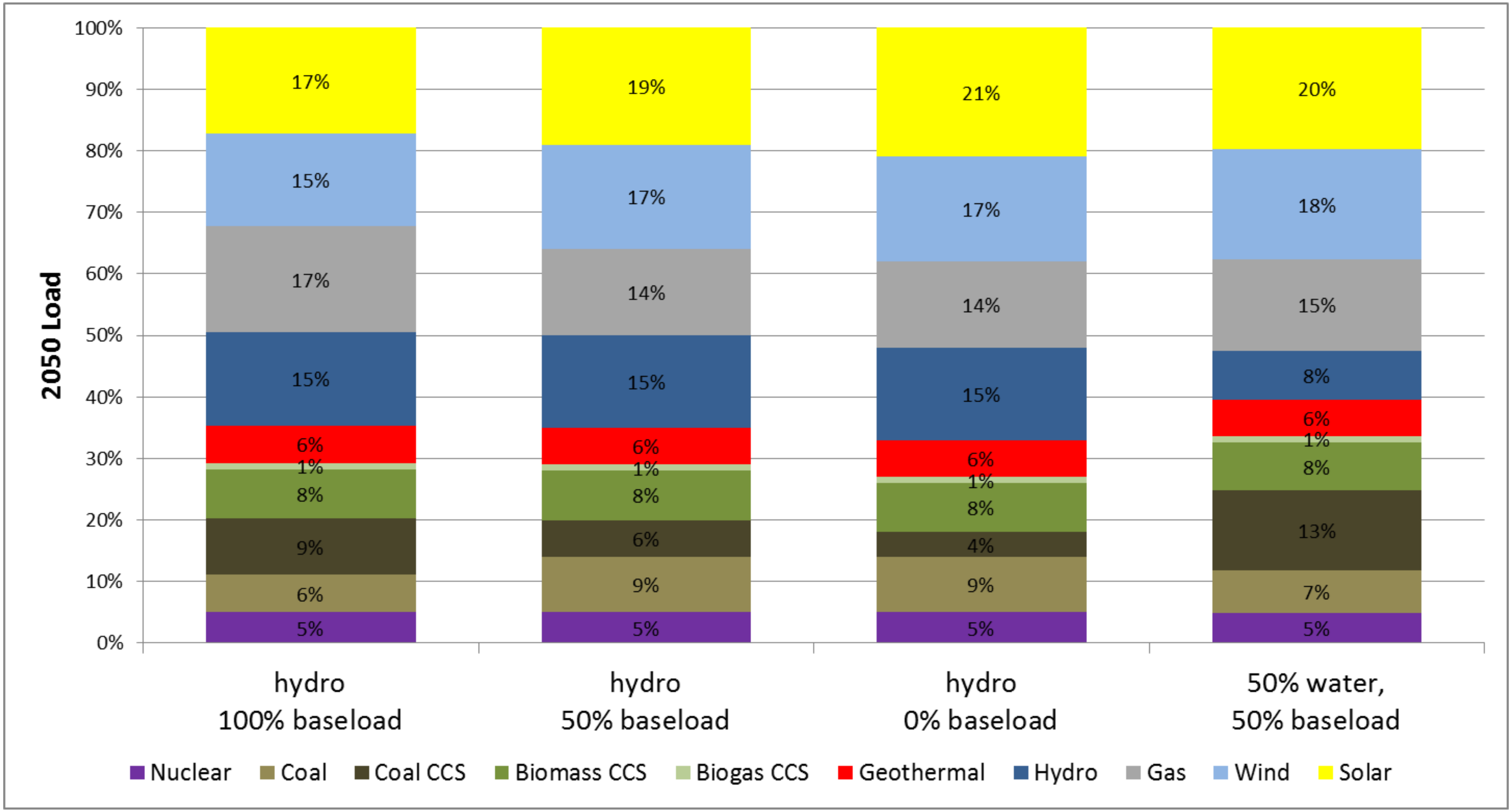
	Base Cost	Low Nuclear Cost	Low Gas Price	High Gas Price	High PV Cost	Low CSP Cost/ High PV Cost
Carbon price adder ($2007/t$CO_2$)	70	59	87	66	84	86
Power cost ($2007/MWh)	113	110	110	114	114	114
Cumulative new transmission built by 2030 (10^3 GW-km)	9.8	6.0	9.0	11.7	12.0	12.3

Projects

- 2030: Aggressive renewable cost scenarios
- 2050: The role of hydropower in renewables integration
- 2050: The role of load response in renewables integration
- 2050: The need for storage

Preliminary runs: Role of Hydropower: 2050, 80% below 1990 carbon emissions
(Ana Mileva)

Power cost	$90.16/MWh	$86.95/MWh	$86.46/MWh	$94.11/MWh
Storage	24 GW	7 GW	6 GW	12 GW



The Role of Hydropower in Integrating Intermittent Renewables

Research Question

- What are the benefits and limitations of extensive net-load balancing with hydropower in the WECC?

More Research Questions

- How does taking into account the interannual variability in hydrological conditions affect the optimal power mix (including storage deployment) and the cost of power?
- What are the constraints on hydro operation and how does that affect the ability of hydro to balance intermittent renewable generation?
- How will climate change affect hydropower and its utility for the electric power system?

Aggressive Solar Scenarios

Research Question

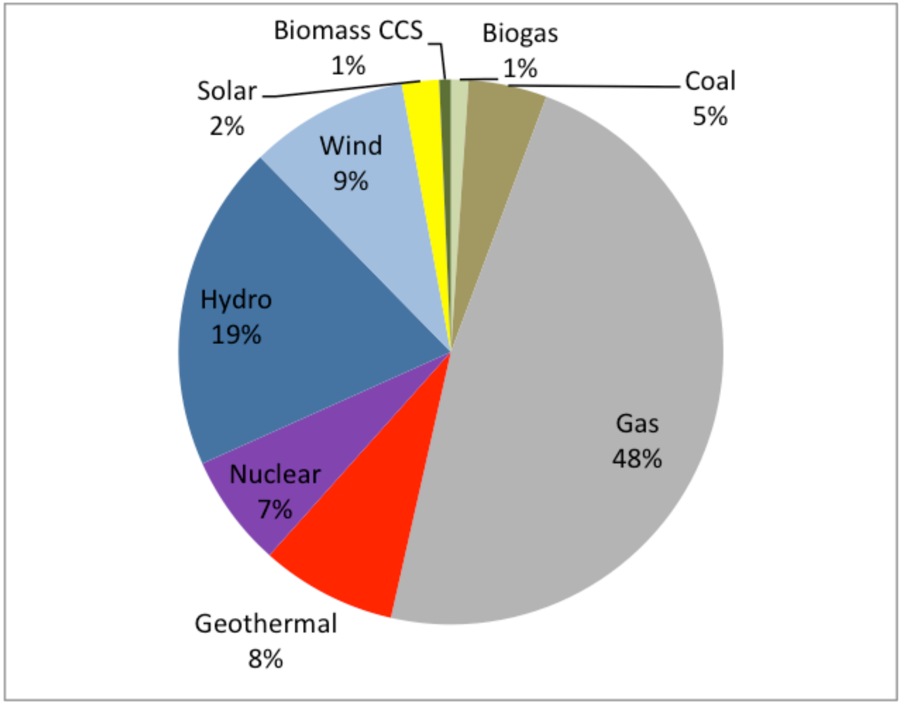
- How would the availability of low-cost solar PV affect the optimal power system by 2030?

Exploratory Results Assumptions

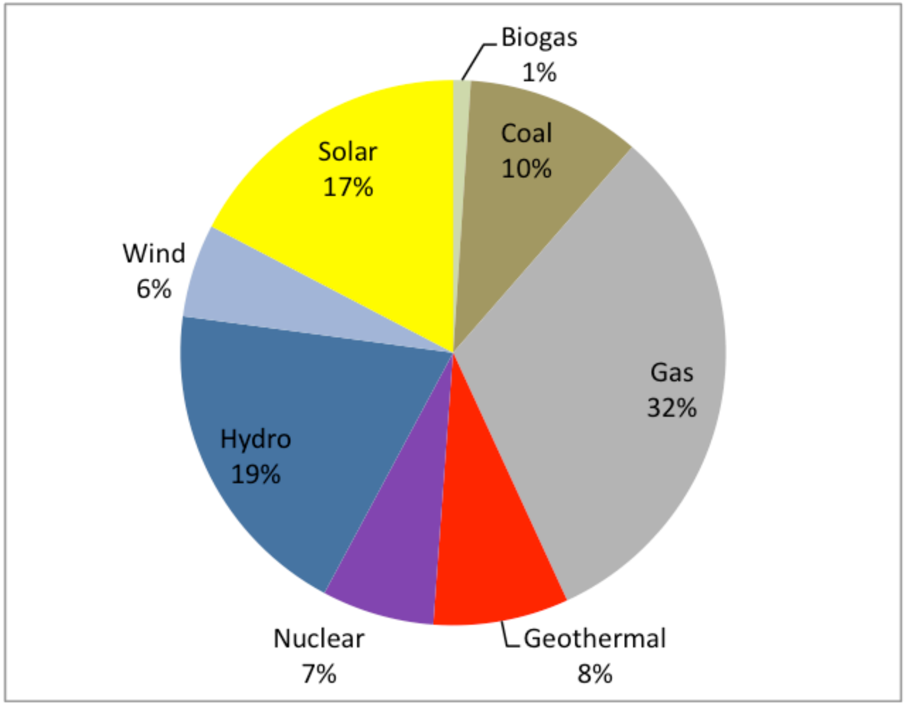
- $1/W for central-station solar PV by 2020 and flat thereafter
- (Default central-station PV costs reach ~$2.5/W by 2020 and ~$2.1/W by 2026, the last investment period)
- RPS standards enforced
- WECC-wide carbon cap (20% below 1990 emissions by 2030)

Energy Mix in the US West: Aggressive Solar Scenarios Exploratory Results: Energy Mix by 2030

Default Solar PV Costs

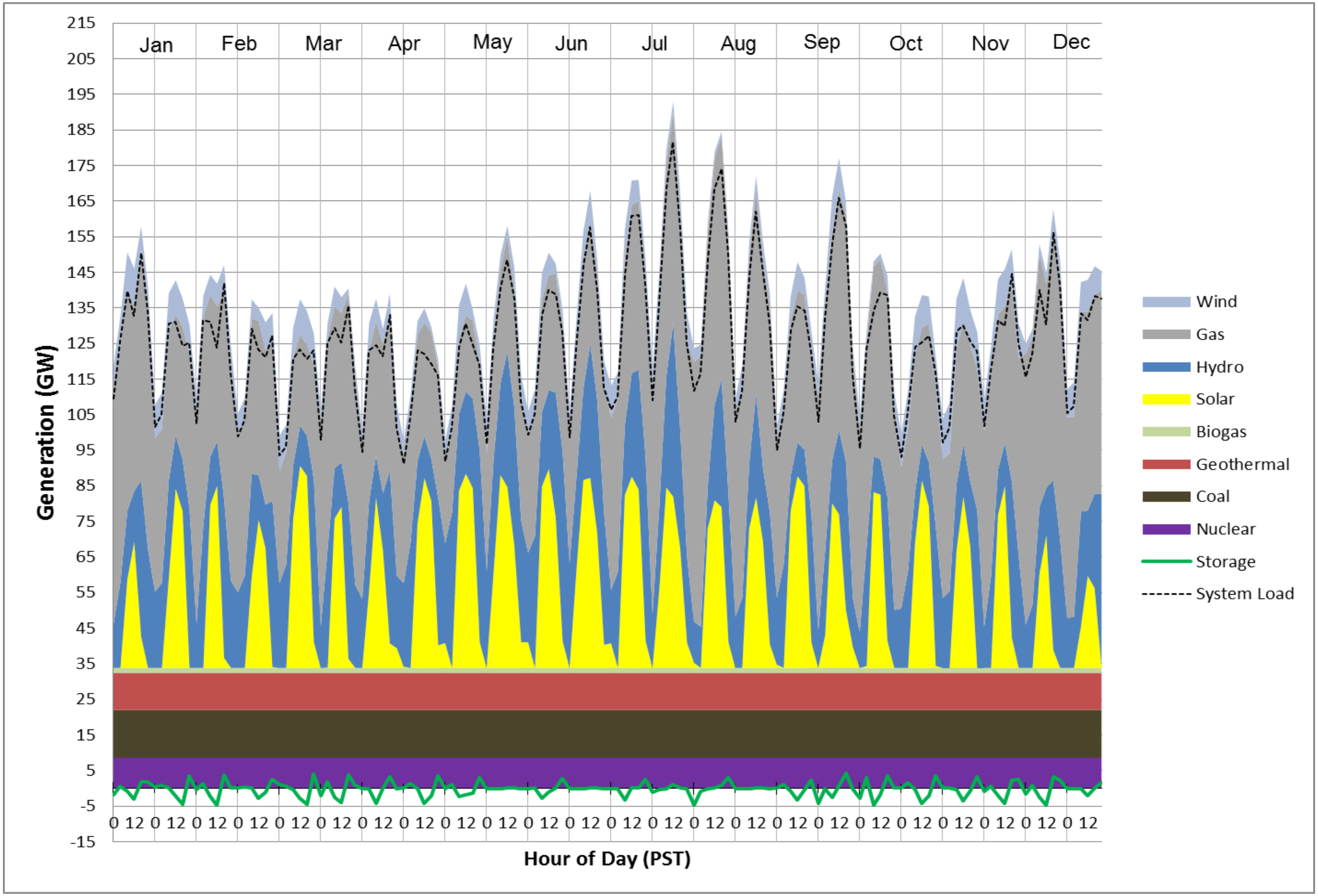


Sunshot Solar PV Costs

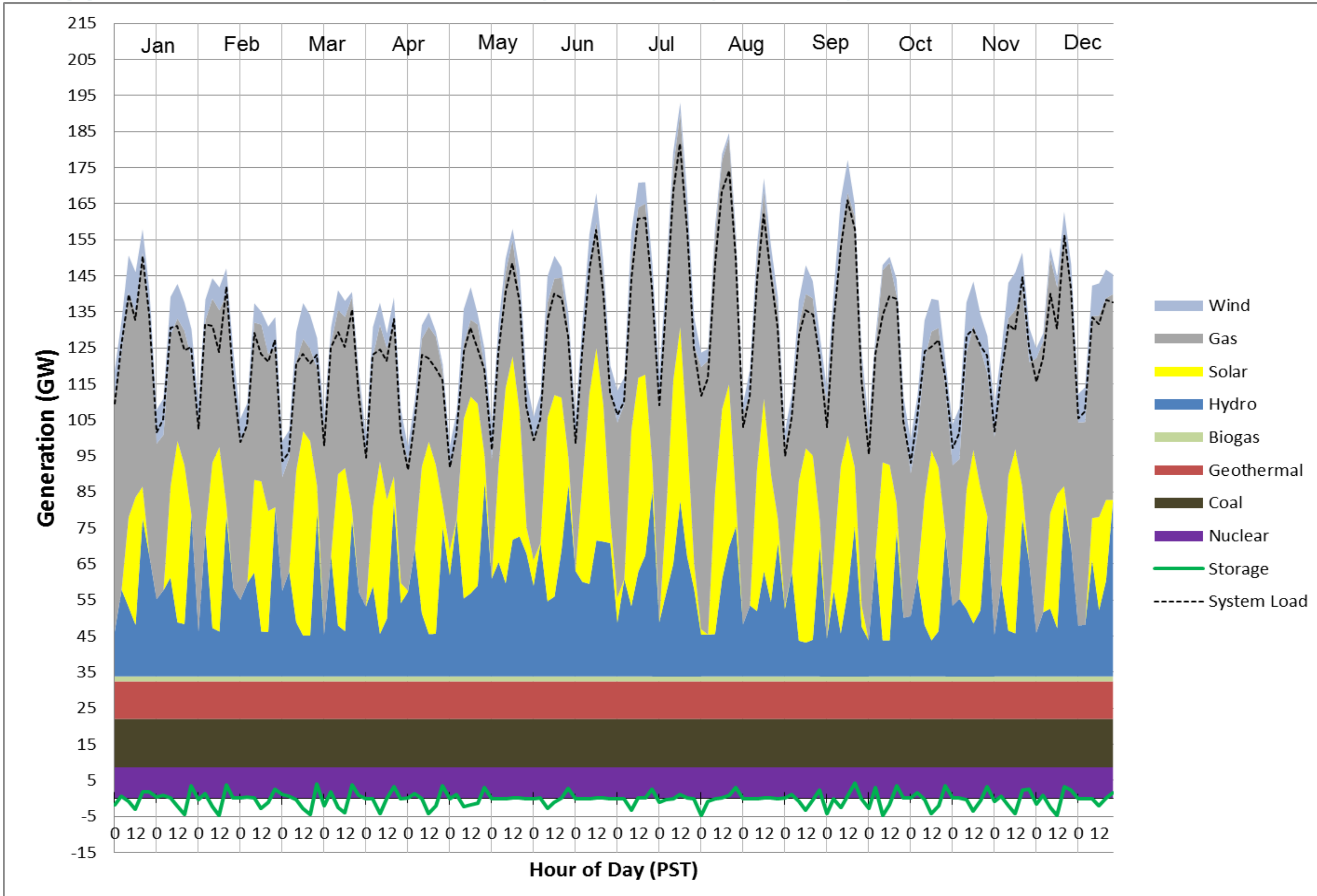


- About 58 GW of utility-scale PV and 6 GW of distributed commercial PV are installed by 2030
- Power costs about 5% less in the Sunshot case

Aggressive Solar Scenarios: System Dispatch by 2030



Aggressive Solar Scenarios: System Dispatch by 2030



Aggressive Solar Scenarios

More Research Questions

- How does the price of natural gas affect the deployment of low-cost solar PV in the 2030 timeframe?
- How does the availability/cost of transmission affect the deployment of low-cost solar PV?
- How does the availability/cost of storage affect the deployment of low-cost solar PV?
- Can solar PV be deployed at this scale within this timeframe?

Load Response

Research Question

- How much can flexible demand reduce system cost and aid in load balancing?