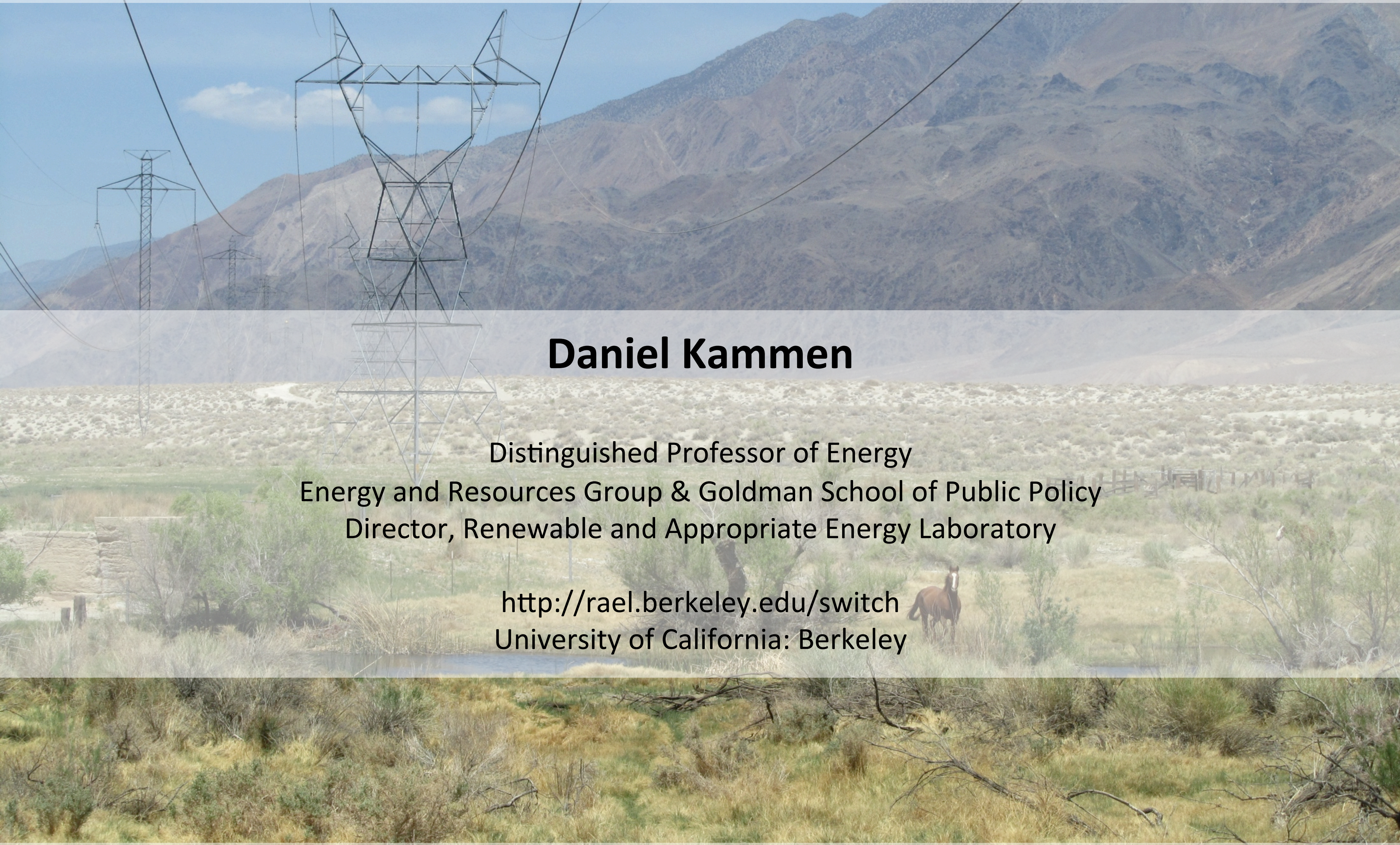
Energy Sustainability: California and Beyond



Daniel Kammen

Distinguished Professor of Energy
Energy and Resources Group & Goldman School of Public Policy
Director, Renewable and Appropriate Energy Laboratory

http://rael.berkeley.edu/switch
University of California: Berkeley

PANC, San Francisco, February 18, 2013

Research team

SWITCH

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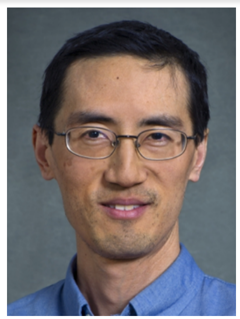
Dr. Jeffery Greenblatt



Dr. Max Wei

SWITCH-WECC support:

State of California Energy Commission

Link Foundation EST. 1953

CITRIS Center for Information Technology Research in the Interest of Society

hp

The Energy Foundation

IBM

The Karsten Family Foundation

Energy and Climate Partnership of the Americas

ECPA

Service to Secretary of State Clinton and Kerry, 2010 - present

enphase ENERGY

RENEWABLE FUNDING

Policy Actions

FERC RPS facilitation

AB32 – California

The California Low Carbon Fuel Standard
(S-1-07)

Property Assessed Clean Energy (PACE)

SB375

CA storage mandate

Business and Program Partnerships and Spinoffs

enphase ENERGY

RENEWABLE FUNDING

powerhive

National Geographic/Shell
Great Energy Challenge

FULBRIGHT

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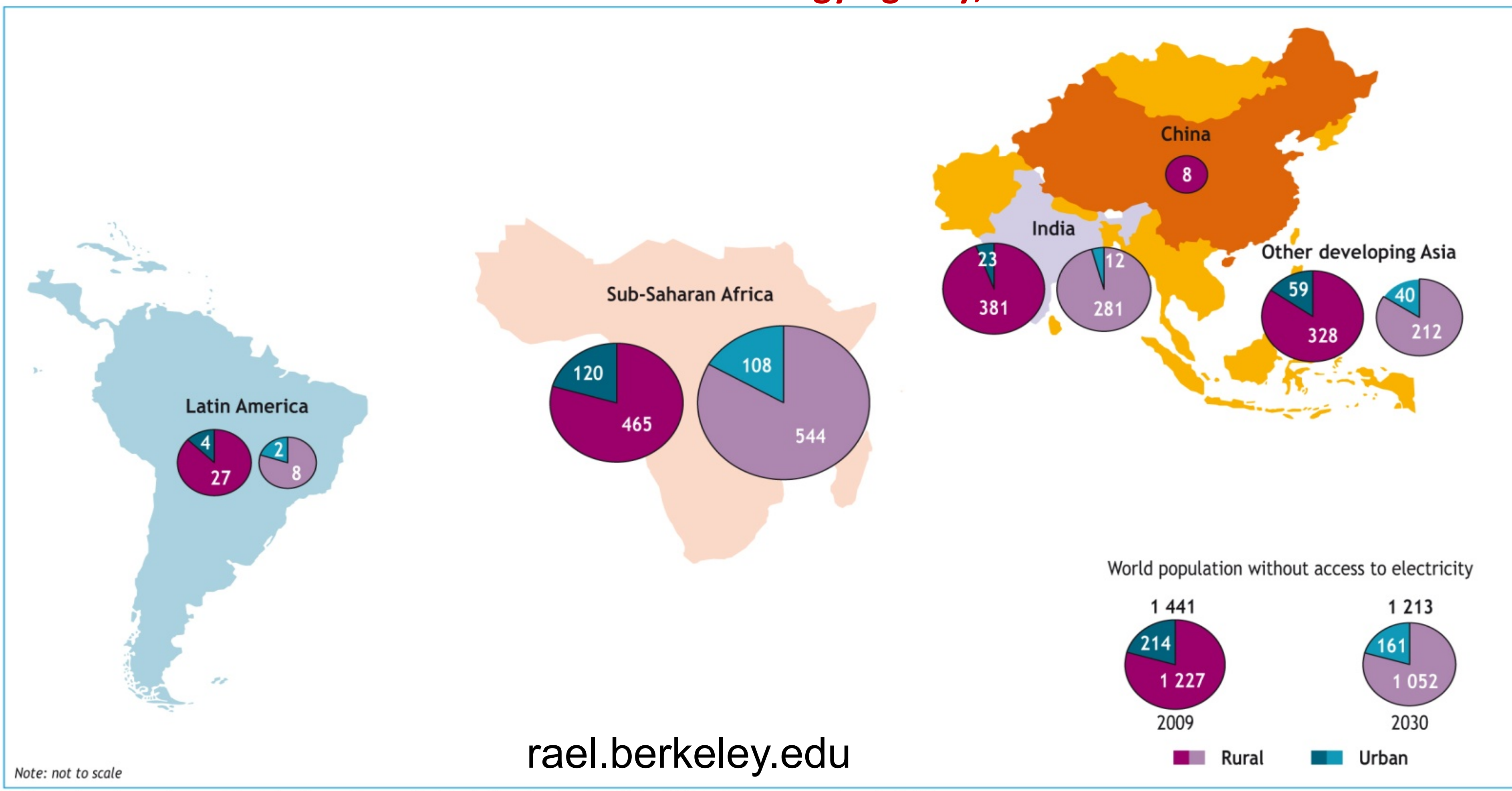
Program Themes, 2014 - 2016

- Renewable Energy, including Micro-Grid Innovations
- Social and Behavioral Adaptation to Climate Change
- Measuring Climate Change and its Impact (Metrics and Standards)
- Climate Change and Biodiversity
- Climate Change and Food and Water Security

Energy Poverty: Forecasts of Failure

There are 1.4 billion people lacking access to electricity today
Based on current trends, 1.2 billion people will still lack access in 2030
Another 1+ billion have intermittent/unreliable access
International Energy Agency, 2010



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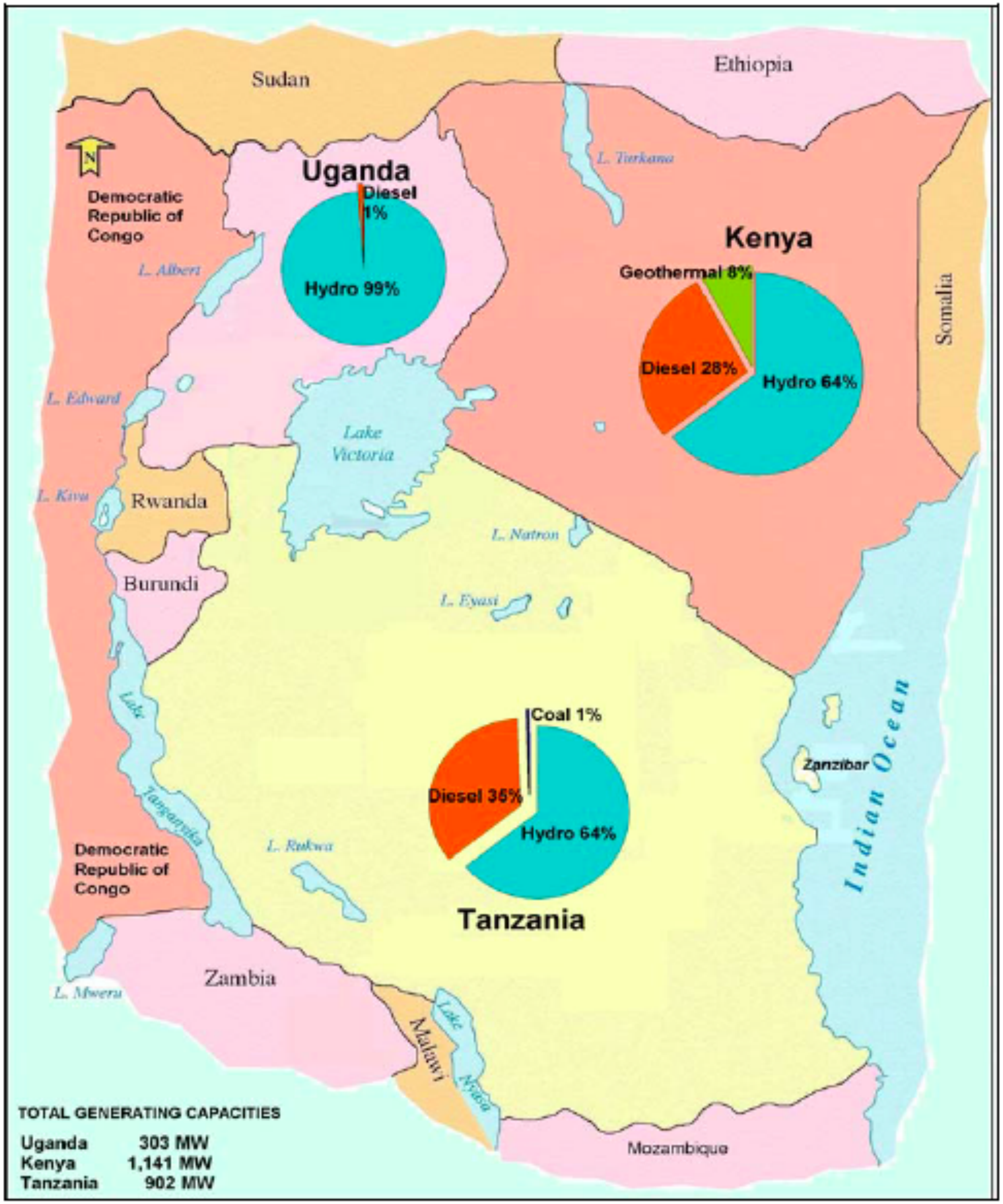
2012 INTERNATIONAL YEAR OF
SUSTAINABLE ENERGY
FOR ALL

United Nations Secretary General's High Level Commission on Sustainable Energy for All (SE4All, http://www.sustainableenergyforall.org/)

- Universal Access to Modern Energy Services
- Doubling the Rate of Improvement in Energy Efficiency
- Doubling the Share of Renewable Energy in Global Energy Mix


Sudan
Ethiopia
Democratic Republic of Congo
Uganda
Diesel 1%
Hydro 99%
L. Albert
L. Turkana
Kenya
Geothermal 8%
Diesel 28%
Hydro 64%
Somalia
L. Edward
Lake Victoria
L. Kivu
Rwanda
L. Natron
Burundi
L. Eyasi
Lake Tanganyika
Coal 1%
Diesel 35%
Hydro 64%
Zanzibar
Indian Ocean
L. Rukwa
Democratic Republic of Congo
Tanzania
Zambia
L. Mweru
Malawi
Lake Nyasa
Mozambique
TOTAL GENERATING CAPACITIES
Uganda 303 MW
Kenya 1,141 MW
Tanzania 902 MW

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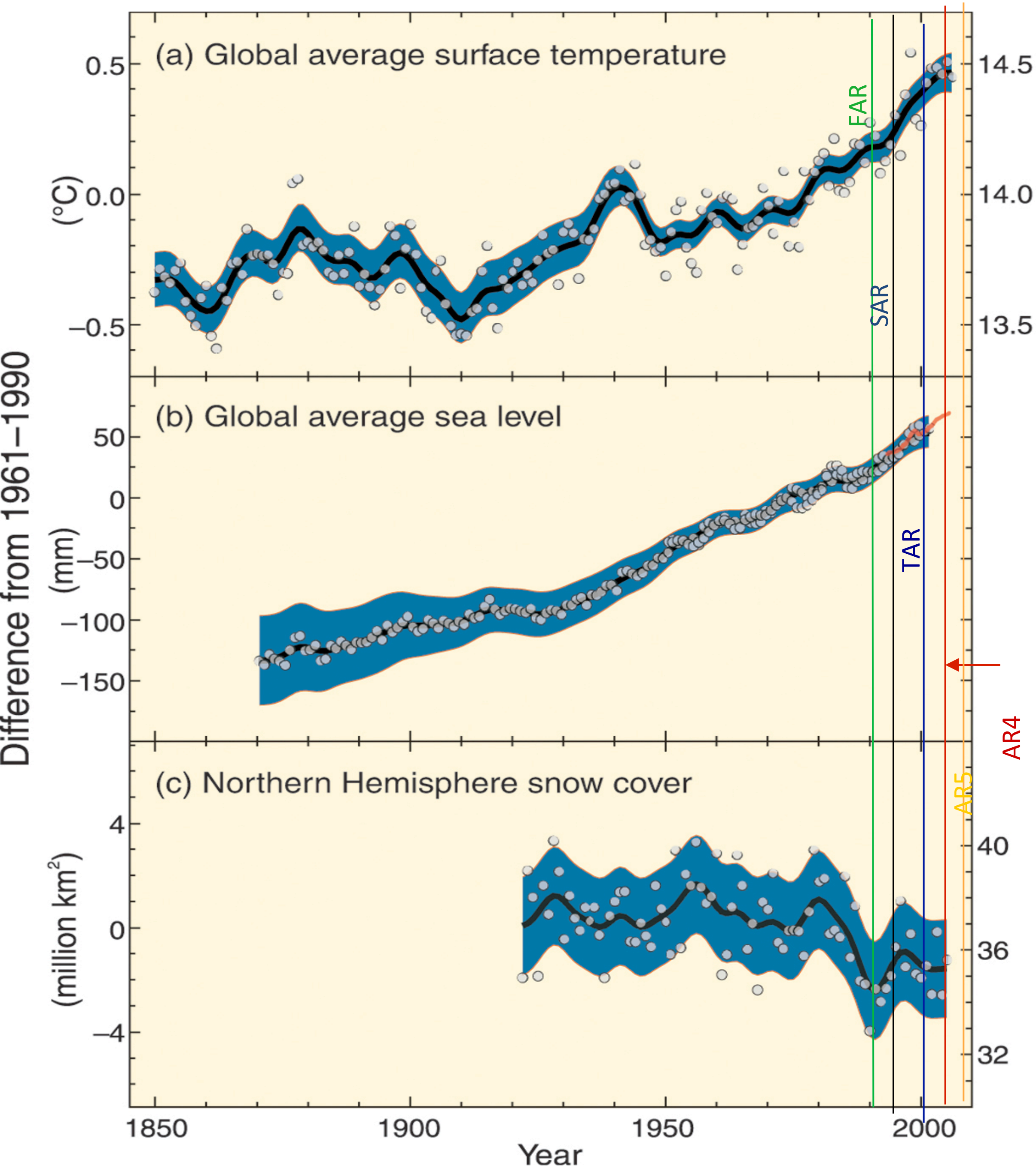
Energy systems and peace-building:
On-and off-grid energy services in South Sudan


Charcoal vendor: Nimule airstrip


Fula Rapids Mini-hydropower site, Nimule, South Sudan


New housing developments in Juba, South Sudan


Photos by Daniel Kammen



FAR - 1st IPCC Assessment (1990): unequivocal detection of human impact not likely for a decade

SAR - 2nd (1995): balance of evidence suggests discernible human influence

TAR - 3rd (2001): most of the warming in the last 50 years is likely (>66%) due to human activities

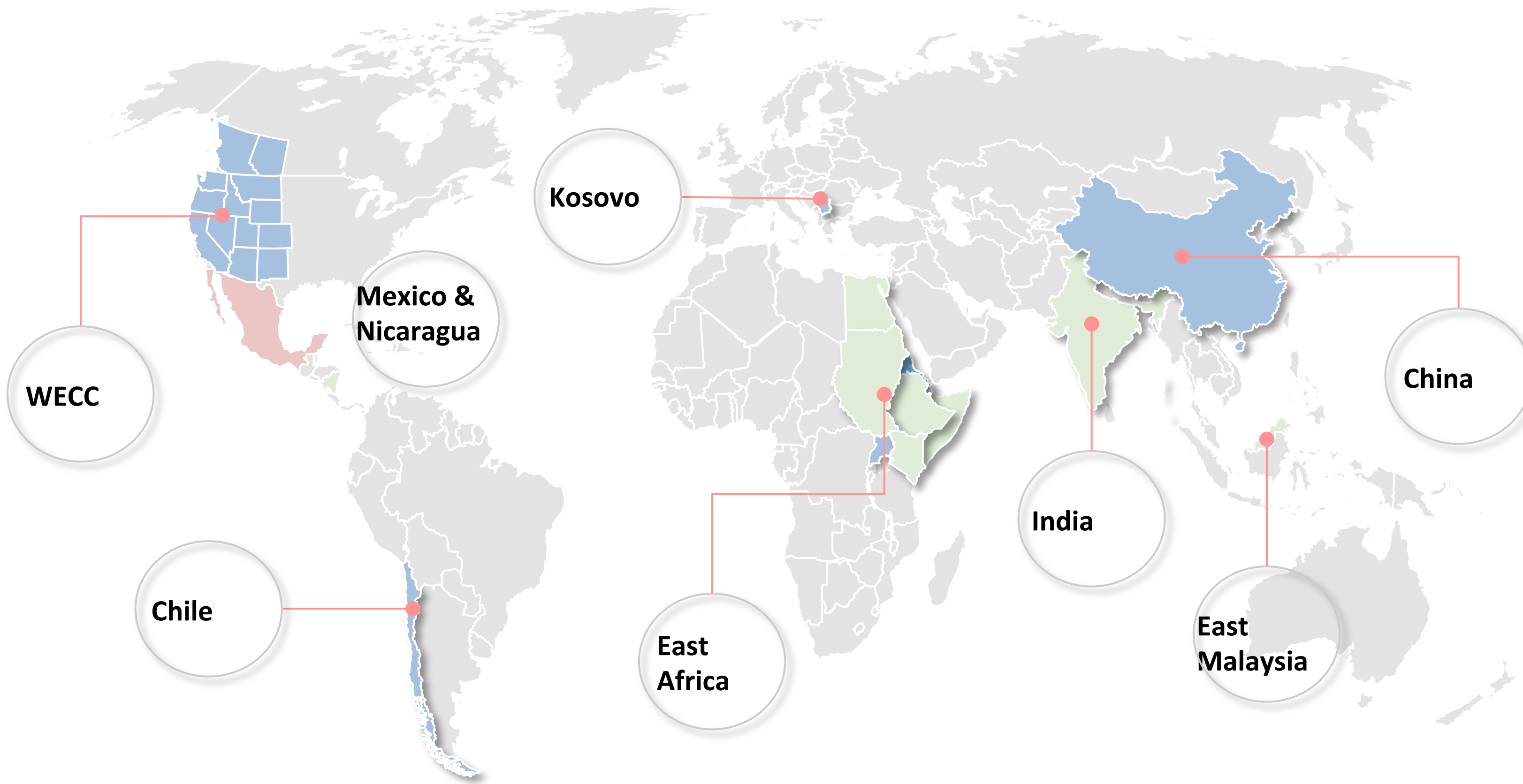
AR4 - 4th (2007): most of the warming very likely (> 90%) due human activity; ***warming will most strongly and quickly impact the global poor***

SRREN (2011): 80% clean by 2050 ***possible, if …***

AR5 (2013) - warming is human caused (95% confidence)

High-Resolution Energy System Modeling Efforts: Solar, wind, integrated with transmission and conventional generation (SWITCH)

Current (blue); under development (green); planned (red)



New profiles can be built to analyze region-specific challenges

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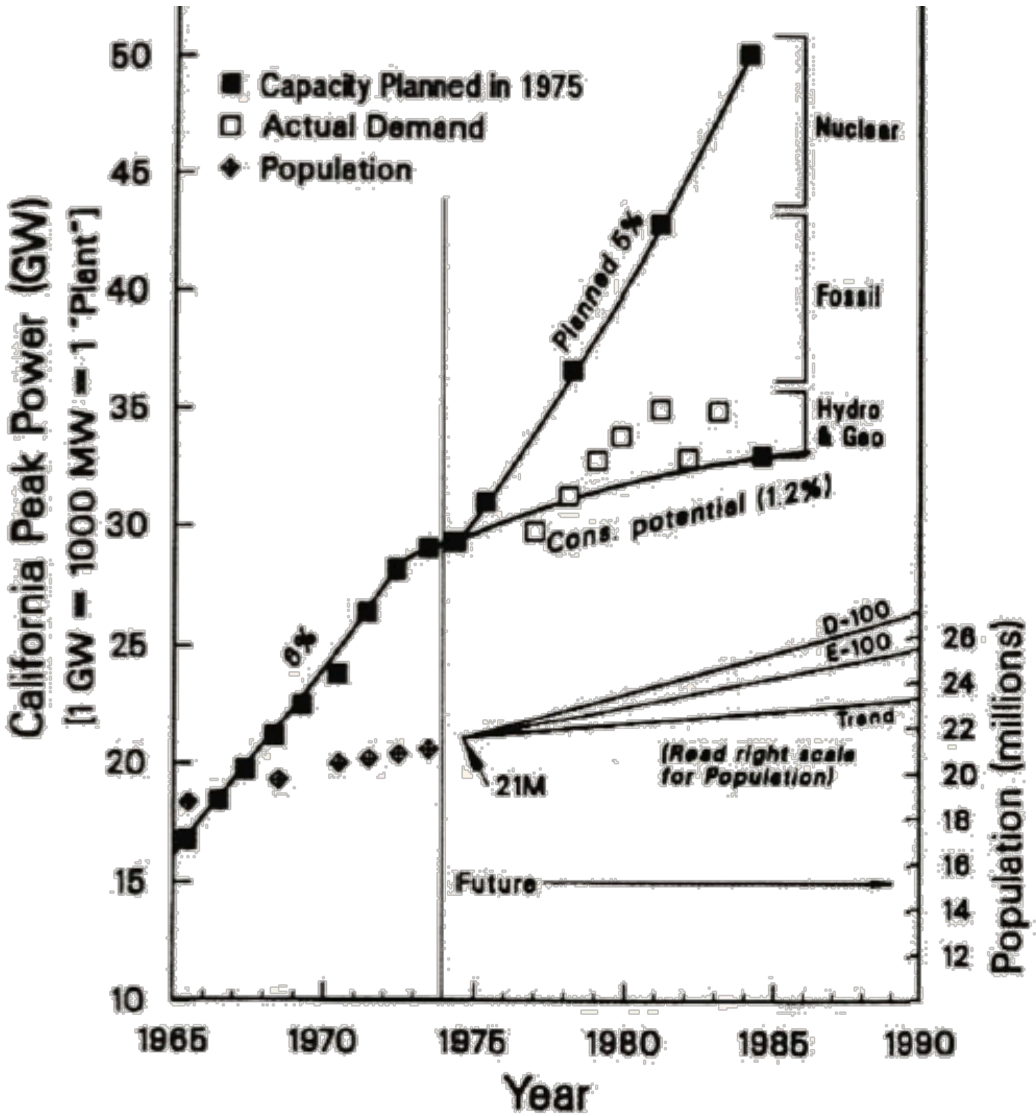
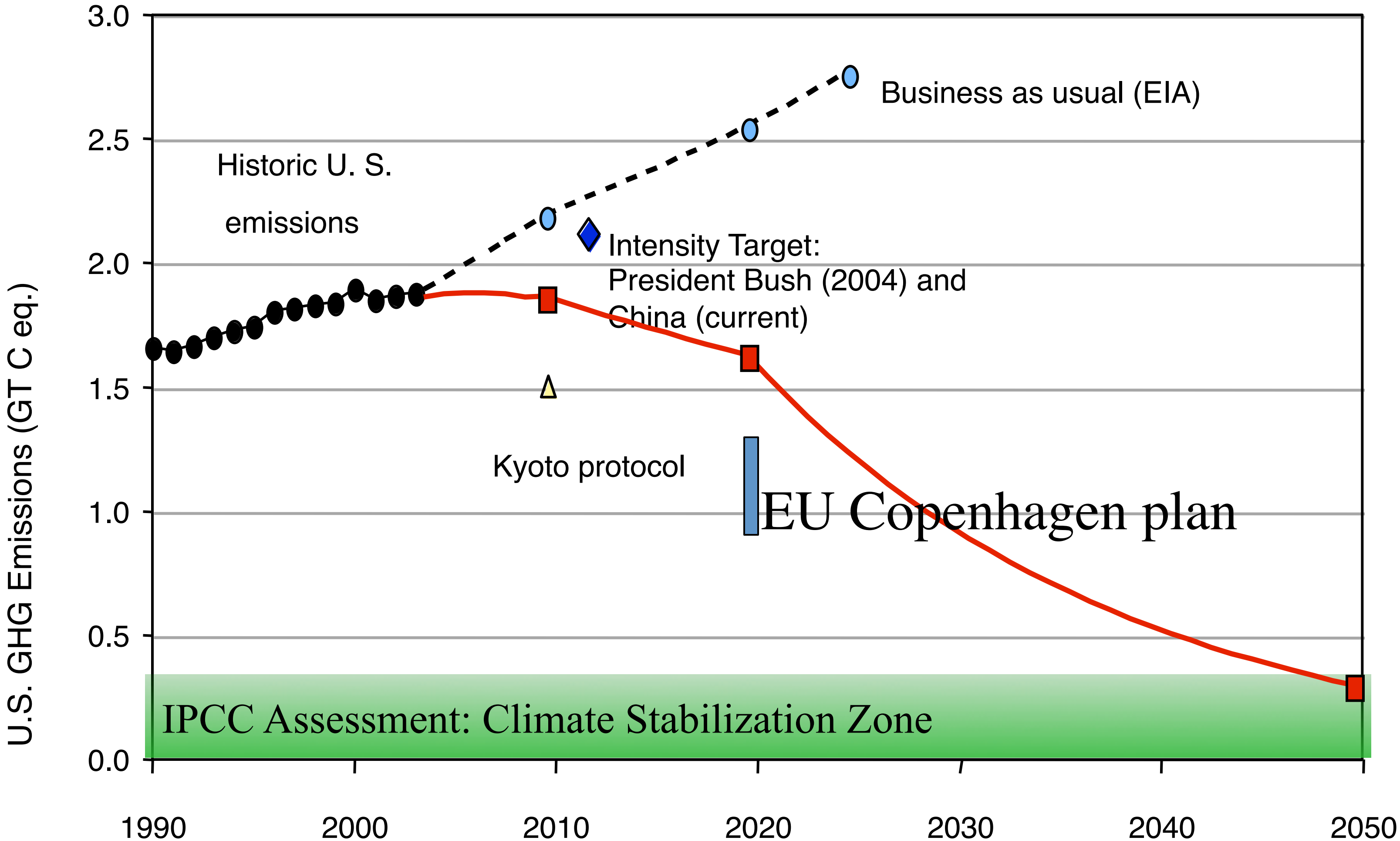
CA Peak Power: Testimony by Goldstein and Rosenfeld (Dec. 1974)



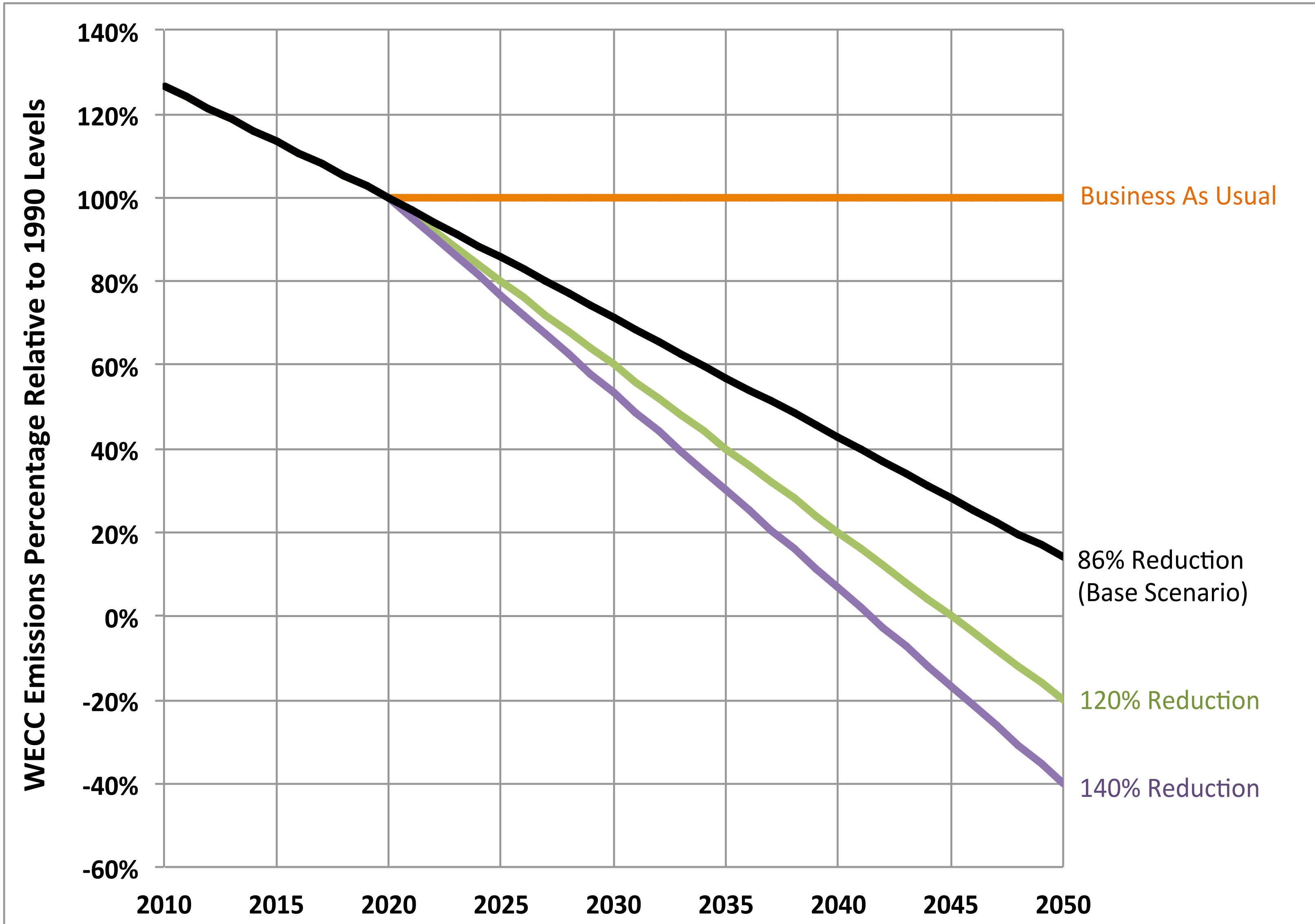
IPCC Science, state and national targets



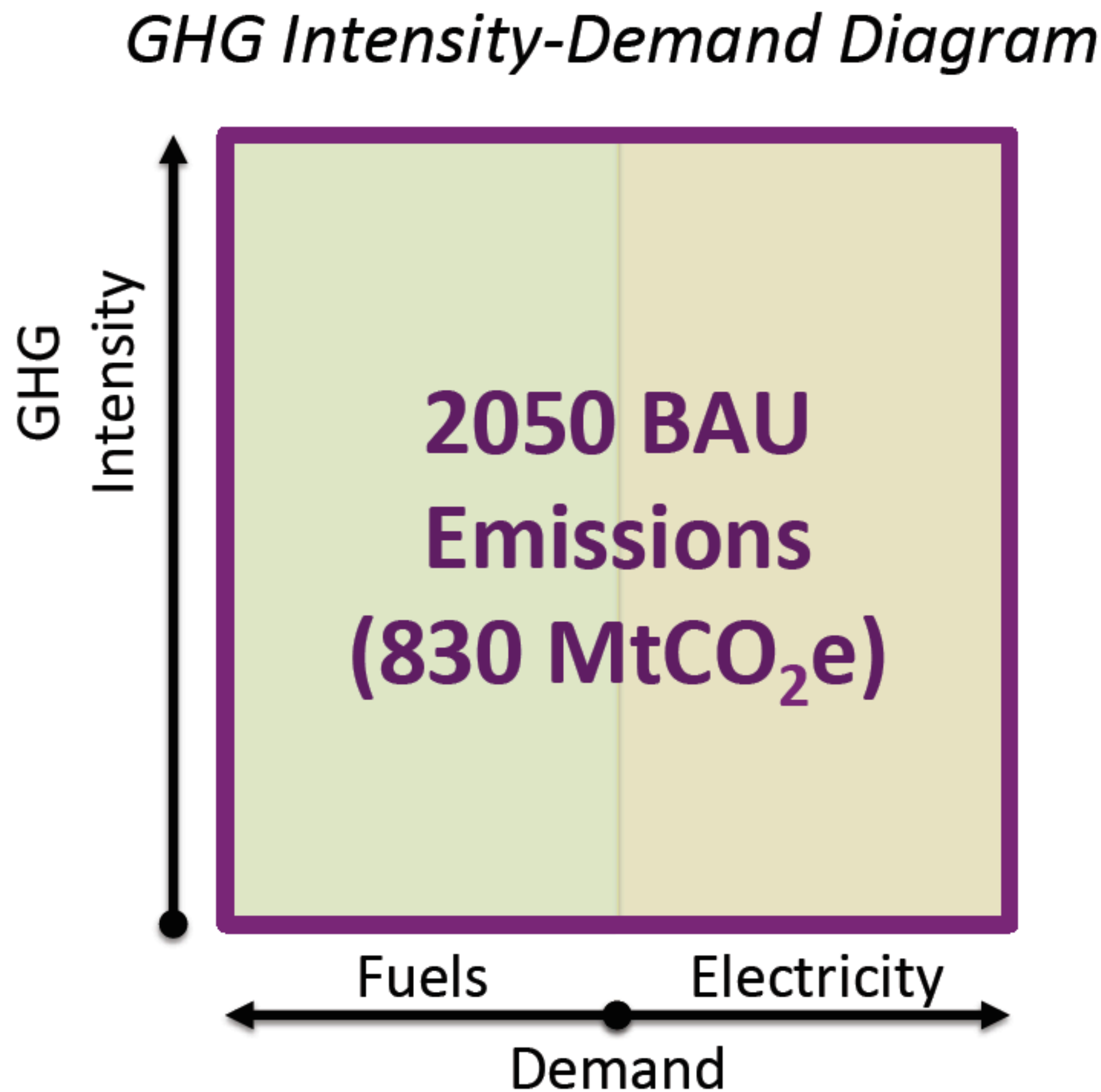
Kammen, "September 27, 2006 – A day to remember", *San Francisco Chronicle*, September 27,

Carbon cap: 86 % below 1990 levels in 2050

- Decarbonization of electricity easier than for other sectors

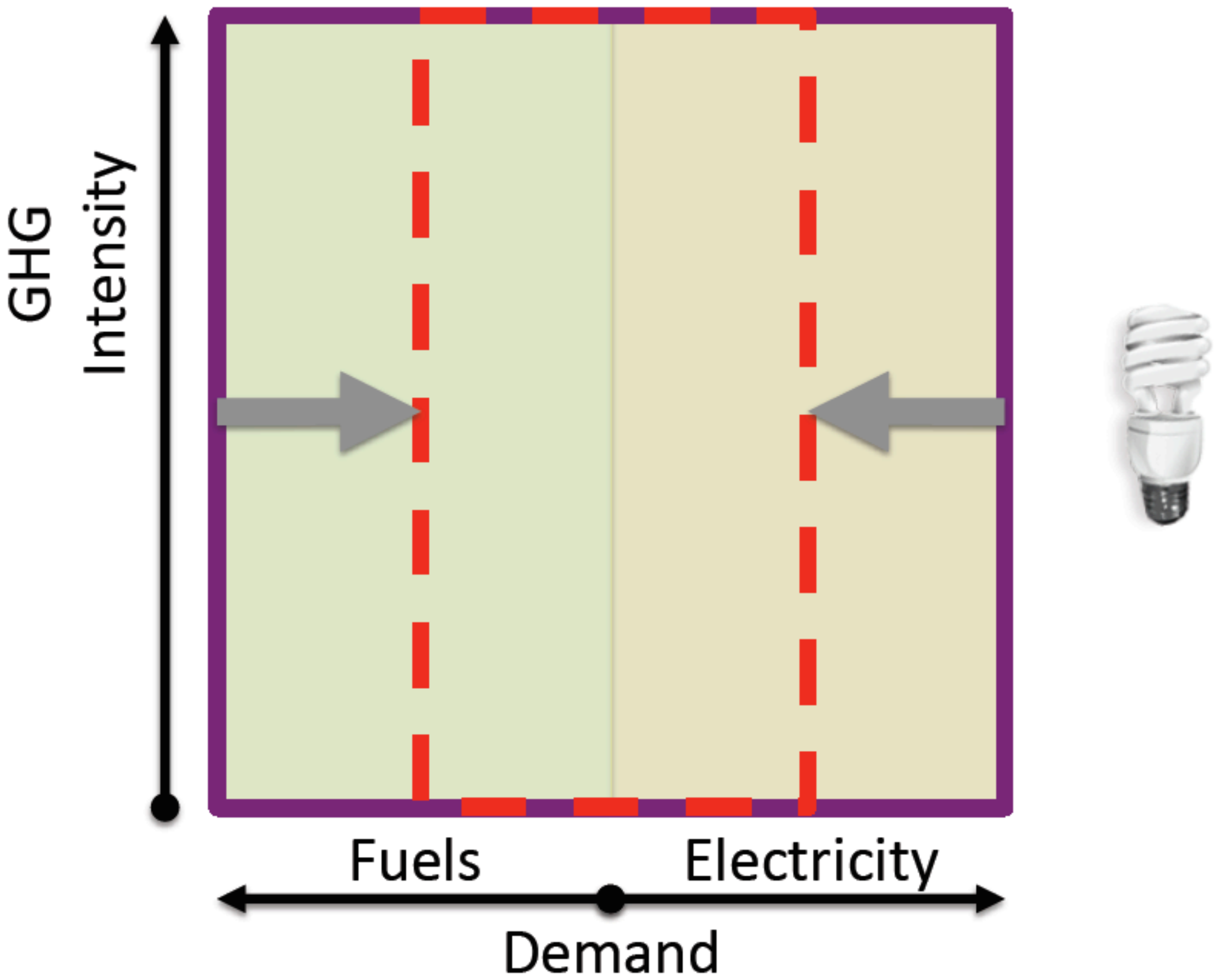


Four actions to reduce emissions



From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

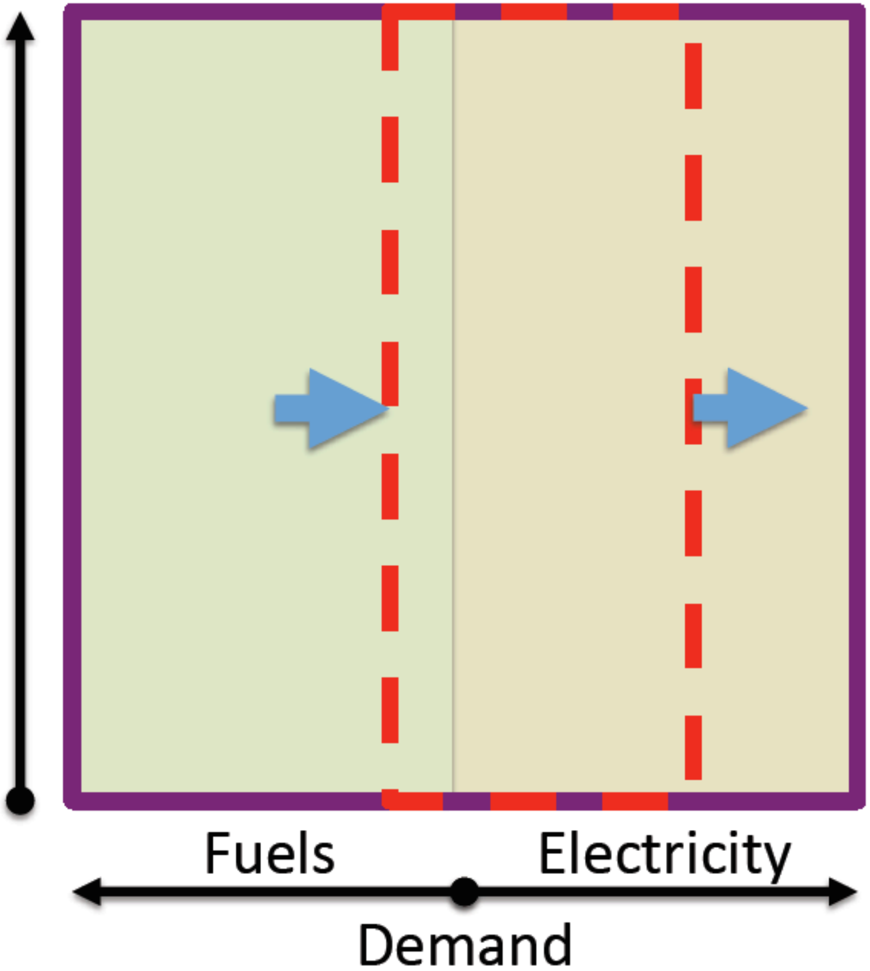
1. Efficiency



From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

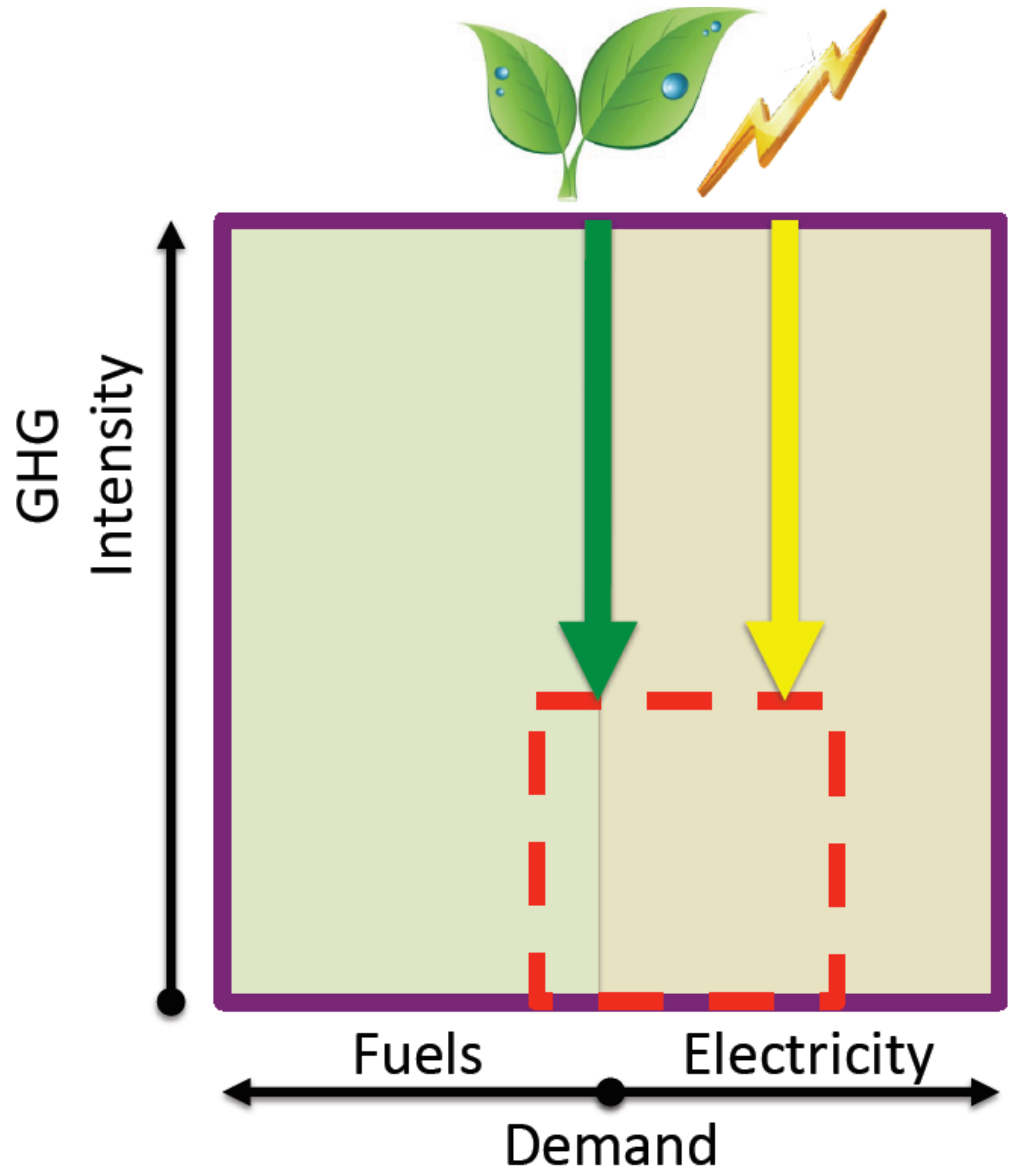
2. Electrification

- Not enough low or zero carbon fuel to go around



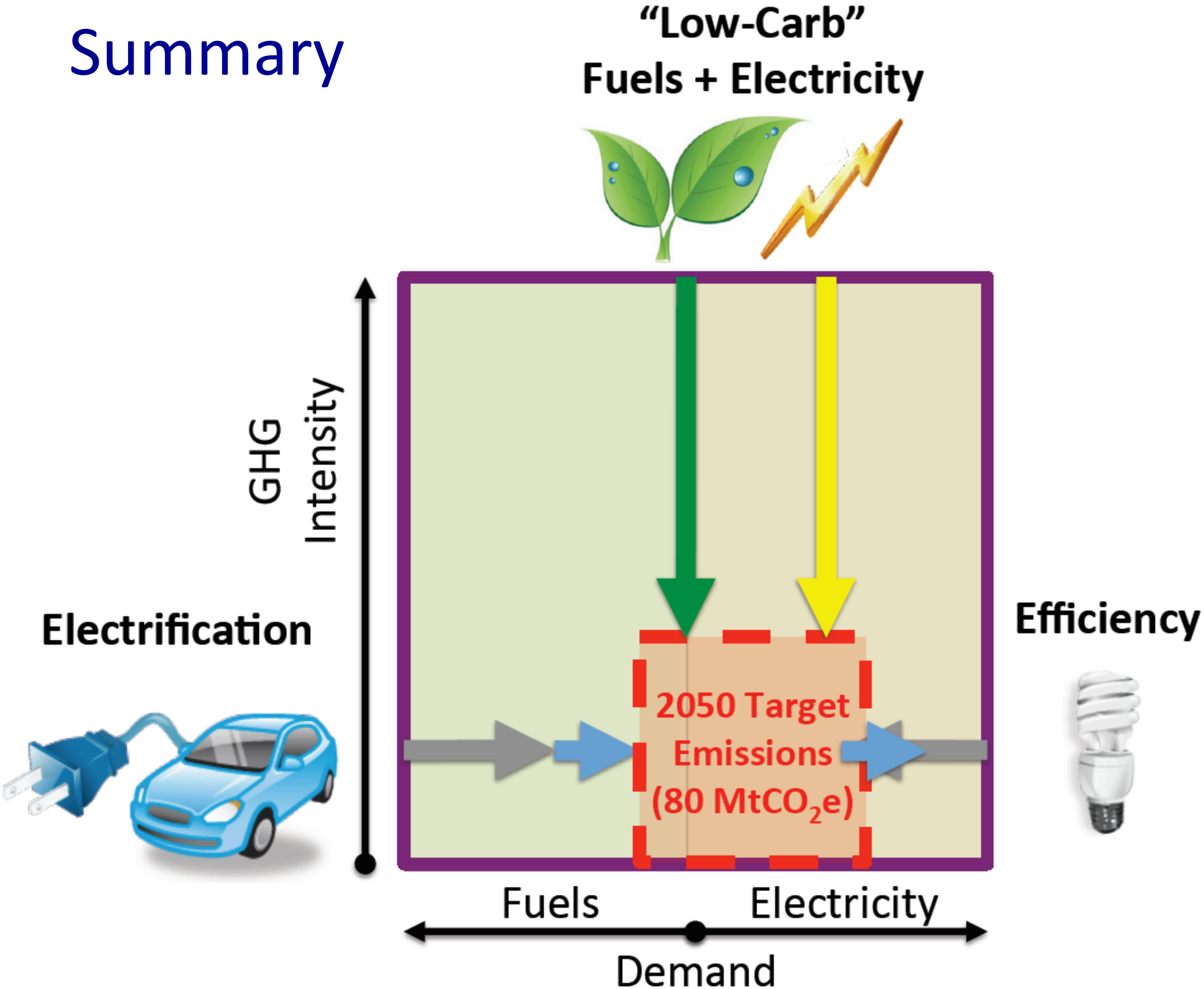
From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

3 + 4 "Low-Carb" Biofuels + Electricity



From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

Summary



From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

Better, Cheaper Lighting – SF Convention Center

The Many Values of Efficiency:

$400,000 saved per year with new lights

(a lesson renewables must learn from fossil fuels)

Moscone Center, San Francisco, CA: 675,000 W
Energy efficiency and renewable energy together

Residential New Construction

- All new residential construction in California will be **zero net energy by 2020**.

Commercial New Construction

- All new commercial construction in California will be zero net energy by 2030.
- Leverage opportunities from emerging technologies initiatives, incentive programs, and local initiatives targeting commercial building/ property developers.

The World's Largest Solar Thermal Power Plant

Ivanpah Solar Thermal Project – 370 MW - San Bernardino County, CA
(official opening tomorrow)

rld's Largest Thin Film Solar PV Project…

Desert Sunlight Solar Project - 550 MW - Riverside County, CA

World's Largest Wind Project

Alta Wind Energy Center – 1550 MW - Kern County

CA Leads in New Solar Home Construction and solar retrofits: goal 1 million solar roofs

Rocklin Zero Energy Community

Million solar roofs by 2020: we are behind schedule, but are over 100,000 so far

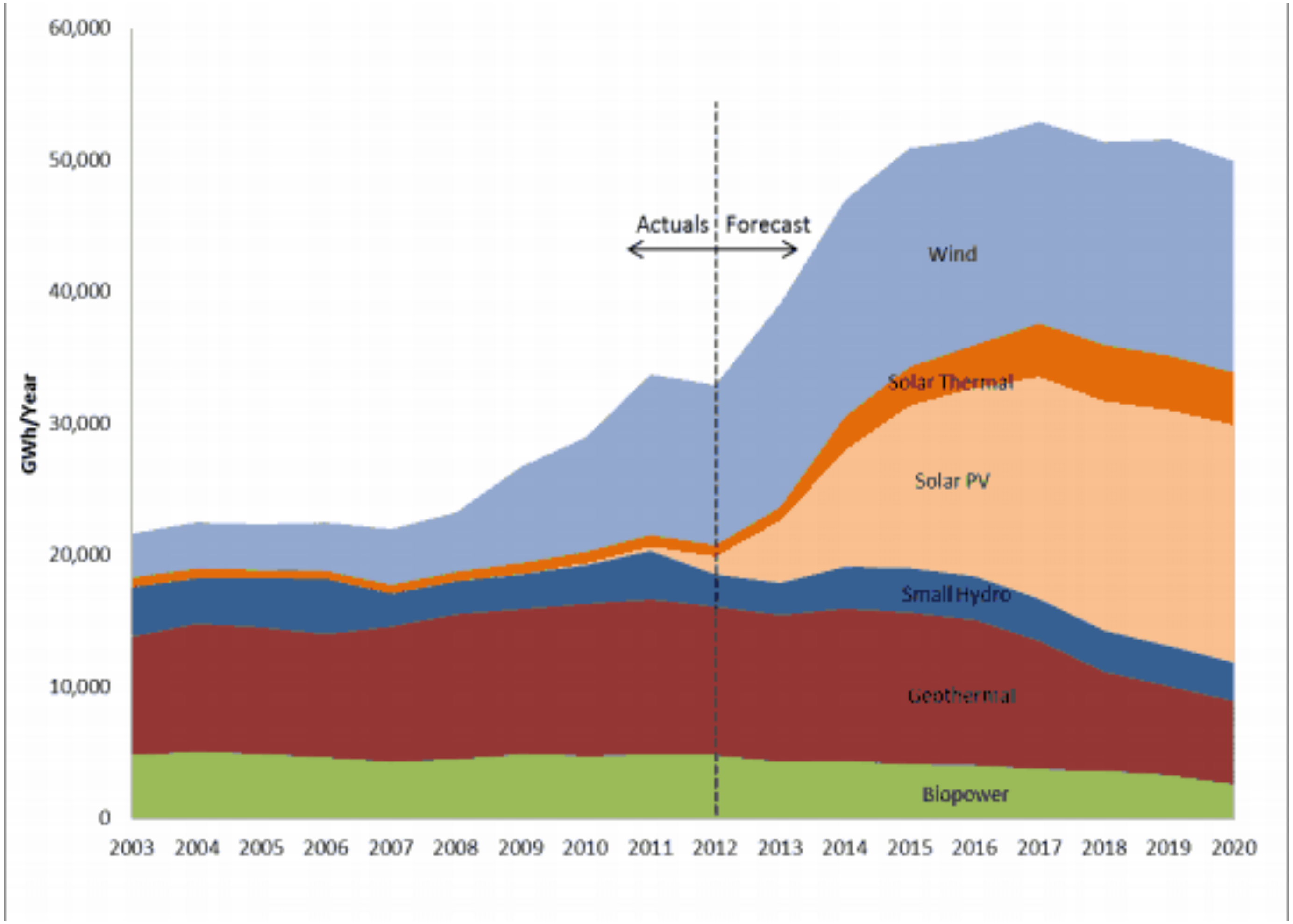
Largest Manufacturing Operation in CA is now Electric Vehicles

Automation is allowing "on-shoring" of manufacturing processes back from Asia

Tesla Factory - Fremont, CA

Over 3,000 workers now working at the Tesla Factory

Almost 80% of the California RPS is Projected to Be Met by Solar & Wind by 2020



Source: CPUC RPS Report

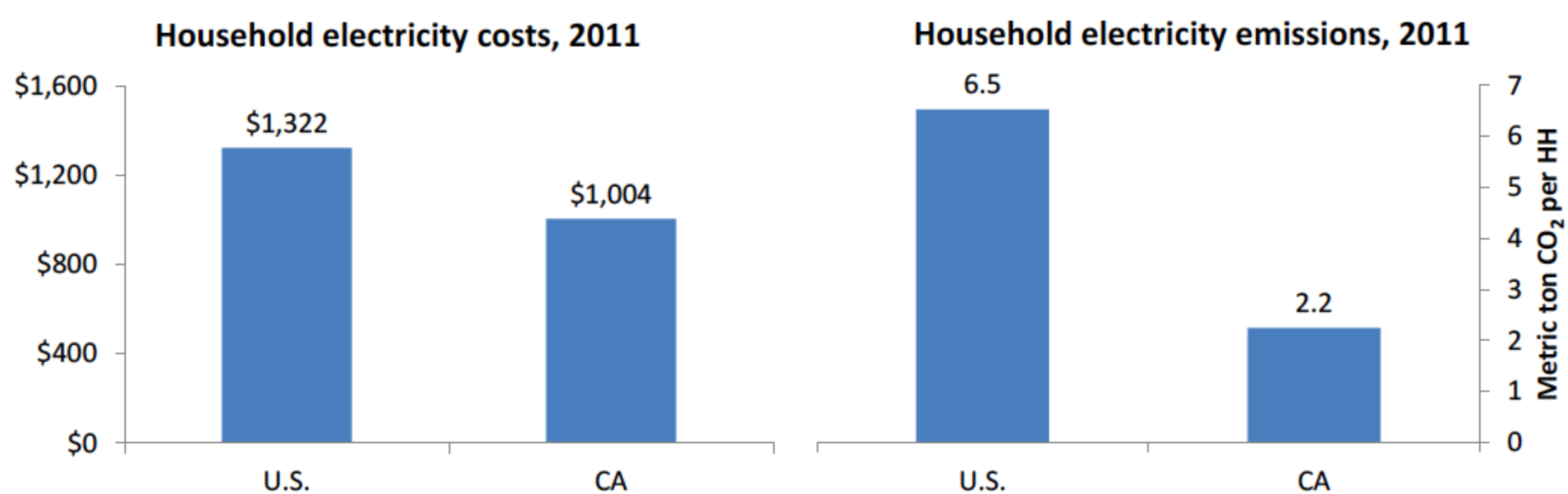
Proposed First Update to the Climate Change Scoping Plan:

Building on the Framework

February 2014

Pursuant to AB 32
The California Global Warming Solutions Act of 2006

Figure 4: Average Household Expenditures on Electricity and Associated GHG Emissions in the United States and California.[42]



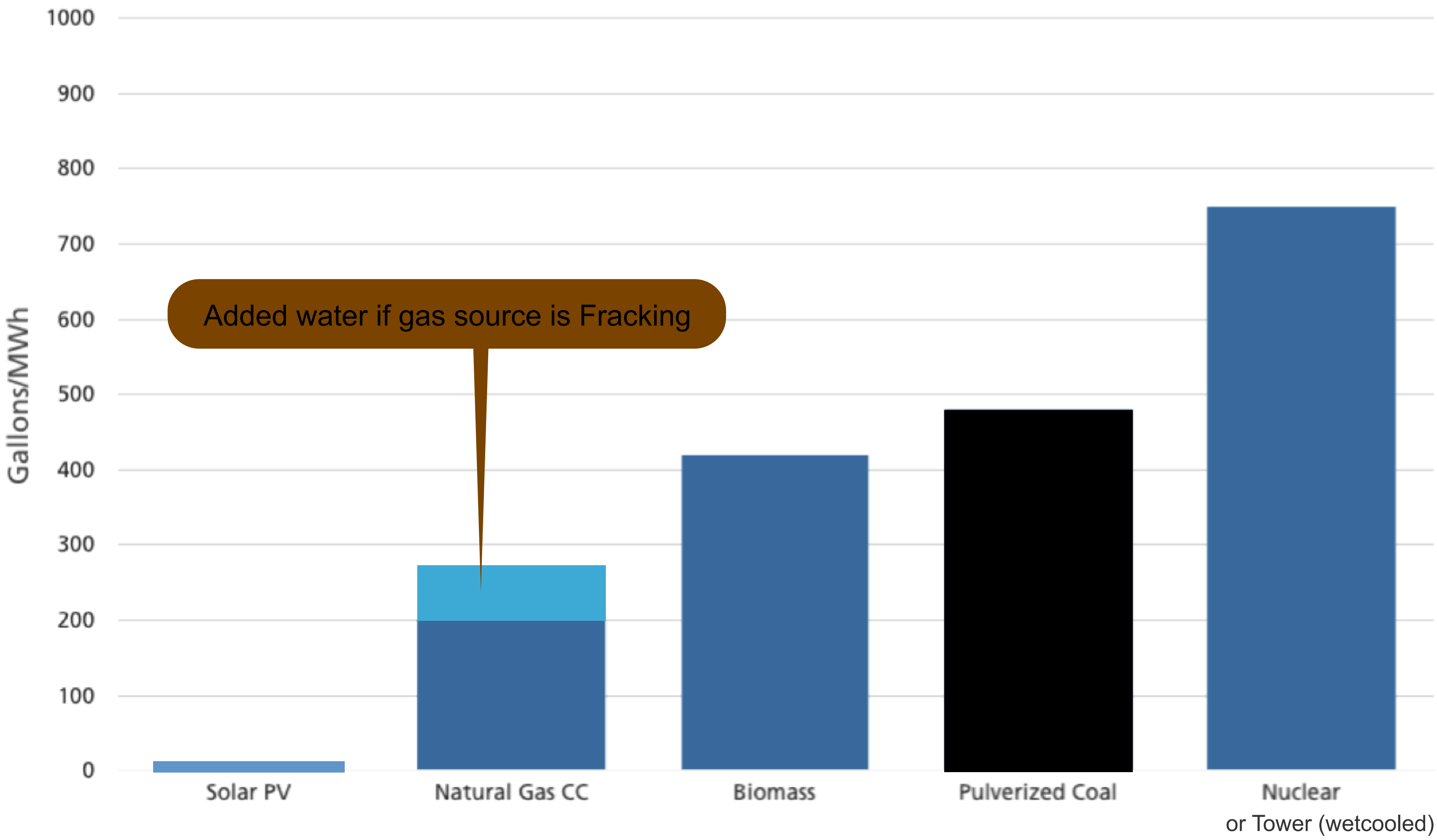
Sources: U.S. Energy Information Administration [EIA] and ARB

Solar Creates Jobs

Average Total Jobs/Megawatts

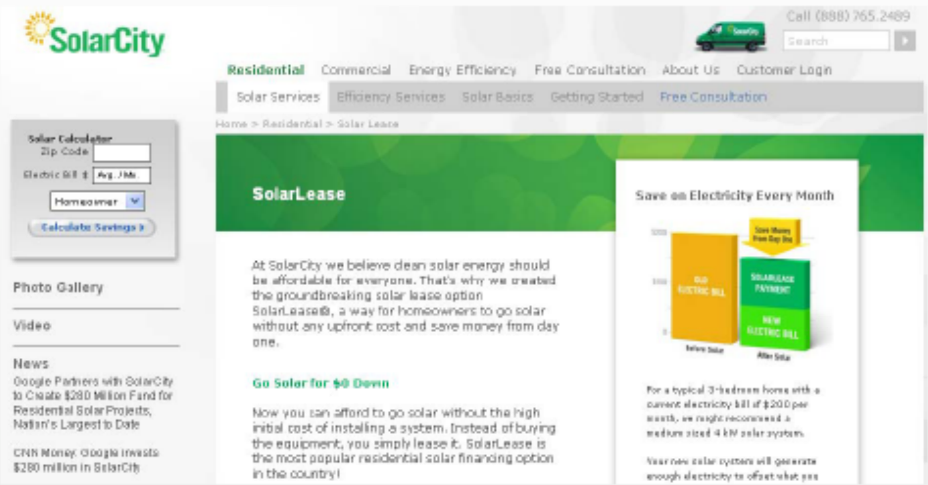
Kammen, M et al, 2004, Report of the Renewable and Appropriate Energy Lab, Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Create?, Energy Resources Group, Goldman School of Public Policy, University of California, Berkeley.
Wei, Max, Patadia, Shana, and Daniel Kammen, 2010, Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Create?, Energy Resources Group, Goldman School of Public Policy and the Haas School of Business, University of California, Berkeley, in Energy Policy, 38(20, 2010.

Solar PV Uses Far Less Water than Other Power Sources



Source: Adapted from DOE 2010, Table 8.3

Solar for $0 Down, in Increasing Markets



- 100% Financing accelerating solar home sales
- Sale of Energy, not equipment
- Never an Increase in your Utility Bill
- >100,000 solar power systems already installed

SWITCH

- Need to merge the capabilities of capacity-expansion and unit-commitment models to more accurately evaluate renewables
- SWITCH co-optimizes capacity investment and hourly system dispatch
- SWITCH was developed in RAEL (first student: Prof. Matthias Fripp) and is free and open-access software that can be redistributed and modified under the terms of the GNU General Public License version 3 (see http://www.switch-model.org)

- Documentation for the WECC version of the model that is being developed and maintained at the Renewable and Appropriate Energy Laboratory at U.C. Berkeley is available at http://rael.berkeley.edu/switch

- Support provided by:

CITRIS Center for Information Technology Research in the Interest of Society

The Energy Foundation

Link Foundation Est. 1953

State of California Energy Commission

IBM

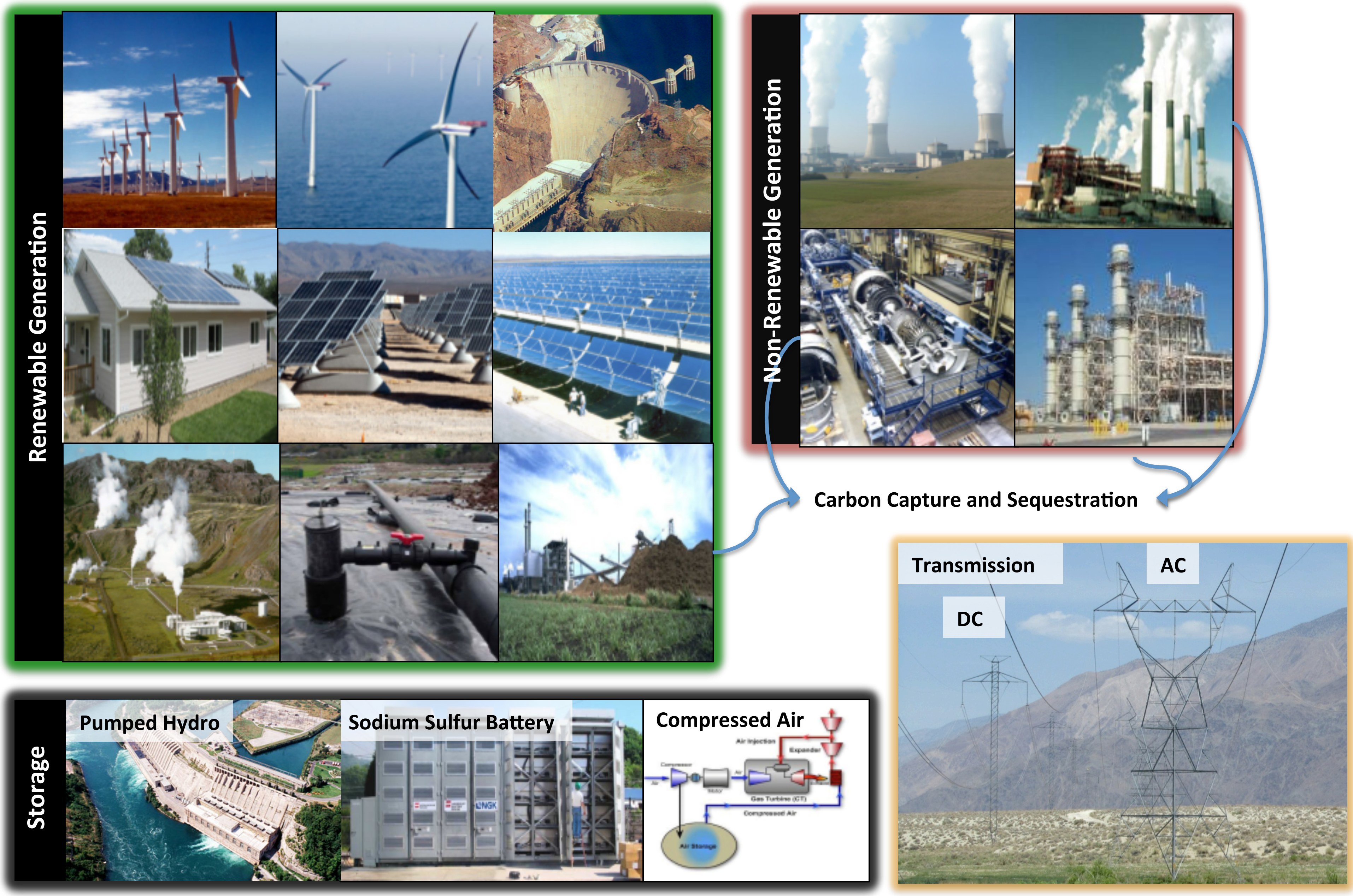
hp

Motivation for new planning model framework

- Electricity planning processes usually involves the creation of "candidate portfolios" that are compared on cost and risk
  - Sophisticated production simulation models used to *evaluate* the candidate portfolios, but the process of *creating* the portfolios is much less detailed[2, 3]
- Renewables integration research has focused on evaluating pre-specified deployments levels and locations of renewable resources
  - Considerable cost-reduction exists through the optimization of the full power system – generation, transmission, storage, demand response, efficiency, etc.
- Need to merge the capabilities of planning and unit-commitment models to more accurately evaluate renewables

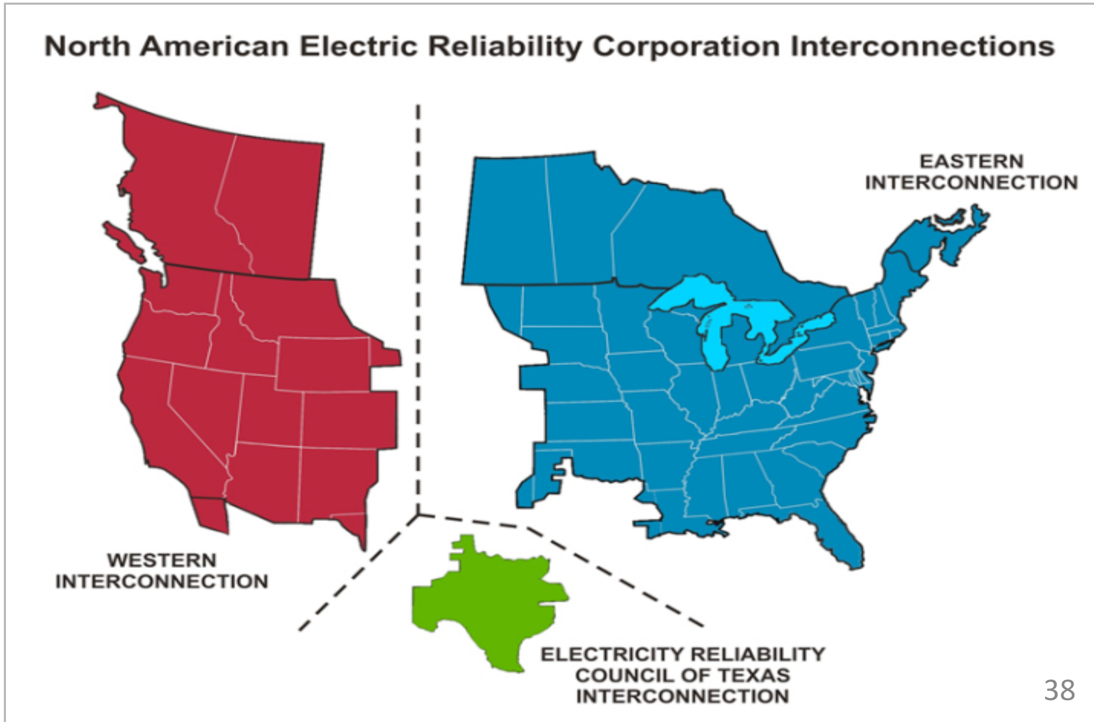
[2]Mills, A., Wiser, R., 2012. An evaluation of solar valuation methods used in utility planning and procurement processes. Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-5933E, December 2012.
[3]Mai, T., *et al.*, 2013. Resource Planning Model: an integrated resource planning and dispatch tool for regional electric systems. National Renewable Energy Laboratory, NREL/TP-6A20-56723, January 2013.

Infinite possible combinations of generation, transmission, storage, efficiency, demand response, electrification….



SWITCH-WECC:
A planning tool for the electric power system

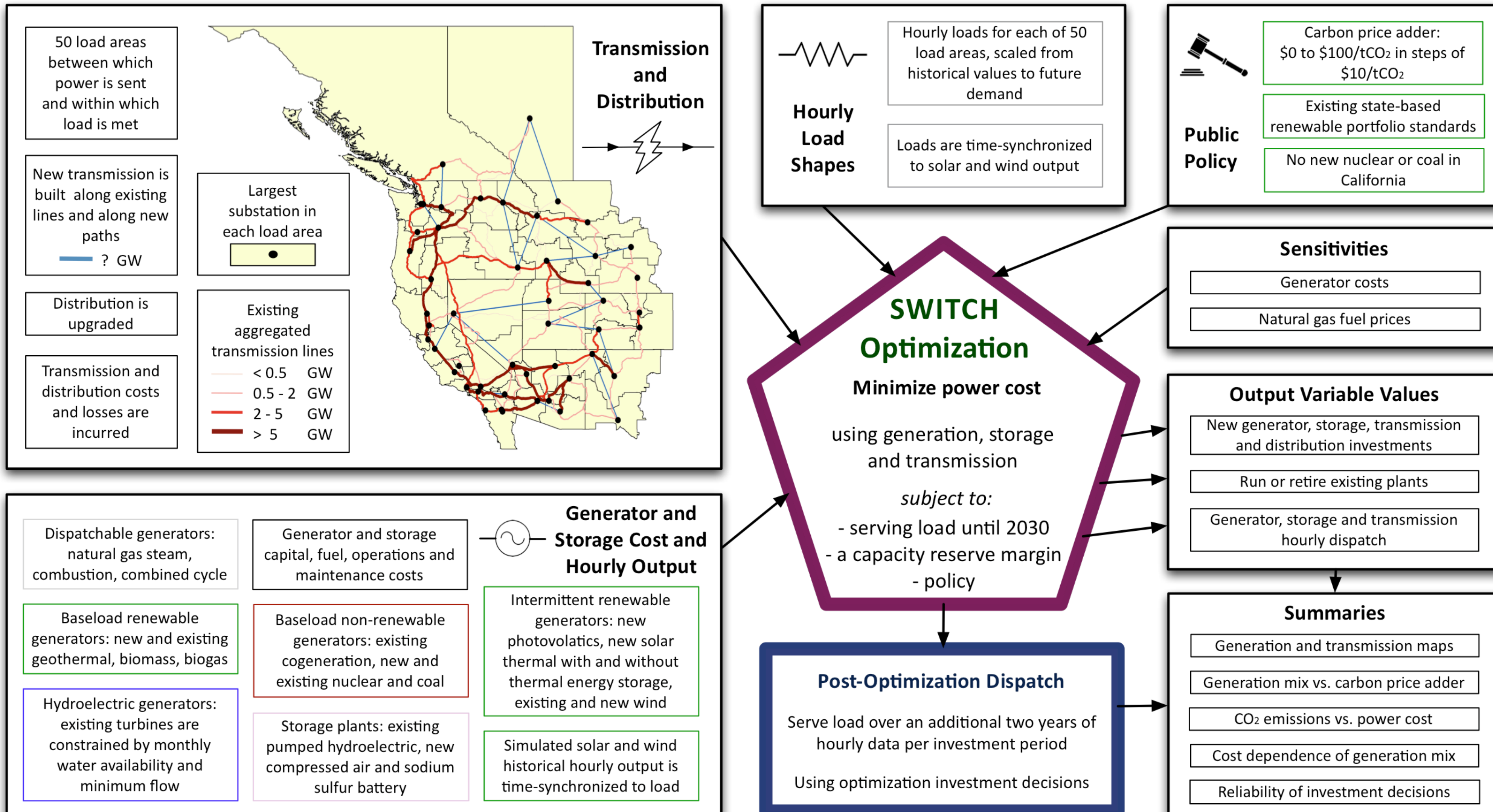
- SWITCH is *not* a forecasting or projection tool
- SWITCH co-optimizes capacity investment and hourly dispatch
- System-wide approach is key
  - Geographic diversity reduces overall variability of demand and renewable output
  - Sharing of flexibility resources
- Hourly demand and renewable output profiles are used
  - Goal is to capture the temporal relationship between demand and renewable power



SWITCH-WECC: Minimize future power system cost while meeting demand, reliability, and policy constraints

- **Main constraints**: demand, reliability, and policy
  - Meet projected electricity demand in every hour
  - Maintain a planning reserve margin in every hour
  - Maintain operating reserves (spinning and quickstart) in every hour
  - Meet renewable portfolio standard (RPS) and distributed generation goals
  - Meet carbon emission cap
- **Main variables**: investment and (linearized) unit commitment
  - Invest in new generation, transmission, and storage capacity in each "investment period"
    - All investment periods are optimized simultaneously
  - Operate or retire existing generation capacity in each investment period
  - Linearized unit commitment for representative hourly timepoints
    - Six categories of generators with different levels of flexibility (baseload, flexible baseload, intermediate, peaker, hydropower, and storage)
    - Transmission, storage, demand response
    - Renewable energy certificates

The SWITCH-WECC Model



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

http://rael.berkeley.edu/switch

Linear Program Around Least Cost

Objective function: minimize the total cost of meeting load			
Generation and Storage	Capital	$\sum_{g,i} G_{g,i} \cdot c_{g,i}$	The capital cost incurred for installing a generator at plant *g* in investment period *i* is calculated as the generator size in MW $G_{g,i}$ multiplied by the cost of that type of generator in $2007 / MW $c_{g,i}$.
Generation and Storage	Fixed O&M	$+(ep_g + \sum_{g,i} G_{g,i}) \cdot x_{g,i}$	The fixed operation and maintenance costs paid for plant *g* in investment period *i* are calculated as the total generation capacity of the plant in MW (the pre-existing capacity ep_g at plant *g* plus the total capacity $G_{g,i}$ installed through investment period *i*) multiplied by the recurring fixed costs associated with that type of generator in $2007 / MW $x_{g,i}$.
Generation and Storage	Variable	$+\sum_{g,t} O_{g,t} \cdot \left(m_{g,t} + f_{g,t} + c_{g,t}\right) \cdot hs_t$	The variable costs paid for plant *g* operating in study hour *t* are calculated as the power output in MWh $O_{g,t}$ multiplied by the sum of the variable costs associated with that type of generator in $2007 / MWh. The variable costs include per MWh maintenance costs $m_{g,t}$, fuel costs $f_{g,t}$, and carbon costs $c_{g,t}$, and are weighted by the number of hours each study hour represents, hs_t.
Transmission		$+\sum_{a,a',i} T_{a,a',i} \cdot l_{a,a'} \cdot t_{a,a',i}$	The cost of building or upgrading transmission lines between two load areas *a* and *a'* in investment period *i* is calculated as the product of the rated transfer capacity of the new lines in MW $T_{a,a',i}$, the length of the new line $l_{a,a'}$, and the regionally adjusted per-km cost of building new transmission in $2007 / MW · km, $t_{a,a',i}$. Transmission can only be built between load areas that are adjacent to each other or that are already connected.
Distribution		$+\sum_{a,i} d_{a,i}$	The cost of upgrading local transmission and distribution within a load area *a* in investment period *i* is calculated as the cost of building and maintaining the upgrade in $2007 / MW $d_{a,i}$.
Sunk		$+ s$	Sunk costs include ongoing capital payments incurred during the study period for existing plants, existing transmission networks, and existing distribution networks. The sunk costs do not affect the optimization decision variables, but are taken into account when calculating the cost of power at the end of the optimization.

Figure 3

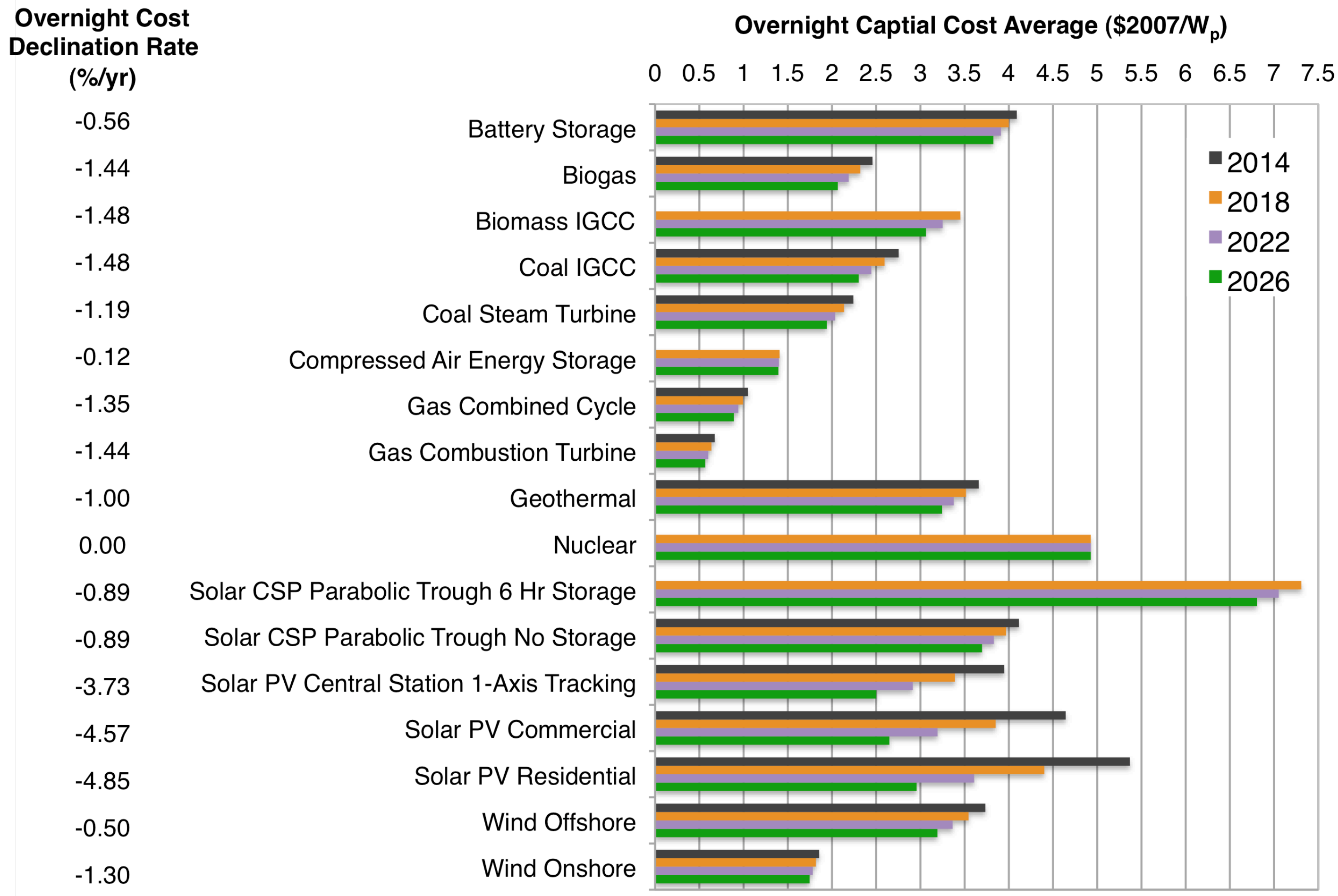


Figure 3: *Annual overnight cost declination rates and overnight capital costs by investment period in the Base Cost scenario for each generator and storage technology. Costs for technologies not available for installation in 2014 are not shown. CSP denotes concentrating solar power (solar thermal). Many of these values are varied in generator cost sensitivity scenarios described in Section 3. Overnight capital costs do not include regional capital cost multipliers, interest during construction, grid connection costs, local grid upgrade costs, and operations and maintenance costs, though these costs are included in each optimization. See the Online Supplemental Information for more information.*

2012 estimate: already too high on solar costs

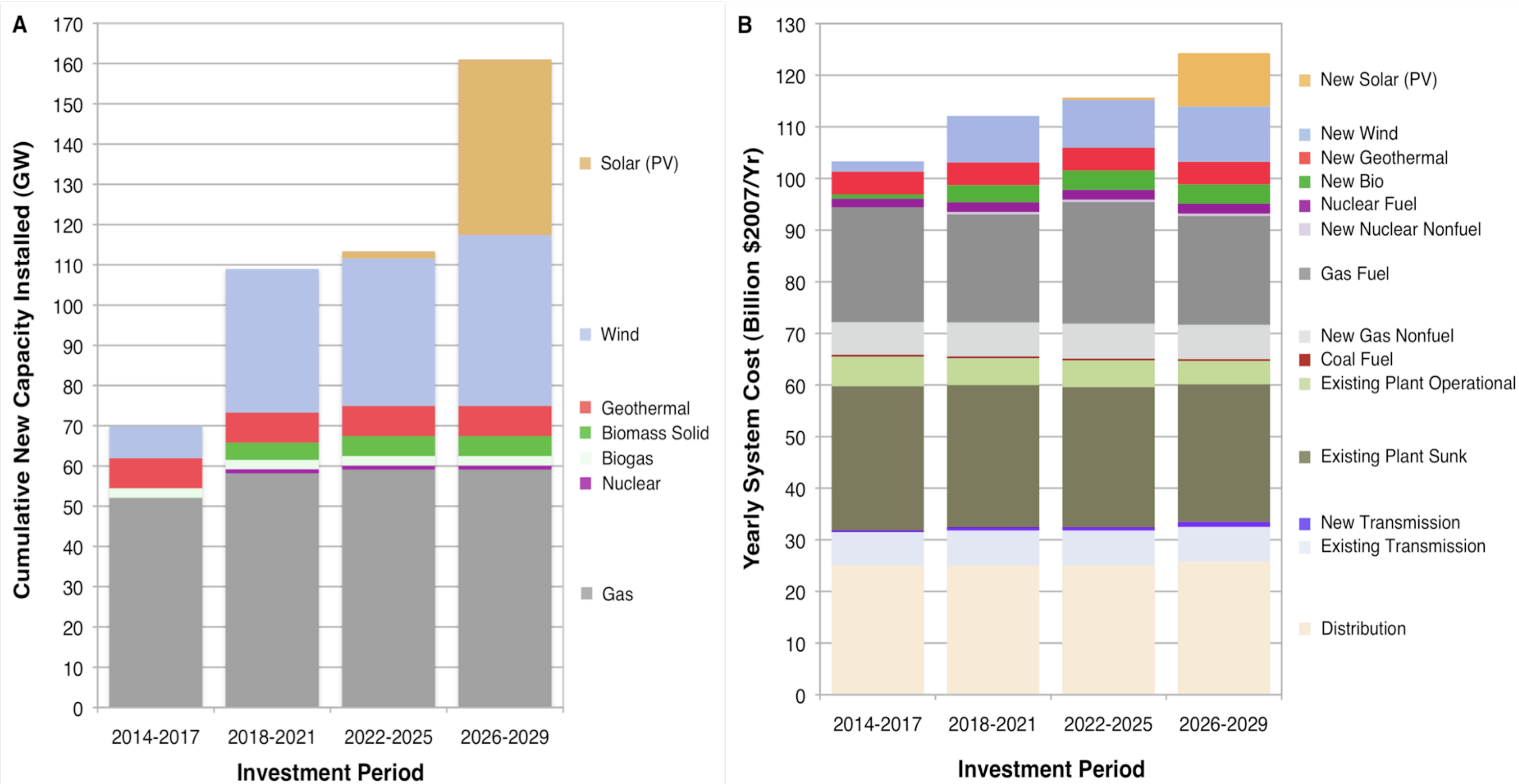
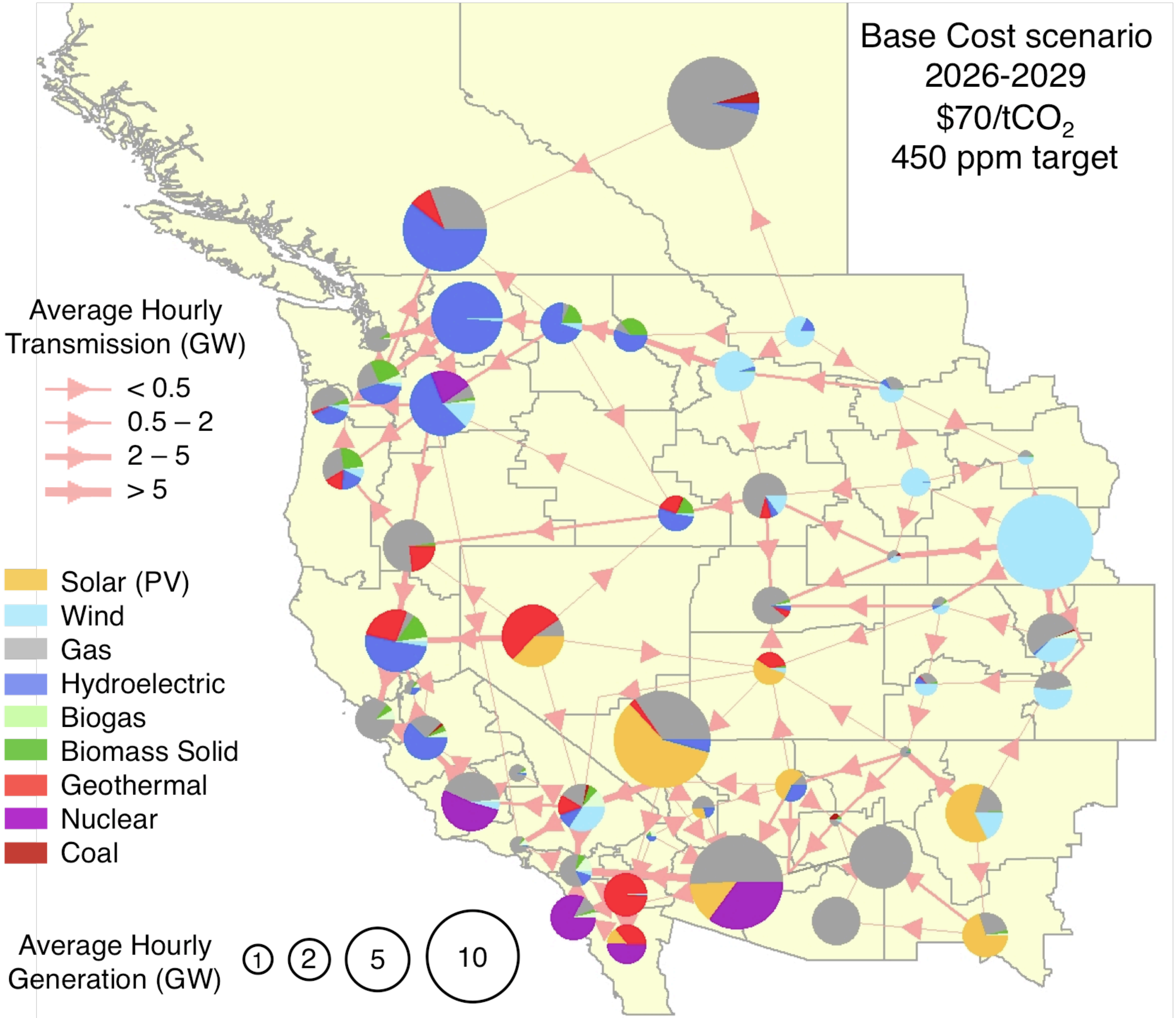


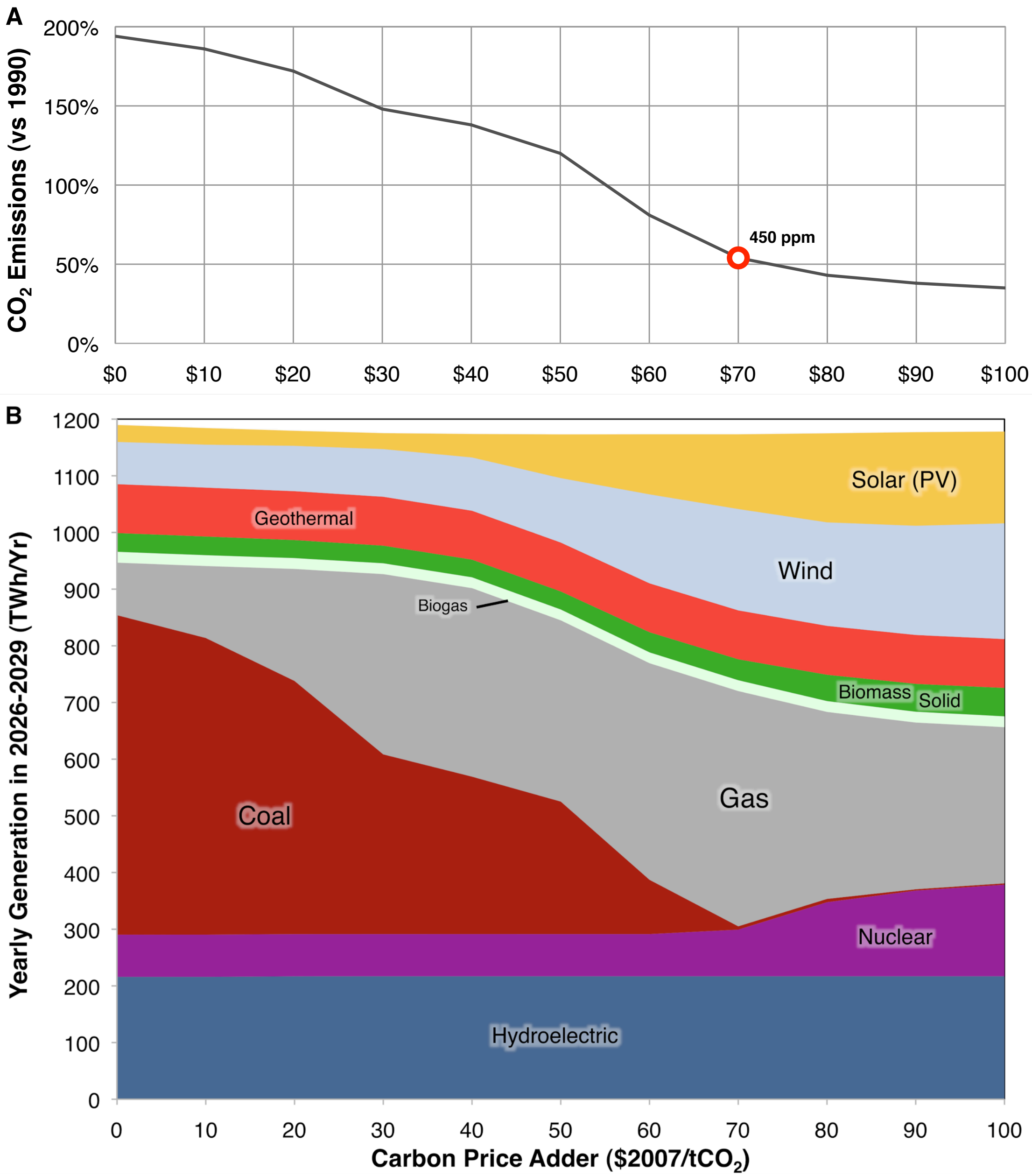
Figure 5. *Base Cost scenario cumulative new capacity additions (A) and yearly average system costs (B) by investment period at \$70/tCO_2 carbon price adder. Nonfuel costs include capital, operations, and maintenance costs.*

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.

High-Resolution Modeling of Clean Energy Futures



HIGH SPATIAL AND TEMPORATL RESOLUTION MODEL OF THE REGIONAL POWER GRID (WESTERN NORTH AMERICA)

LEAST-COST LINEAR PROGRAM MODEL FOR WESTERN NORTH AMERICA:

- **TOP: CO_2 emissions relative to 1990**
- **BOTTOM: power generation by fuel in 2022029 as a function of carbon price adder**
- **Climate stabilization target of 450 ppm is reached at a carbon price adder of ~ $70/tCO$_2$.**

http://rael.berkeley.edu

Renewable & Appropriate Energy Laboratory RAEL

Figure 9

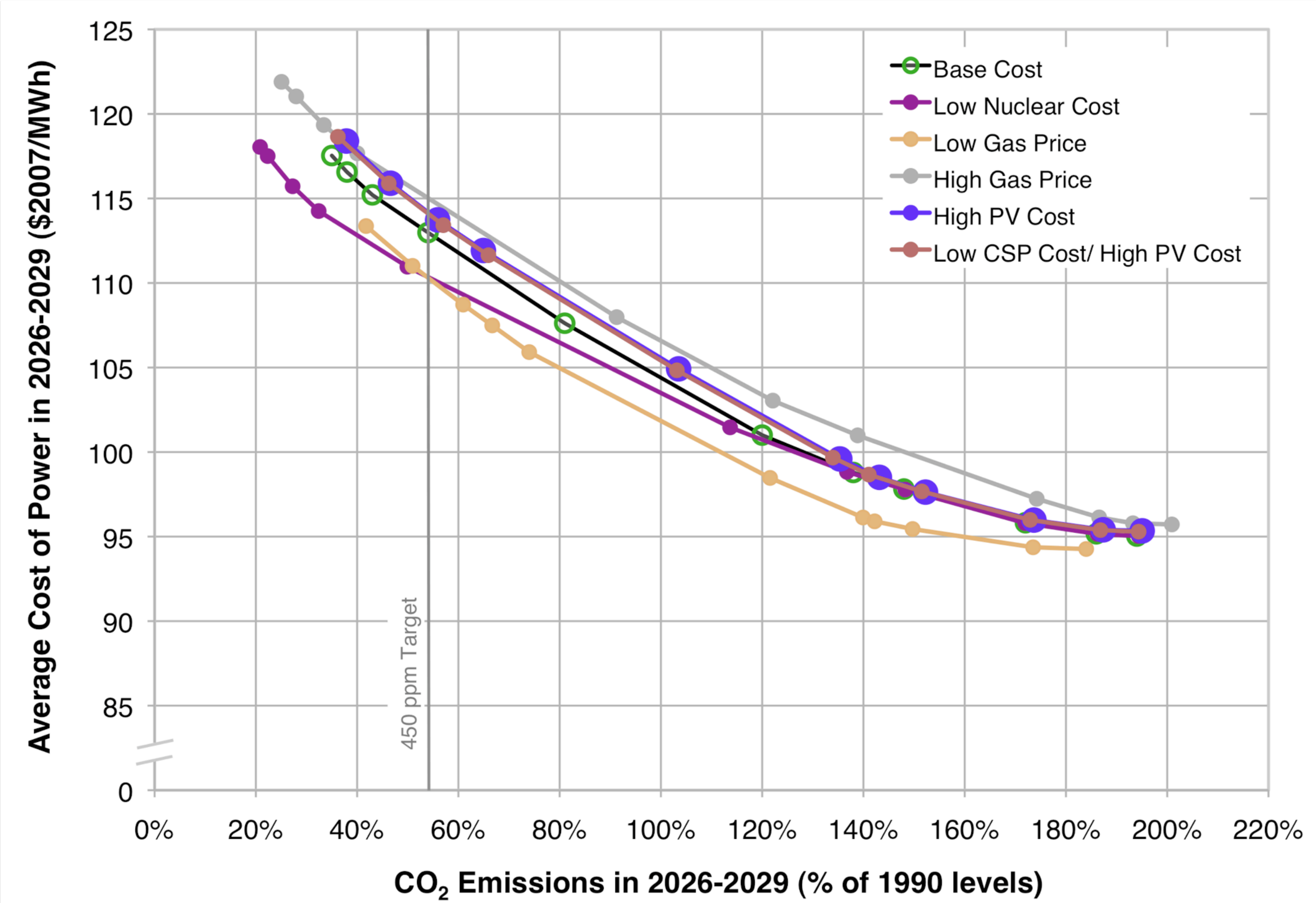
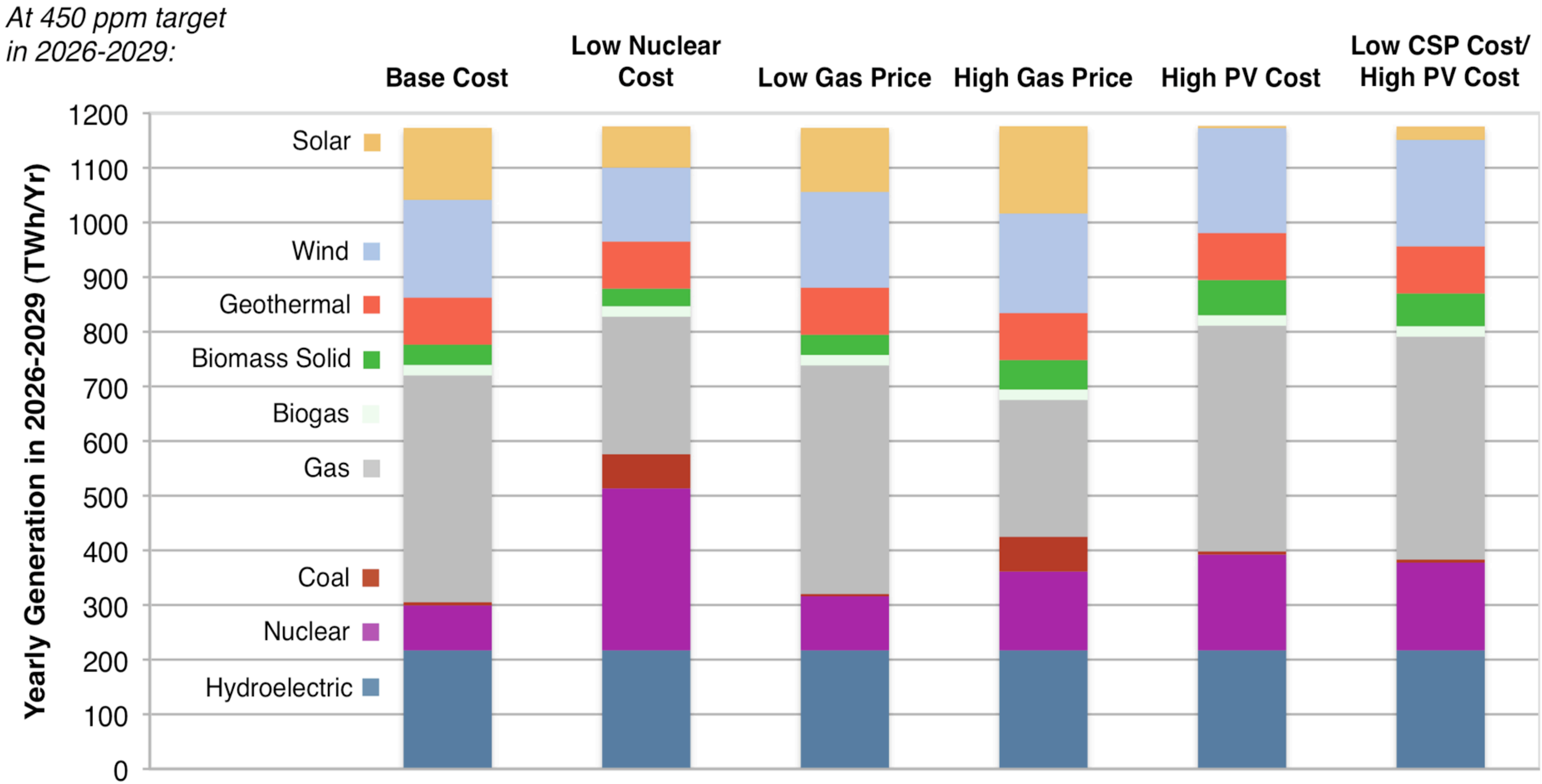


Figure 9. *Average cost of power in 2026-2029 as a function of carbon emissions for all scenarios. Each point represents an optimization performed at a distinct carbon price adder, with the rightmost and leftmost points on each line representing optimizations at \$0/t*CO_2 *and \$100/t*CO_2 *respectively. Intermediate points range between these values in steps of \$10/t*CO_2*. The broken y-axis allows for ease of comparison of the cost of power between scenarios but visually overstates the magnitude of power cost differences. For example, the Base Cost scenario power cost increases by only 18% when moving from the far right of this plot to the 450 ppm target line.*

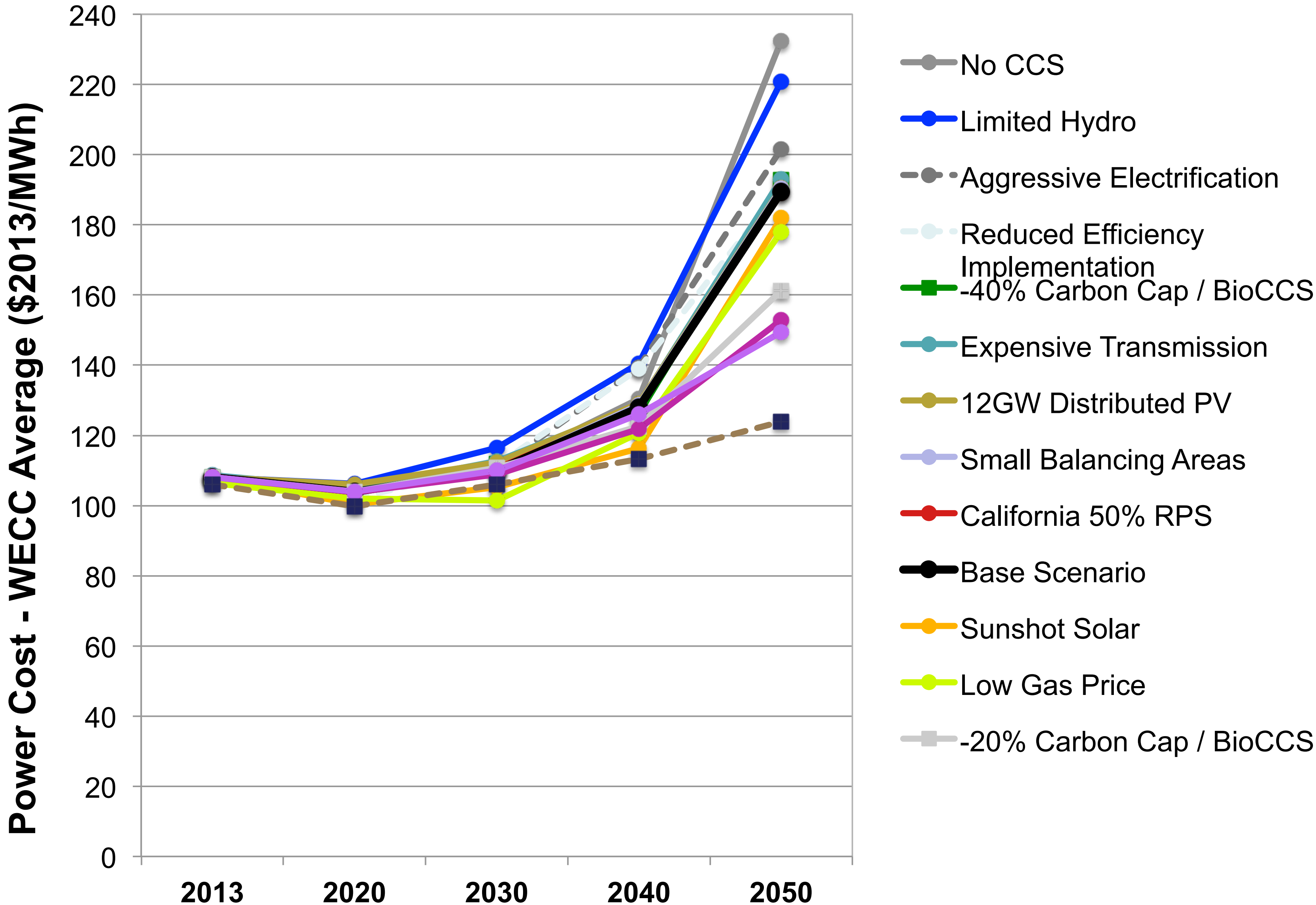


	Base Cost	Low Nuclear Cost	Low Gas Price	High Gas Price	High PV Cost	Low CSP Cost/ High PV Cost
Carbon price adder ($2007/tCO$_2$)	70	59	87	66	84	86
Power cost ($2007/MWh)	113	110	110	114	114	114
Cumulative new transmission built by 2030 (10^3 GW-km)	9.8	6.0	9.0	11.7	12.0	12.3

Nelson, J. et al., *Energy Policy*, 43 (**2012**) 436–447 | http://rael.berkeley.edu/switch

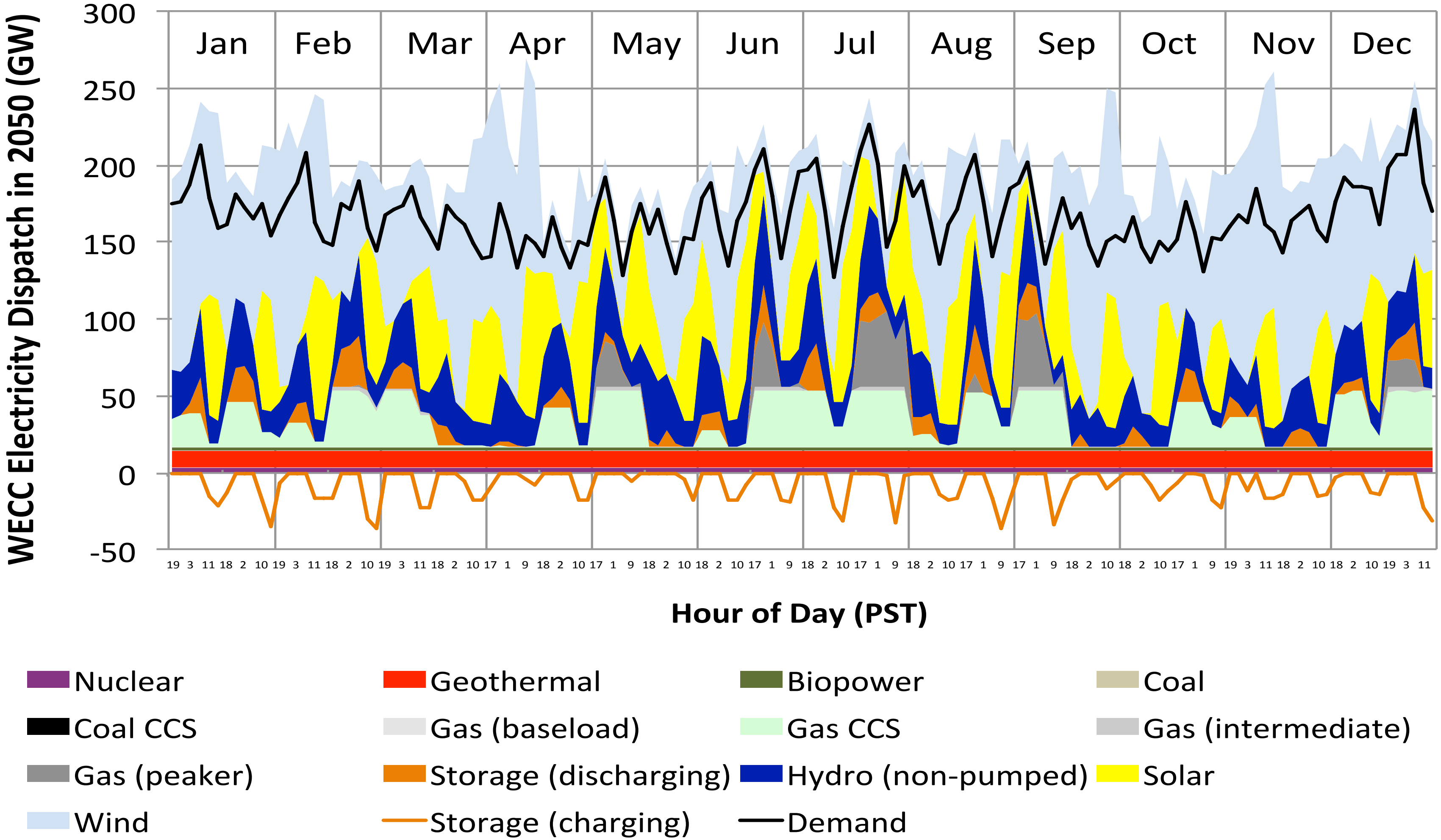
Power cost uncertain but not limiting post-2030

- System flexibility crucial to cost containment by 2050



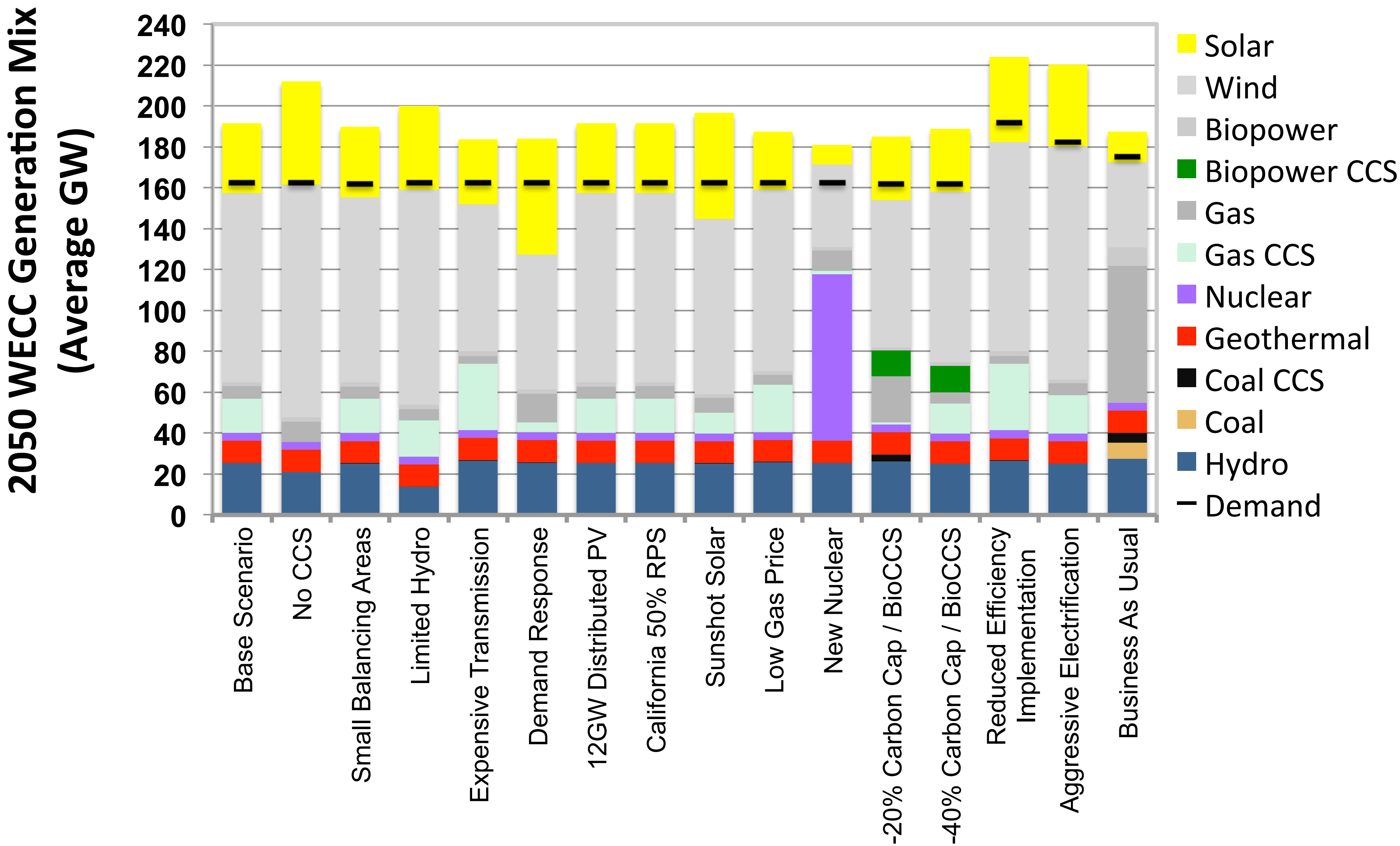
Dispatch in 2050: Flexibility and variable renewables dominate

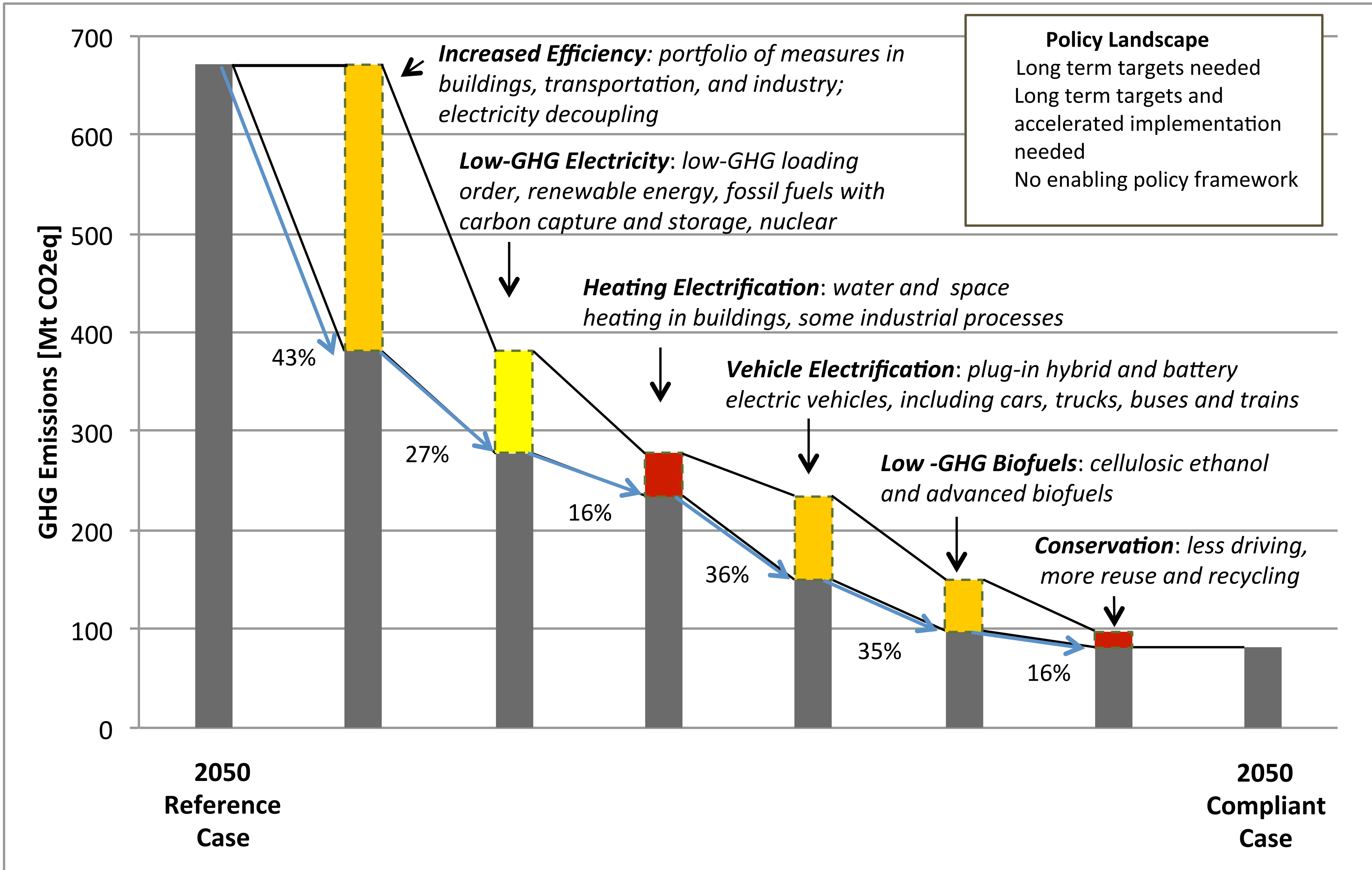
- Storage almost exclusively moves solar to the night
- Geothermal only remaining substantial baseload



Drastic emission reductions possible even without nuclear, CCS, large-scale bioelectricity

- Scenarios to meet 80% decarbonization (450 ppmv equivalent)

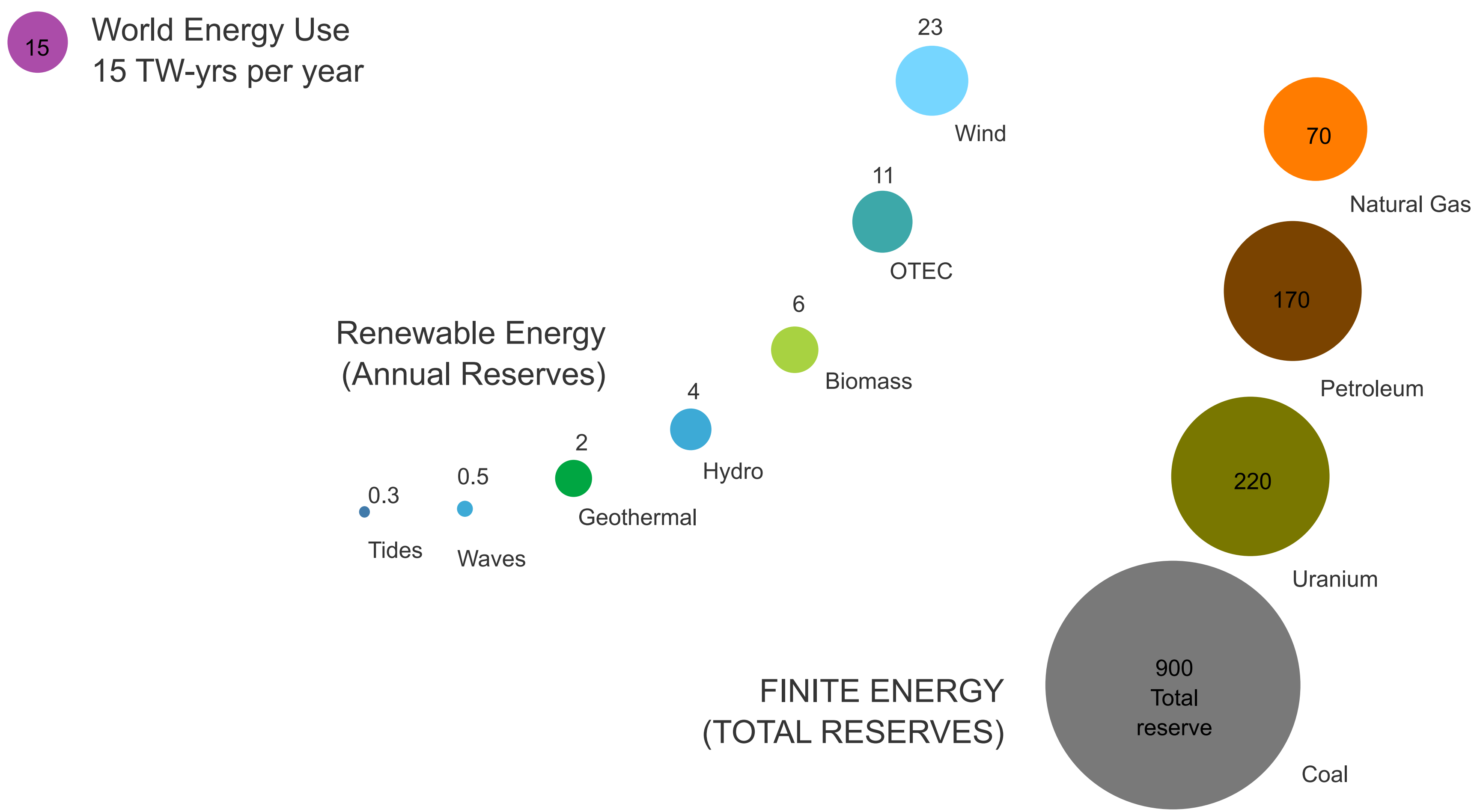




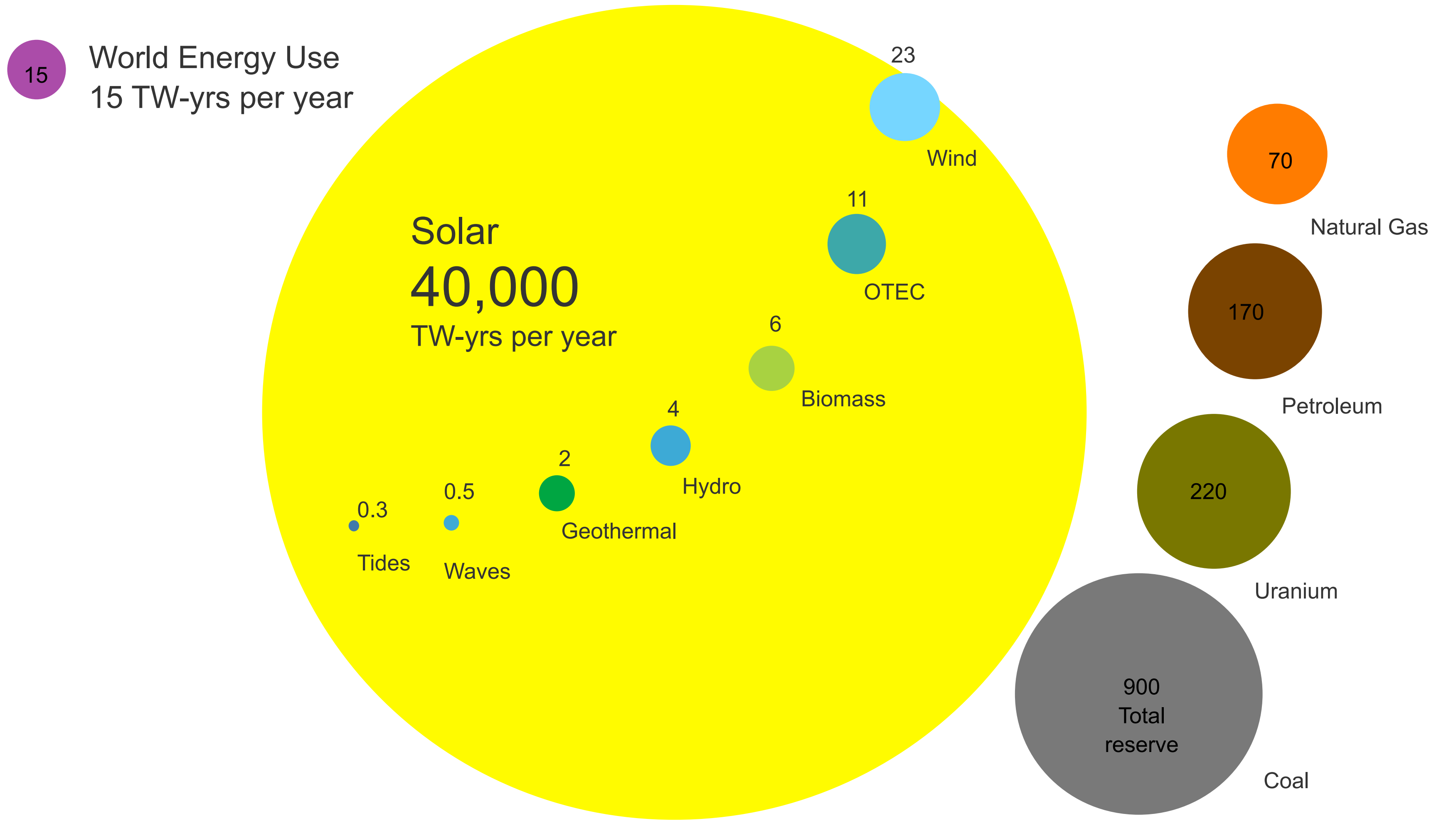
Wei M, Nelson, J.H, Greenblatt, J.B., Mileva, A., Johnston, J.,Ting, M., Jones, C.M., Yang, C., McMahon, J.E., Kammen, D.M., *Deep carbon reductions in California require electrification and integration across economic sectors*. Environmental Research Letters (8) 014038

Exploration of Solar Targets

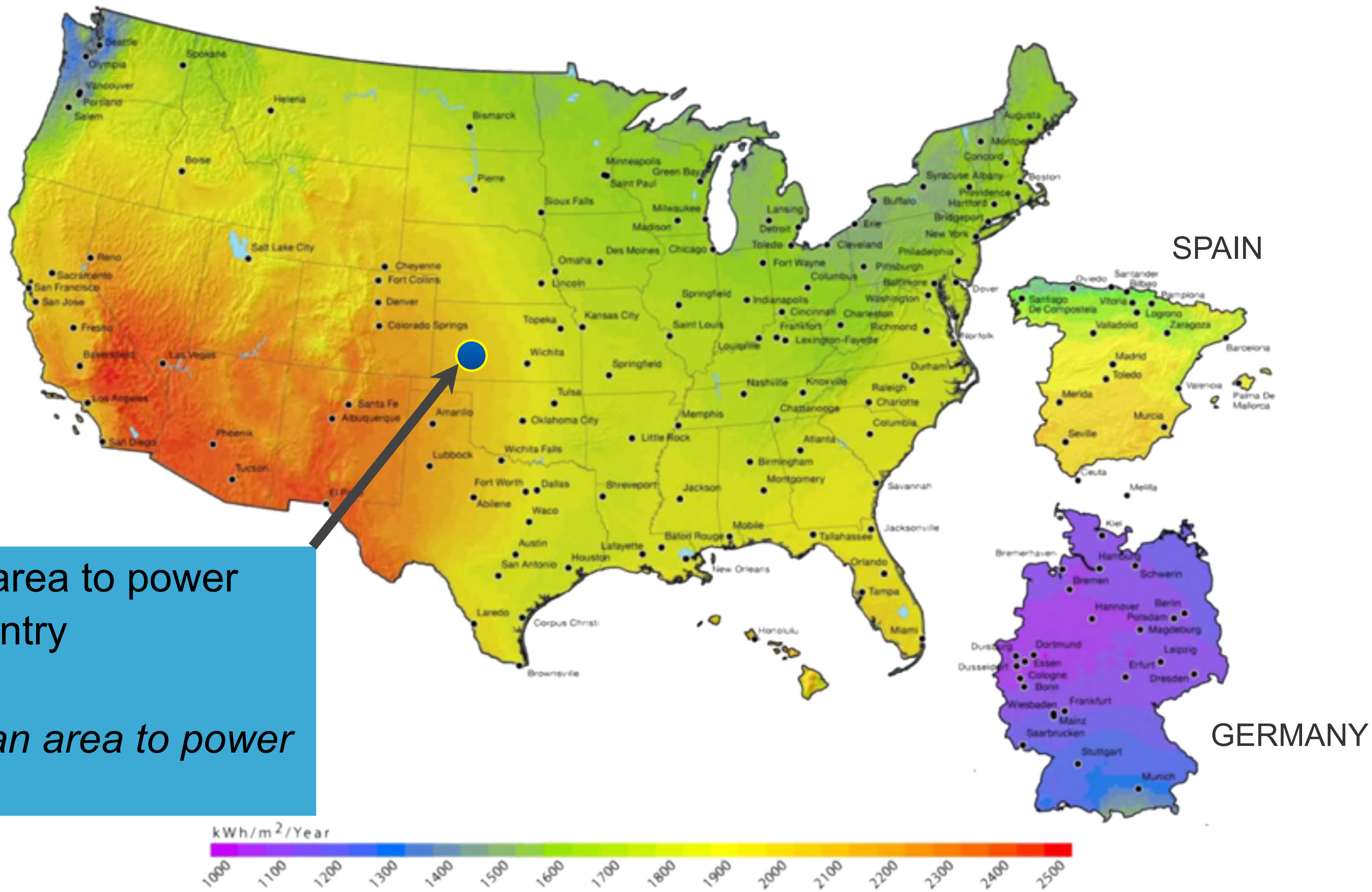
Among Global Energy Sources



Solar is by Far the Most Abundant



US Solar Resource Dwarfs Other Markets

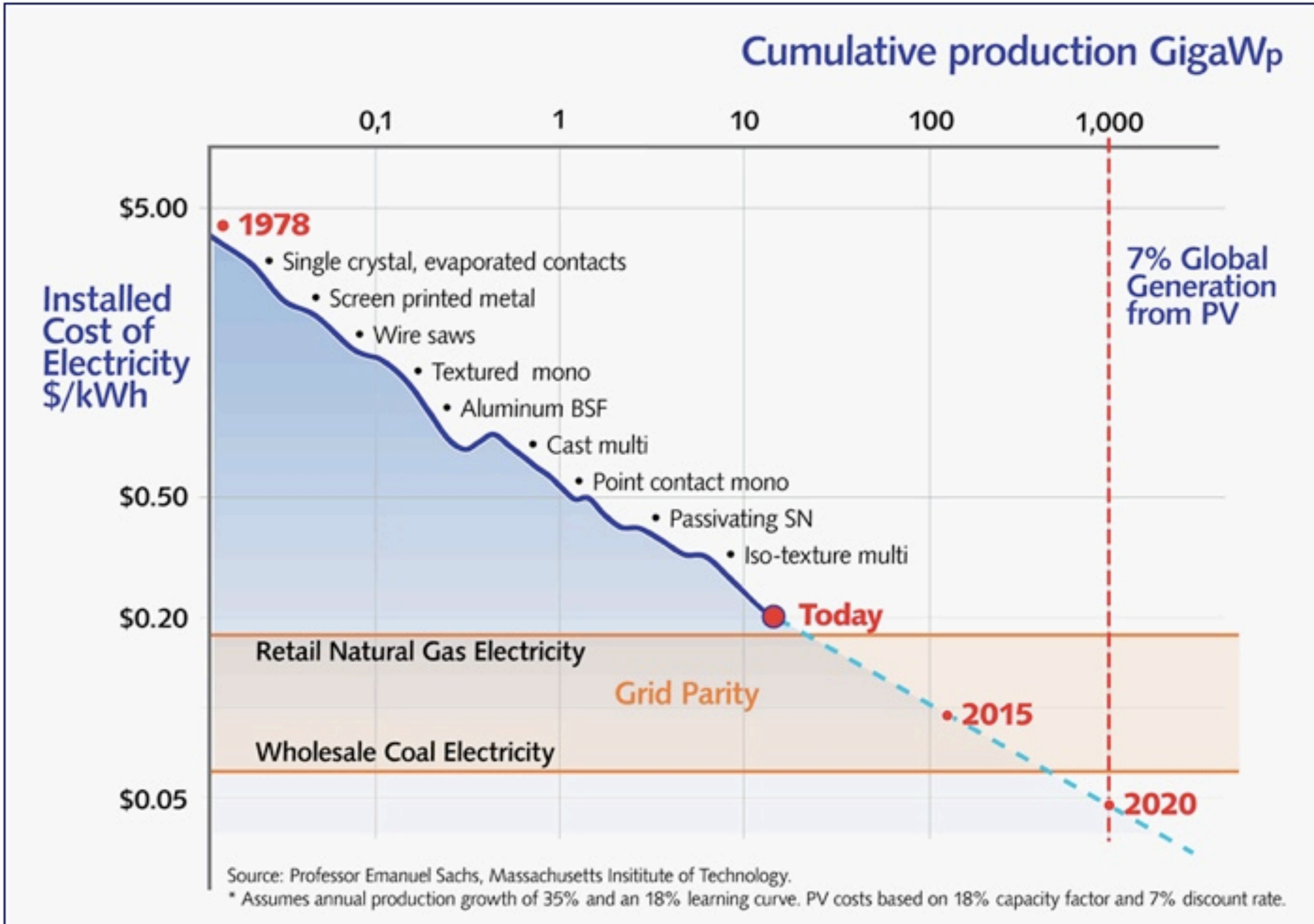


Enough land area to power the whole country

Sufficient *urban area to power the country*

Map Source: National Renewable Energy Laboratory for the U.S. Department of Energy

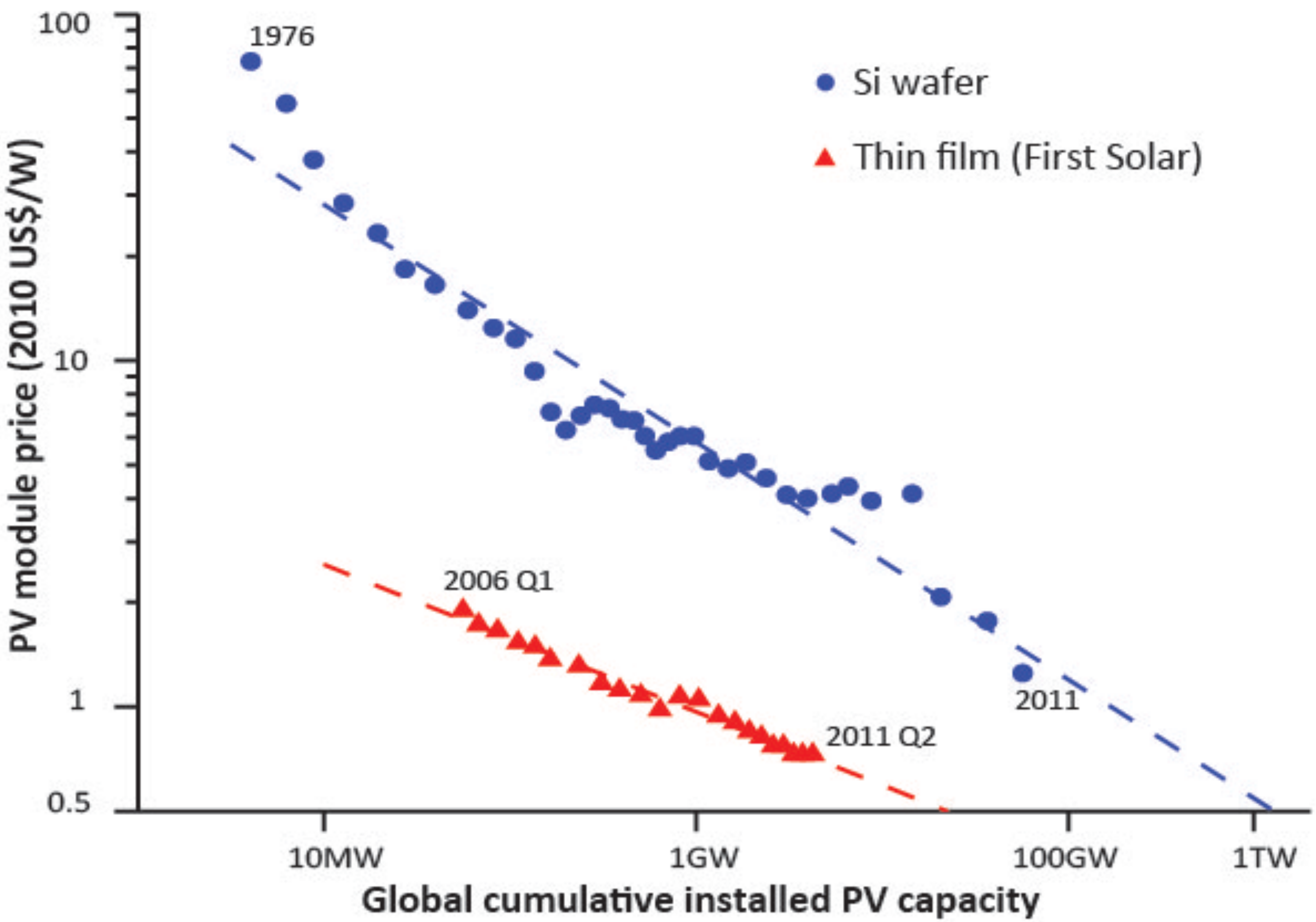
Solar cost decreases 10% per year



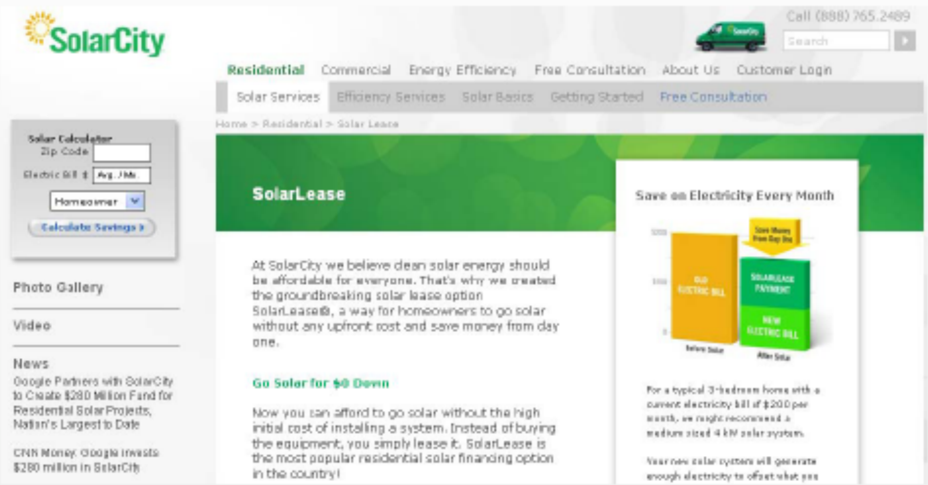
Source: Professor Emanuel Sachs, Massachusetts Insititute of Technology.

*Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 18% capacity factor and 7% discount rate.

The Evolving Solar Energy Economy

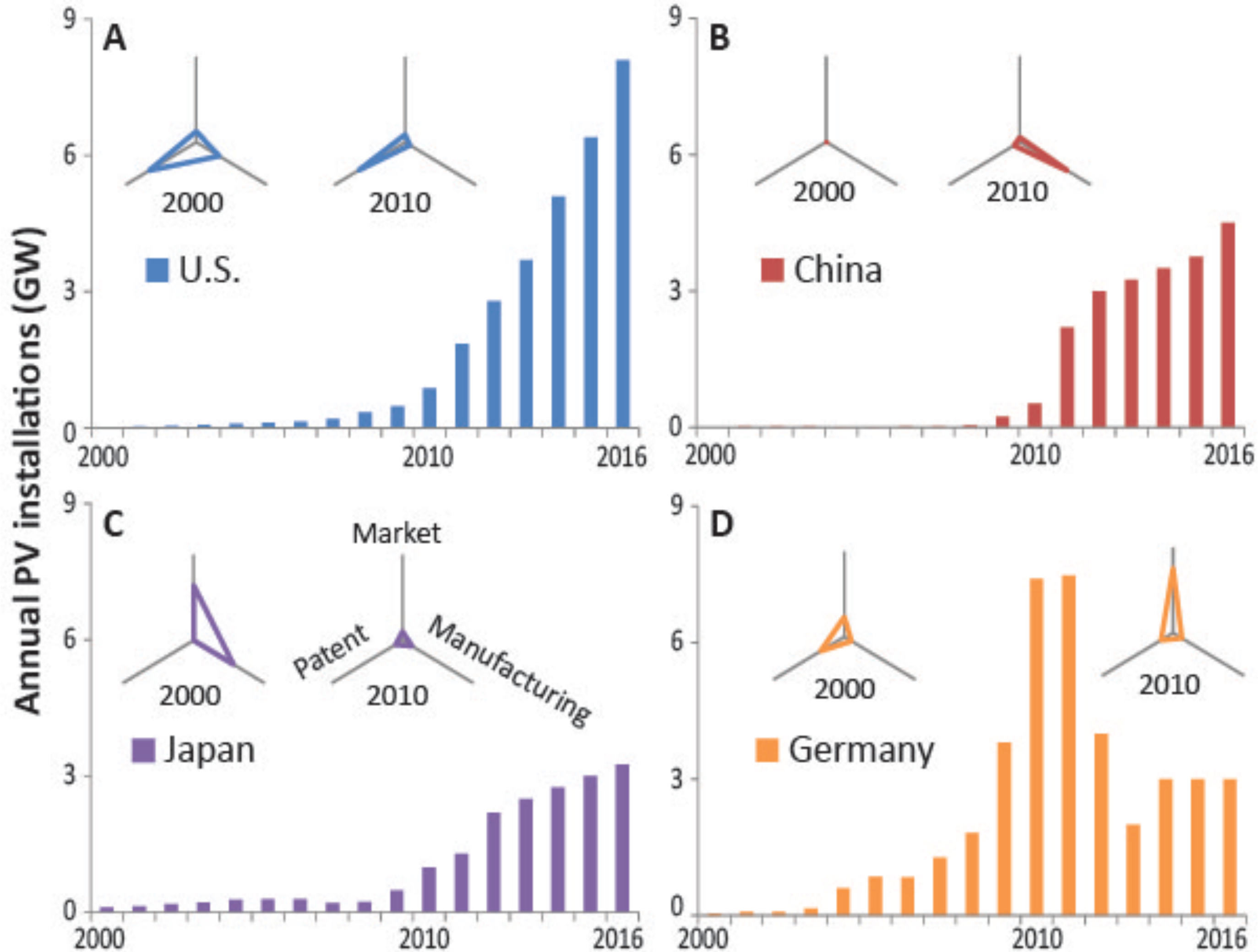


Solar for $0 Down, in Increasing Markets

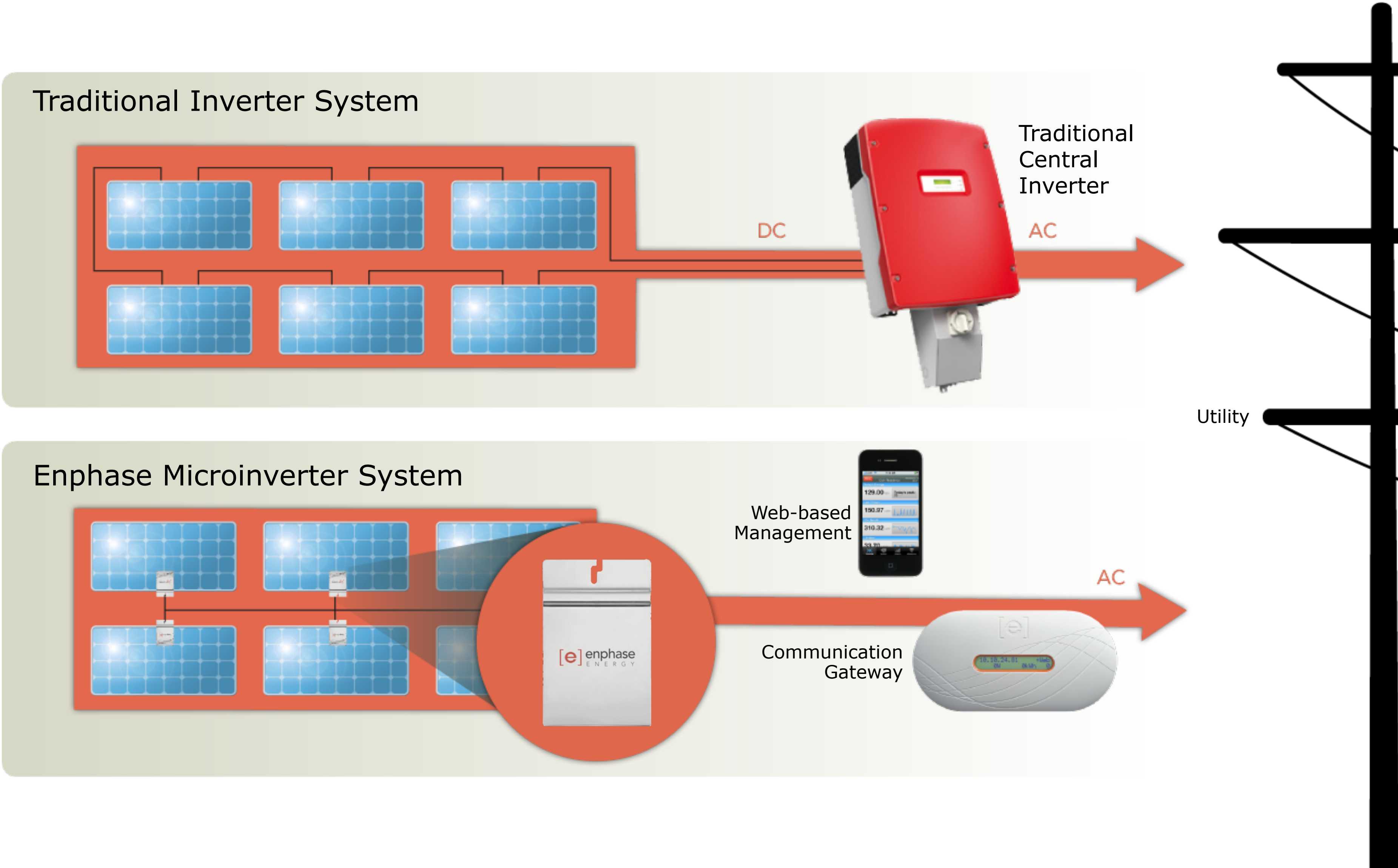


- 100% Financing accelerating solar home sales
- Sale of Energy, not equipment
- Never an Increase in your Utility Bill
- >100,000 solar power systems already installed

The Evolving Solar Energy Economy



Microinverters: A device-level subtle revolution



ALL-ELECTRIC Vehicles (EVs) Entering the Marketplace

Ford
Focus
100 mi

Nissan Leaf, 100 mi
$32k

TESLA MOTORS

Model S $56k+
160-300mi

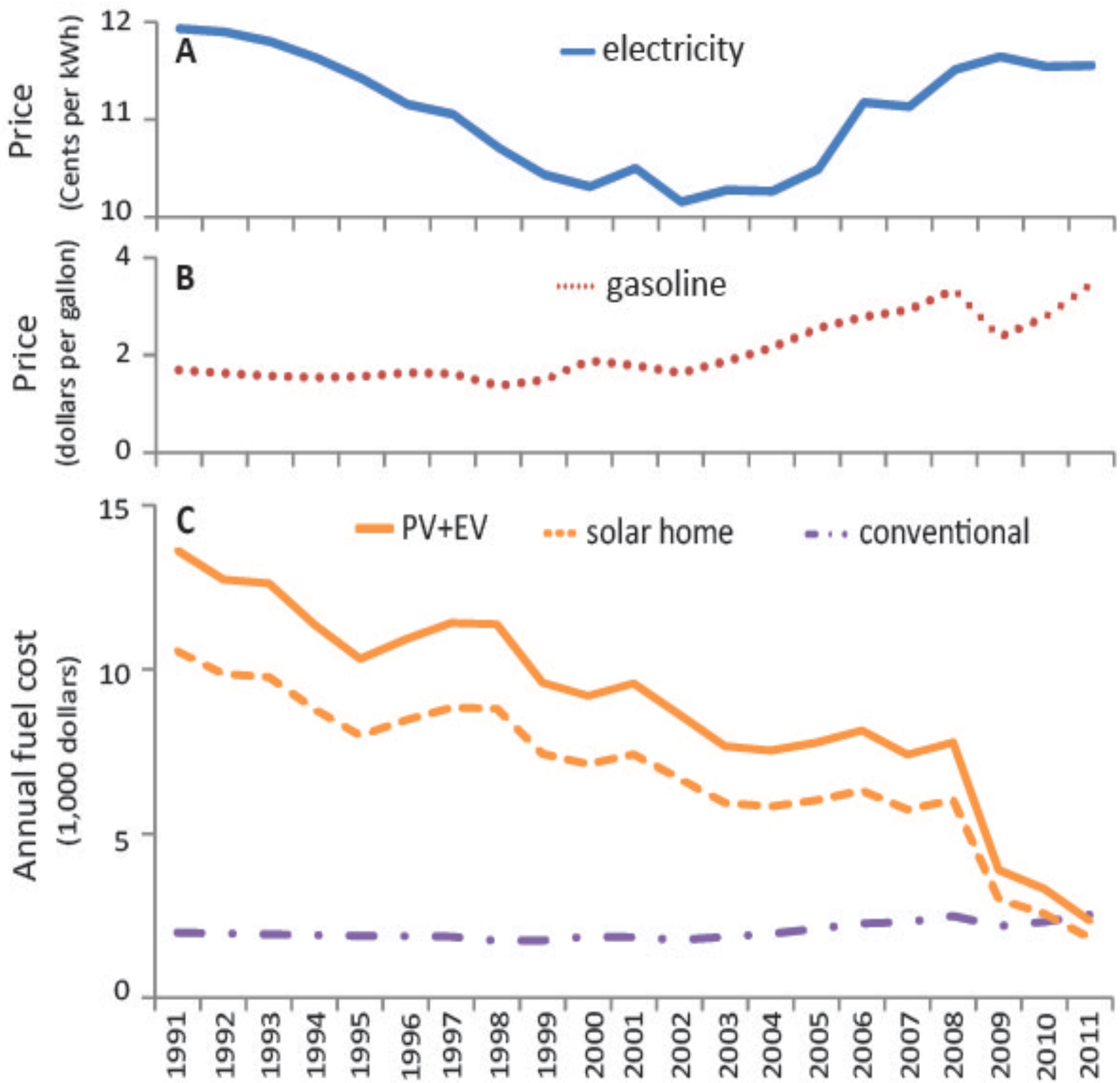
Roadster $109k

BMW Mini E

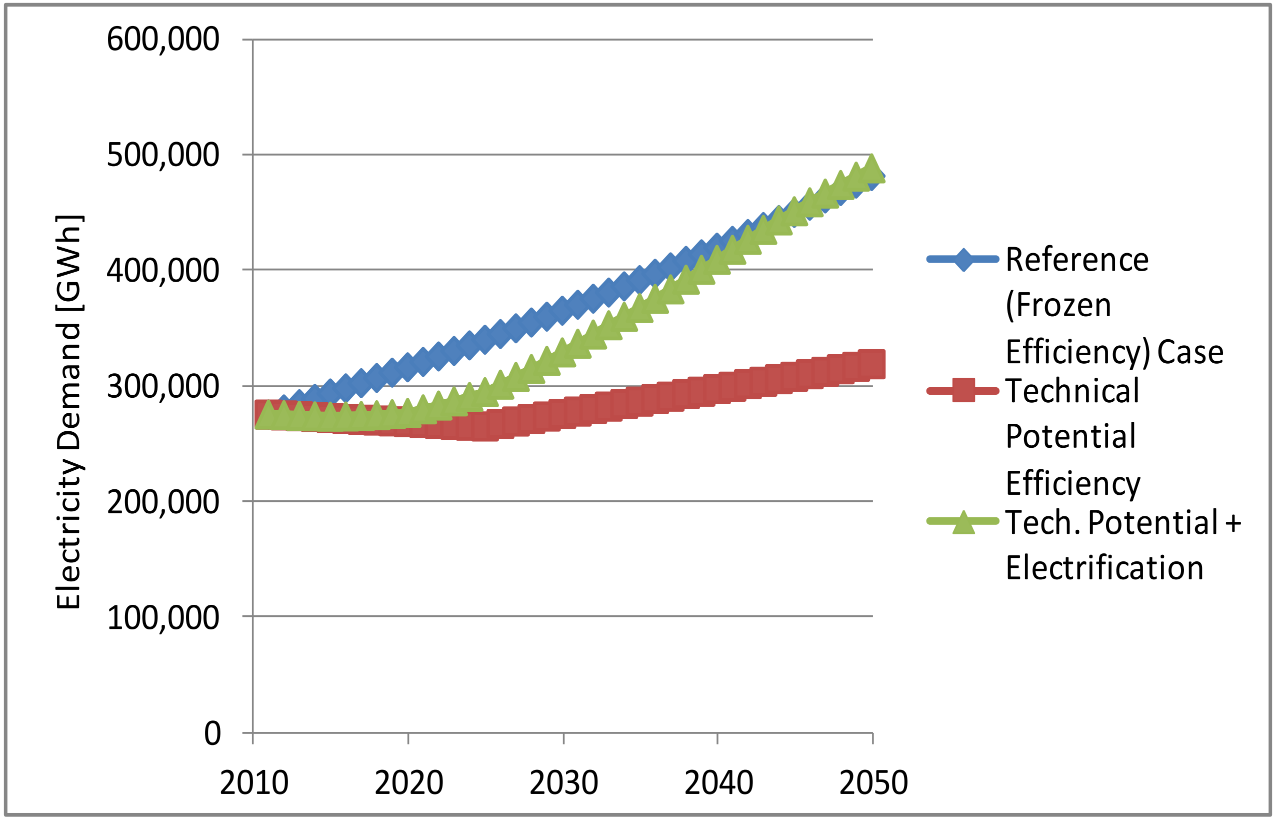
Smart $24k

Coda
$20k

The Evolving Solar Energy Economy

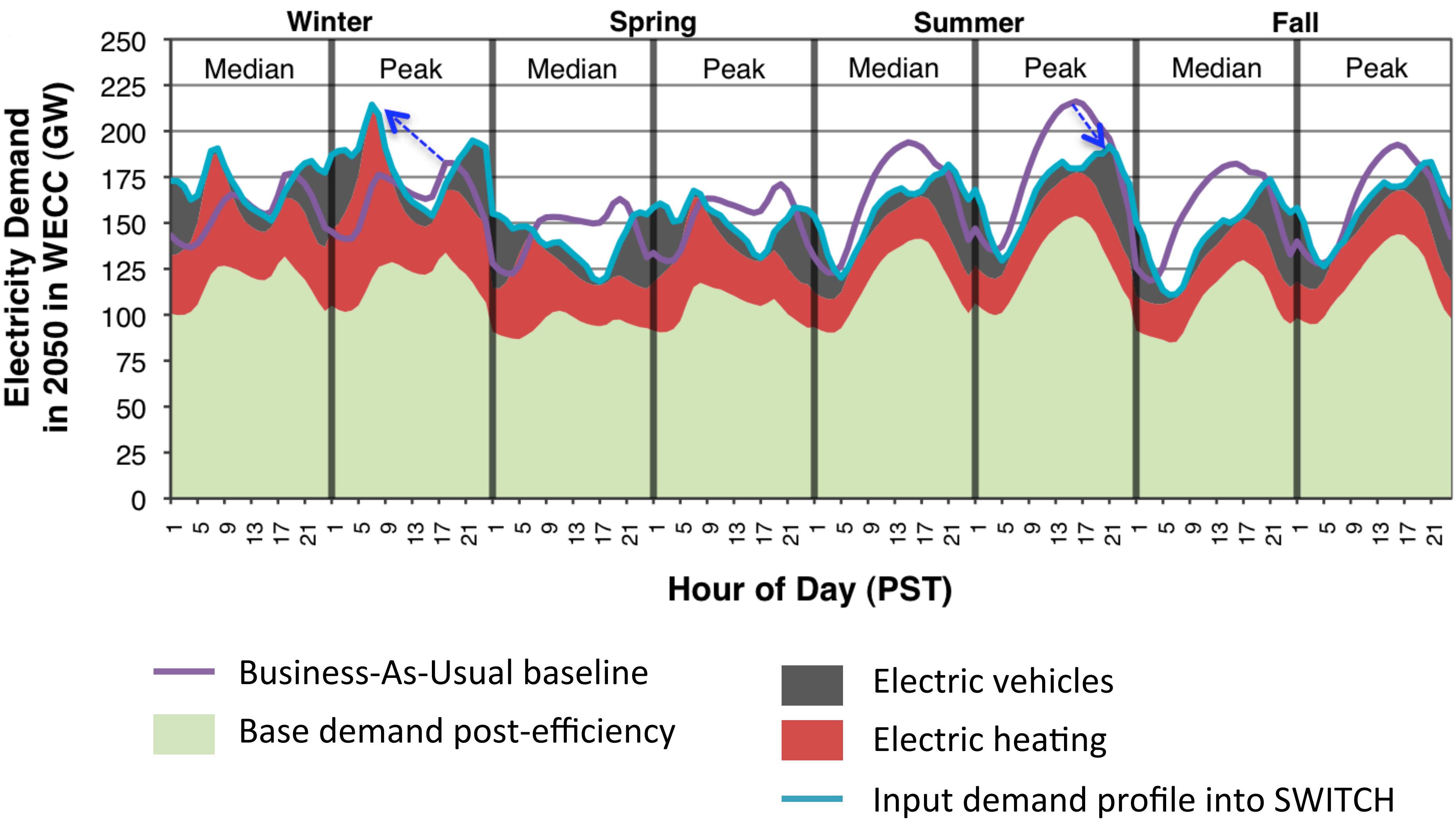


Electricity demand increases despite drastic efficiency



- California demand with drastic efficiency and electrification of vehicles and heating (green curve) increases ~70 % relative to current electricity demand
  - Extra services (transport and heating) provided
  - Electrification creates winter night peak demand

Electrification Creates Winter Nighttime Peak Demand



Wei, M., Nelson, J., Greenblatt, J., Mileva, A., Johnston, J., Ting, M., Yang, C., Jones, C., McMahon, J., Kammen, D., 2013. Deep carbon reductions in California requires electrification and integration across economic sectors. *Environmental Research Letters* 8 (1), 014038.

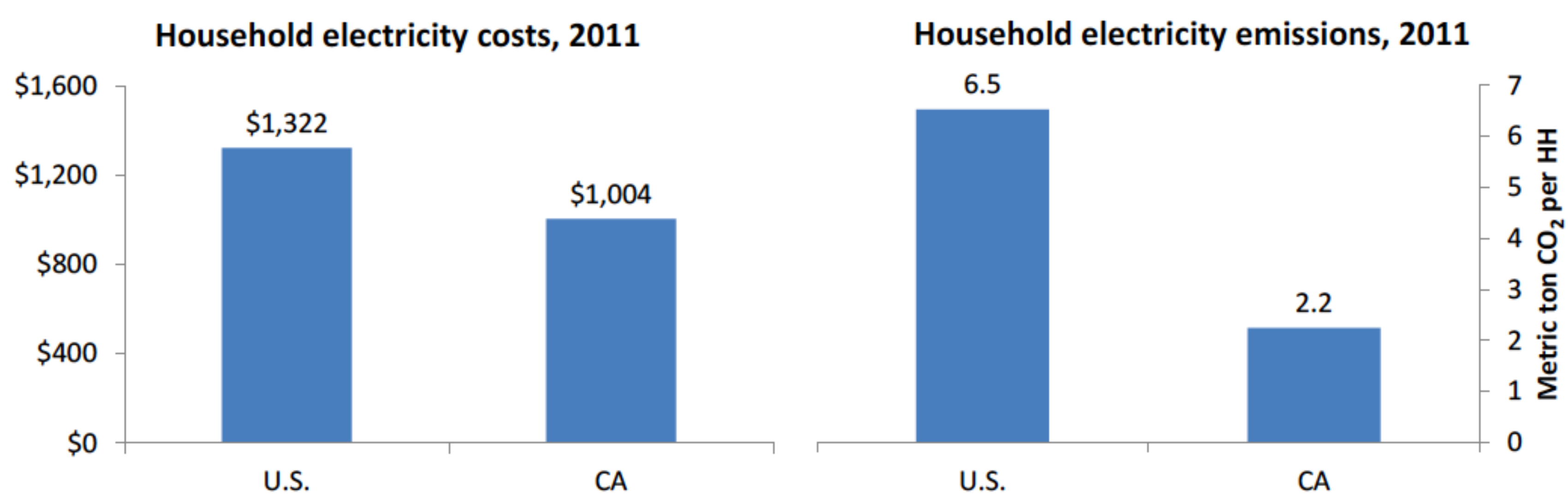
Proposed First Update to the Climate Change Scoping Plan:

Building on the Framework

February 2014

Pursuant to AB 32
The California Global Warming Solutions Act of 2006

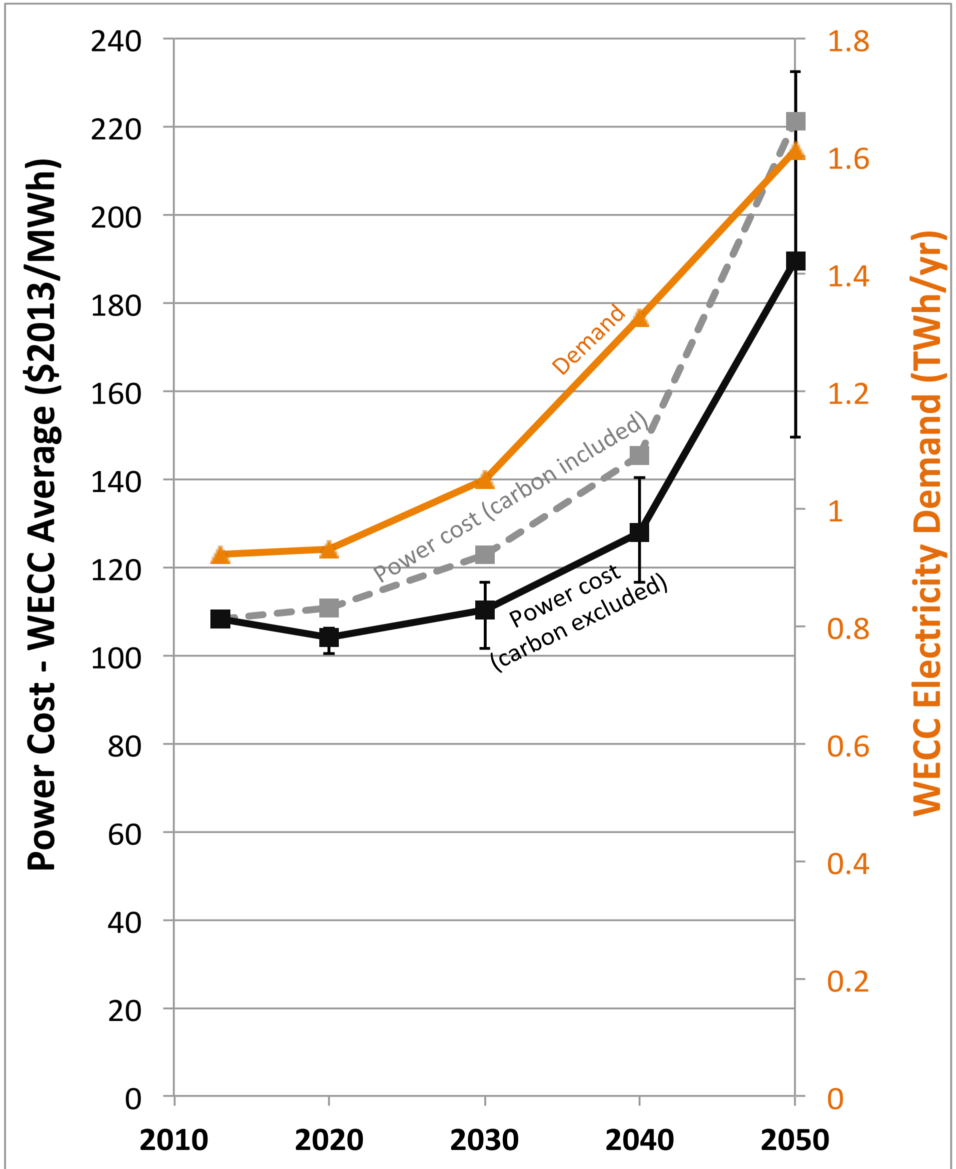
Figure 4: Average Household Expenditures on Electricity and Associated GHG Emissions in the United States and California.[42]



Sources: U.S. Energy Information Administration [EIA] and ARB

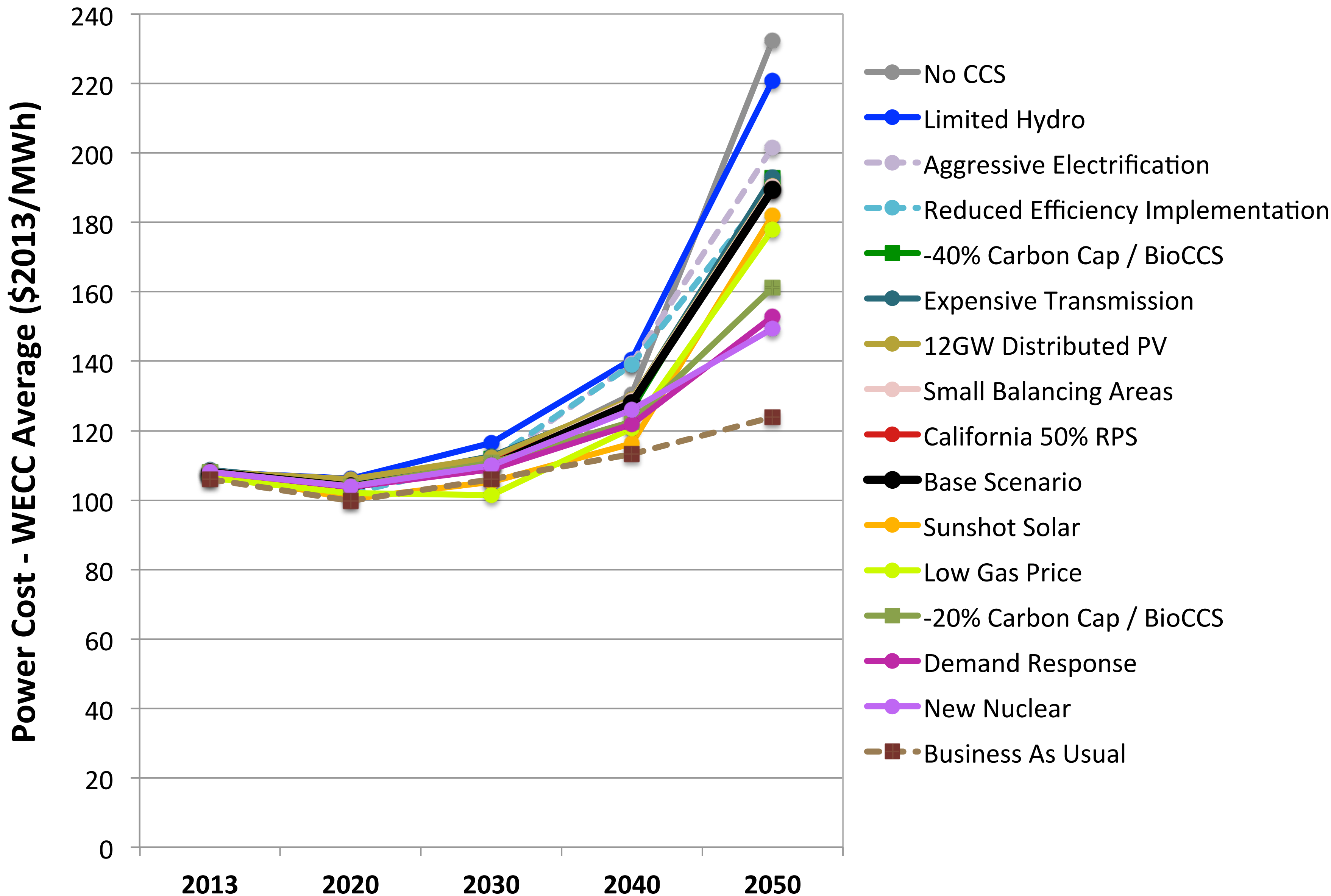
Drastic power system emission reductions by 2050 are feasible under a wide range of possible futures

- Power cost to meet 2030 emissions target:
  - Similar to present day
- Power cost to meet 2050 emissions target:
  - 21 % to 88 % increase from Business-As-Usual
  - 39 % to 115 % increase from present day
- Cost increase is in the context of increasing total demand
- Little technological progress assumed
  - Cost estimates likely represent an upper bound



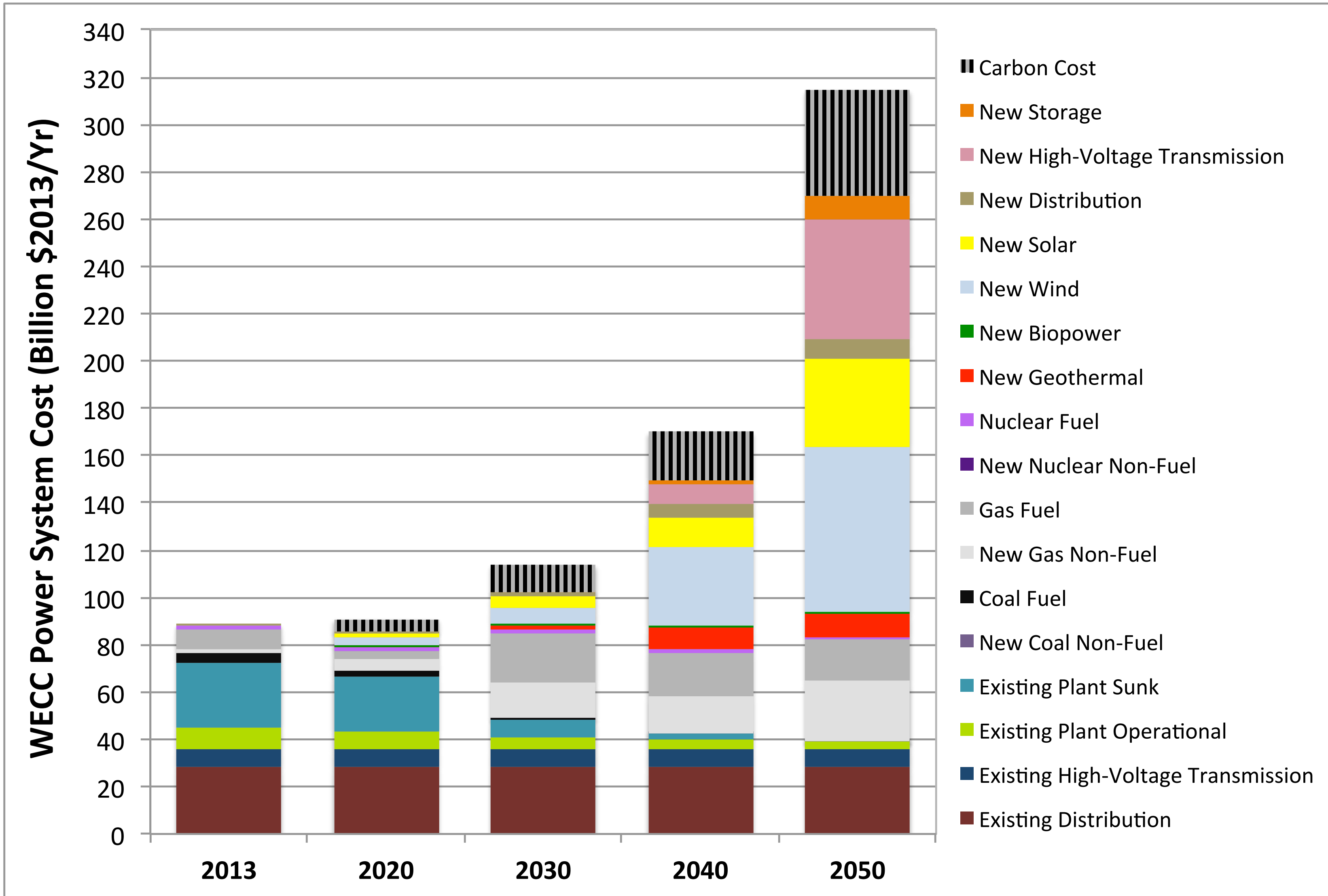
Power cost uncertain but not limiting post-2030

- System flexibility crucial to cost containment by 2050



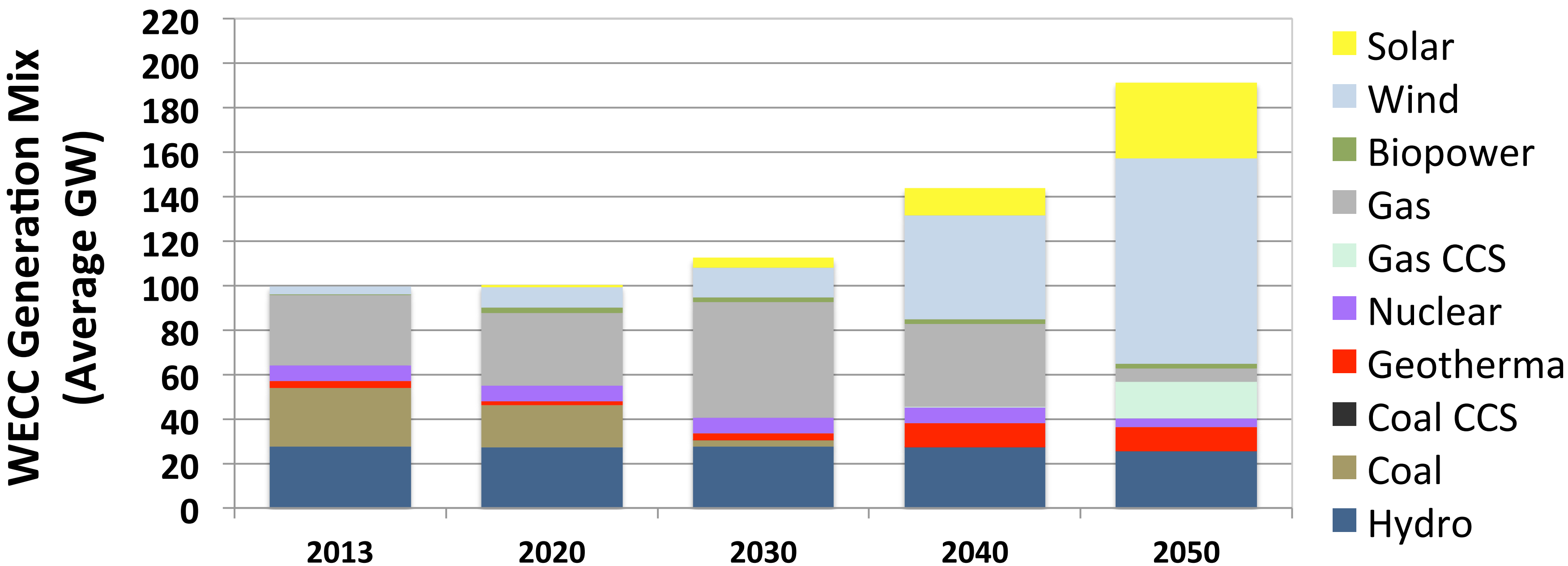
Power system cost increasingly dominated by flexibility rather than energy

- Allocation of carbon revenues also increasingly important



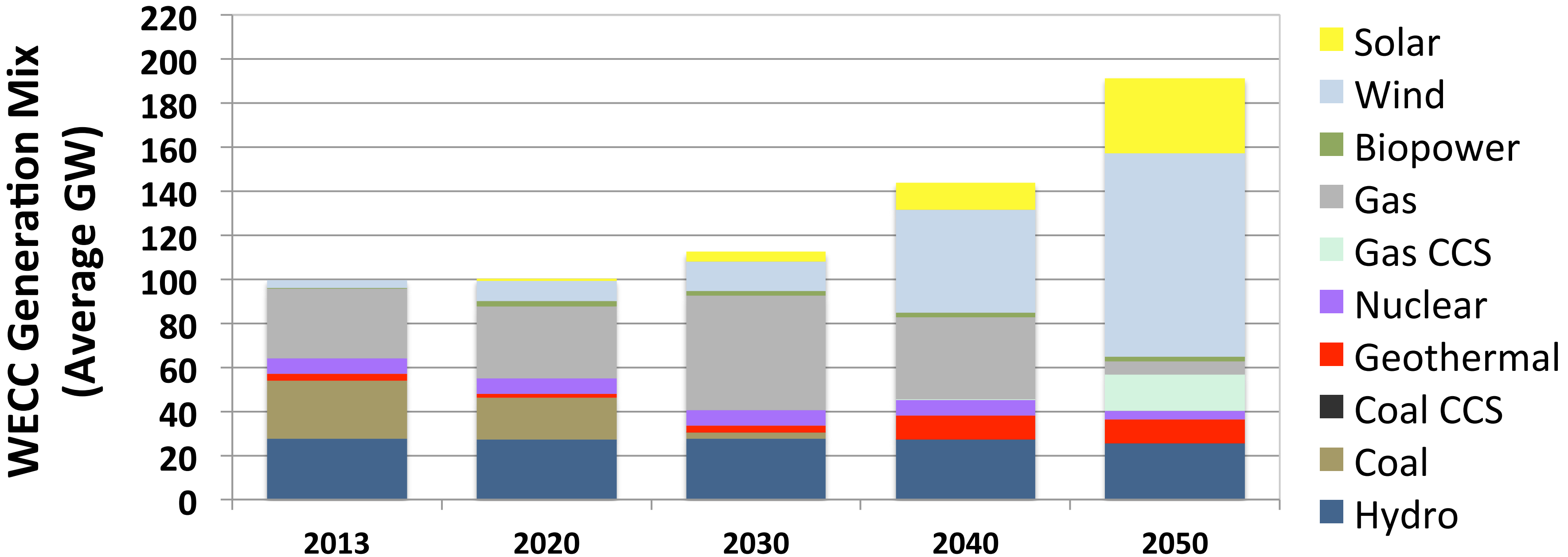
Present day to 2030: efficiency, RPS, coal retirements

- Energy efficiency and retirement of coal creates flexibility in existing power system to integrate wind and solar
  - Little new transmission or storage built
- Coal is replaced with gas and renewables
  - Gas is a source of system flexibility
- Wind and solar deployment driven first by renewable policy targets, then carbon cap post-2020



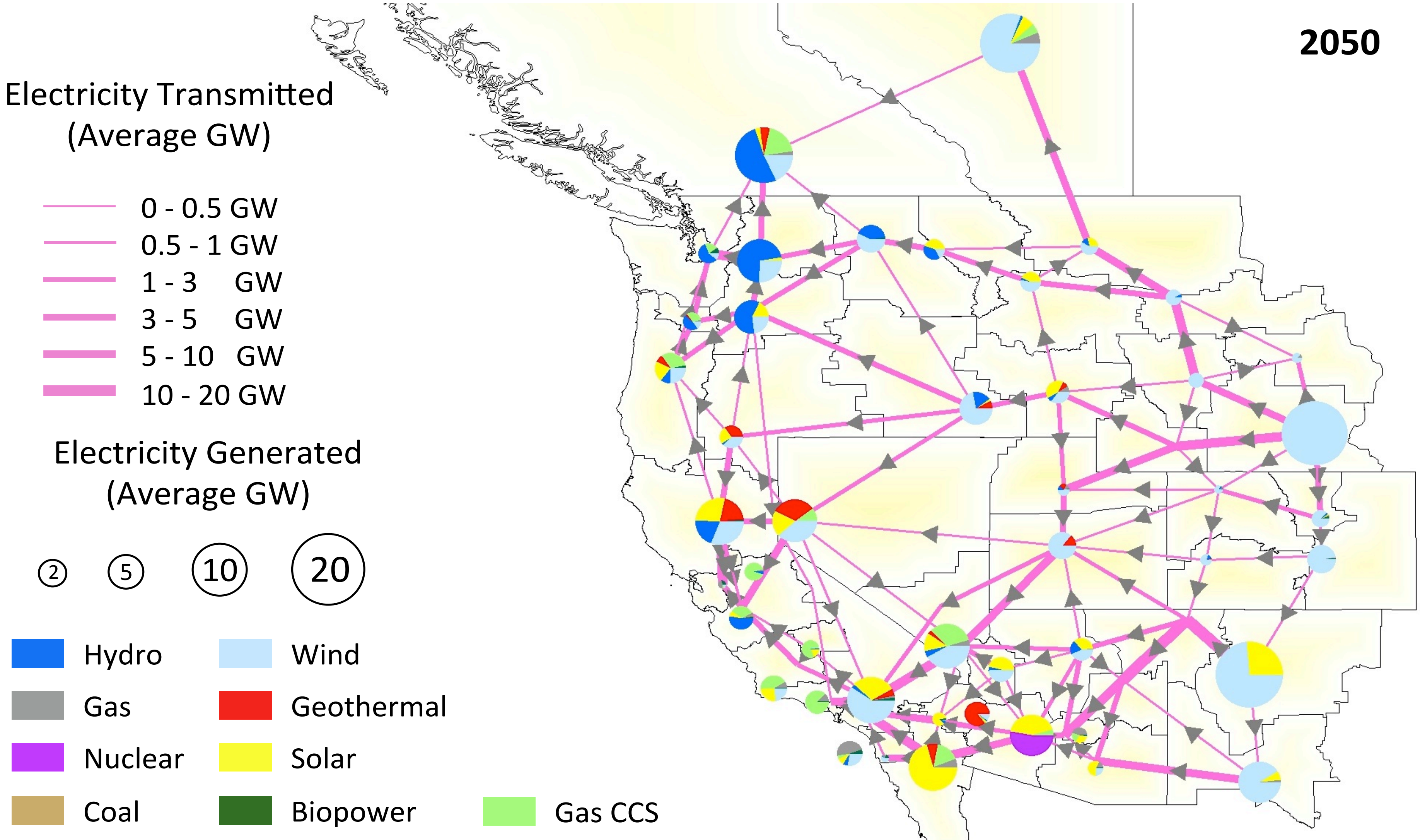
2030 to 2050: renewables, transmission, storage, gas

- Wind and solar key elements in decarbonization
  - 37 – 56 % and 17 – 32 % of energy respectively across WECC
  - Some curtailment – who pays?
- Gas installed capacity relatively constant
  - Capacity factor of non-CCS gas drops precipitously by 2050
  - CCS added to some gas capacity, especially in California
    - Used to integrate variable renewables
    - Gas CCS NOT operated in baseload mode



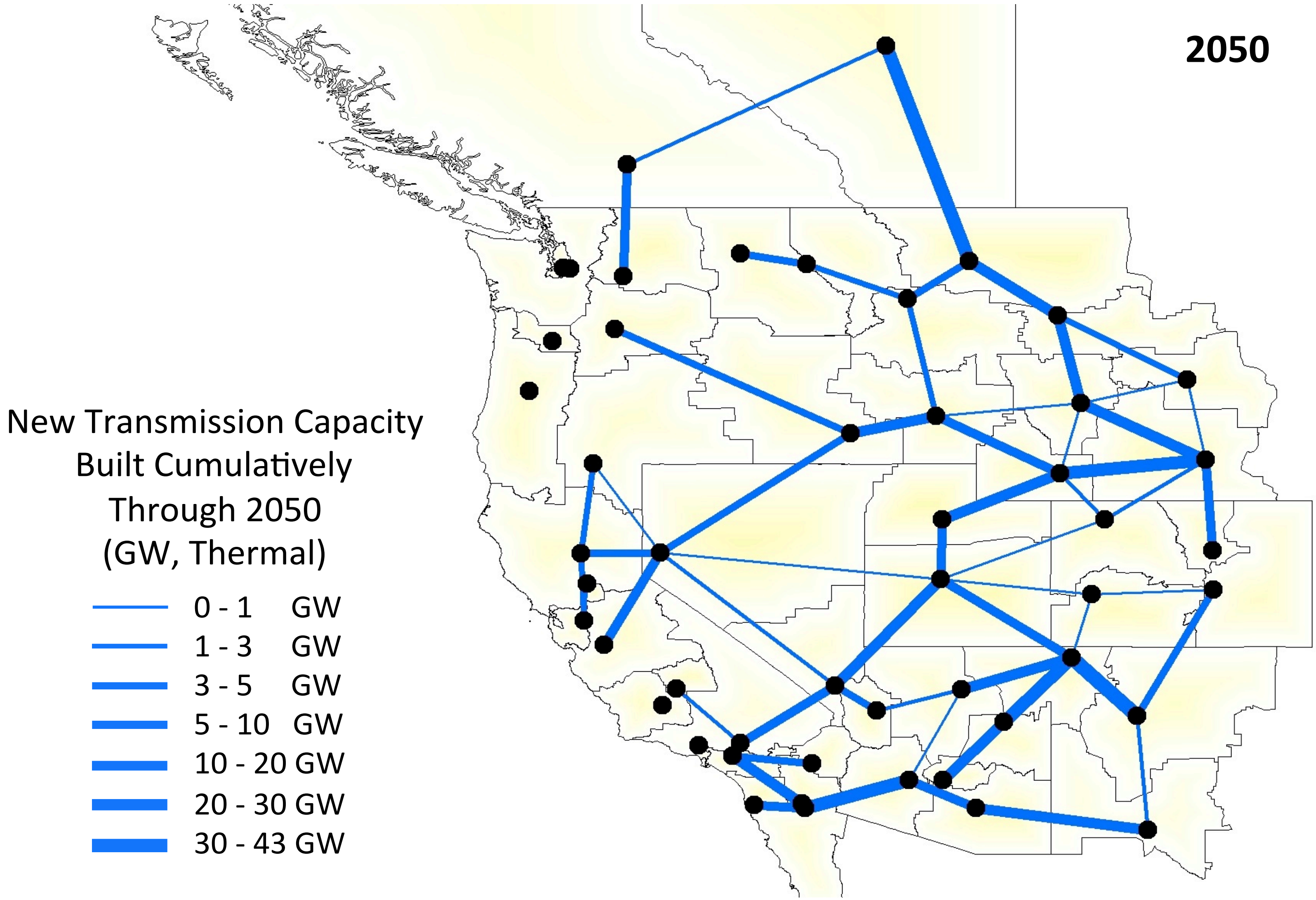
Wind in the east, solar in the south

- Gas CCS deployed mostly in California
- Pacific Northwest hydro not readily available to California
- Wind sent westward towards coast



Transmission built to bring renewables toward coast

- Remote wind is a key driver
- Long distances and high power → DC lines?

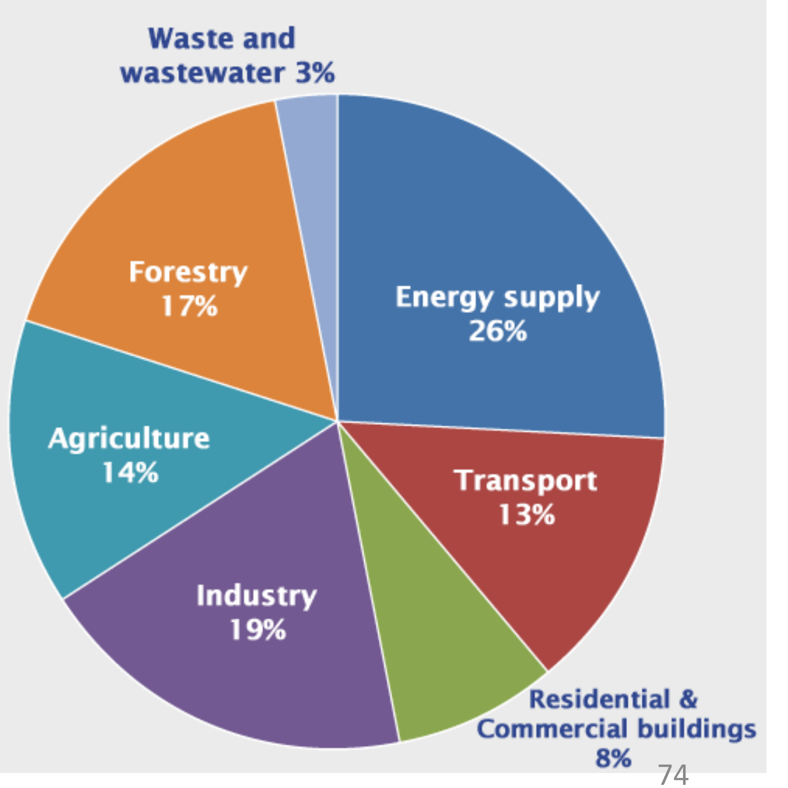


How Leakage Impacts the Role of Natural Gas in a Low-Carbon Grid

Motivation

- Climate change threatens human society
  - Impacts water, food, jobs, conflict, ecosystem services, sea level, …
- Lower emissions critical
- Electricity is biggest slice
- Natural gas can enable clean energy, but leakage could overwhelm benefits

Global GHG emissions by sector, 2004



IPCC 2007

Natural Gas Roles

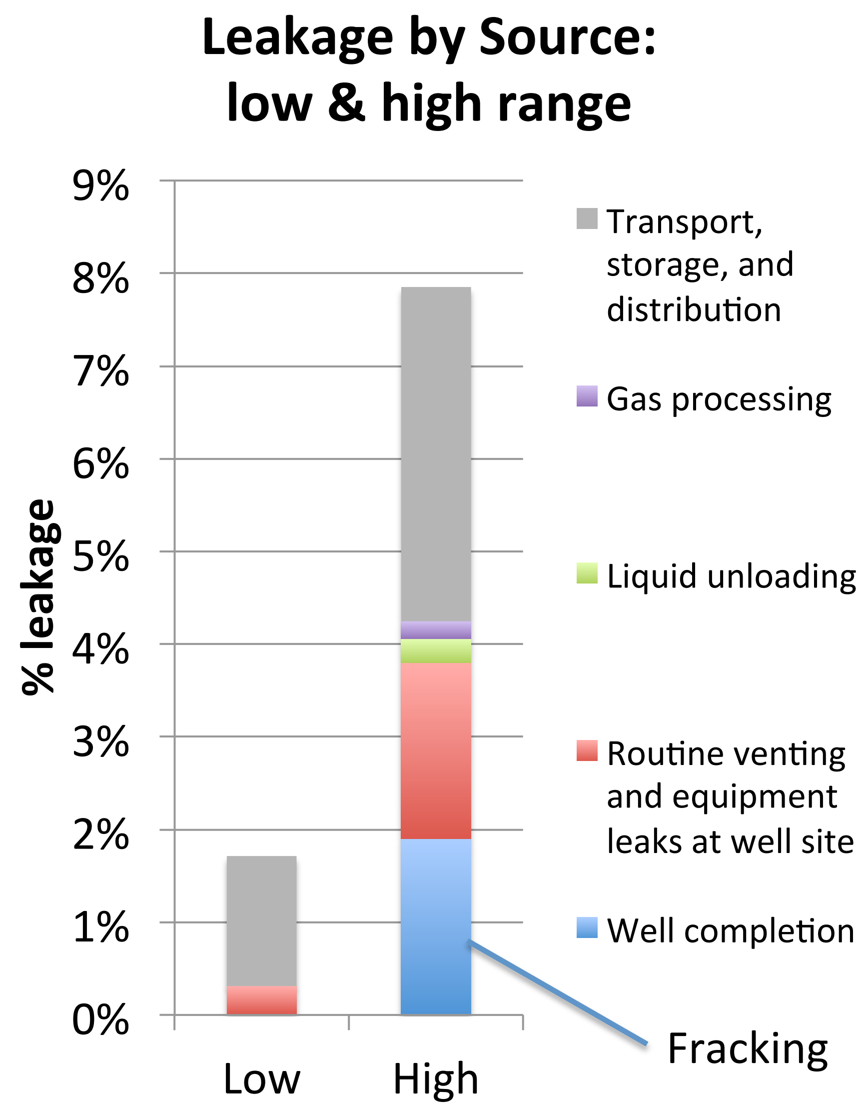
- Flexibility can compensate for variability and uncertainty of renewable energy
- Replacement for coal with less than ~½ the CO_2 emissions

- However -

- Leakage of CH4 ranges from 1.7-7.9%, enough to change the story…

Natural Gas Leakage

- Estimates vary
  - 1.7-7.9% bottom-up estimates. Howarth, 2010.
  - 2.3-7.7% overall atmospheric measurements, Pétron, 2012.
  - 1.5%. EPA, 2012



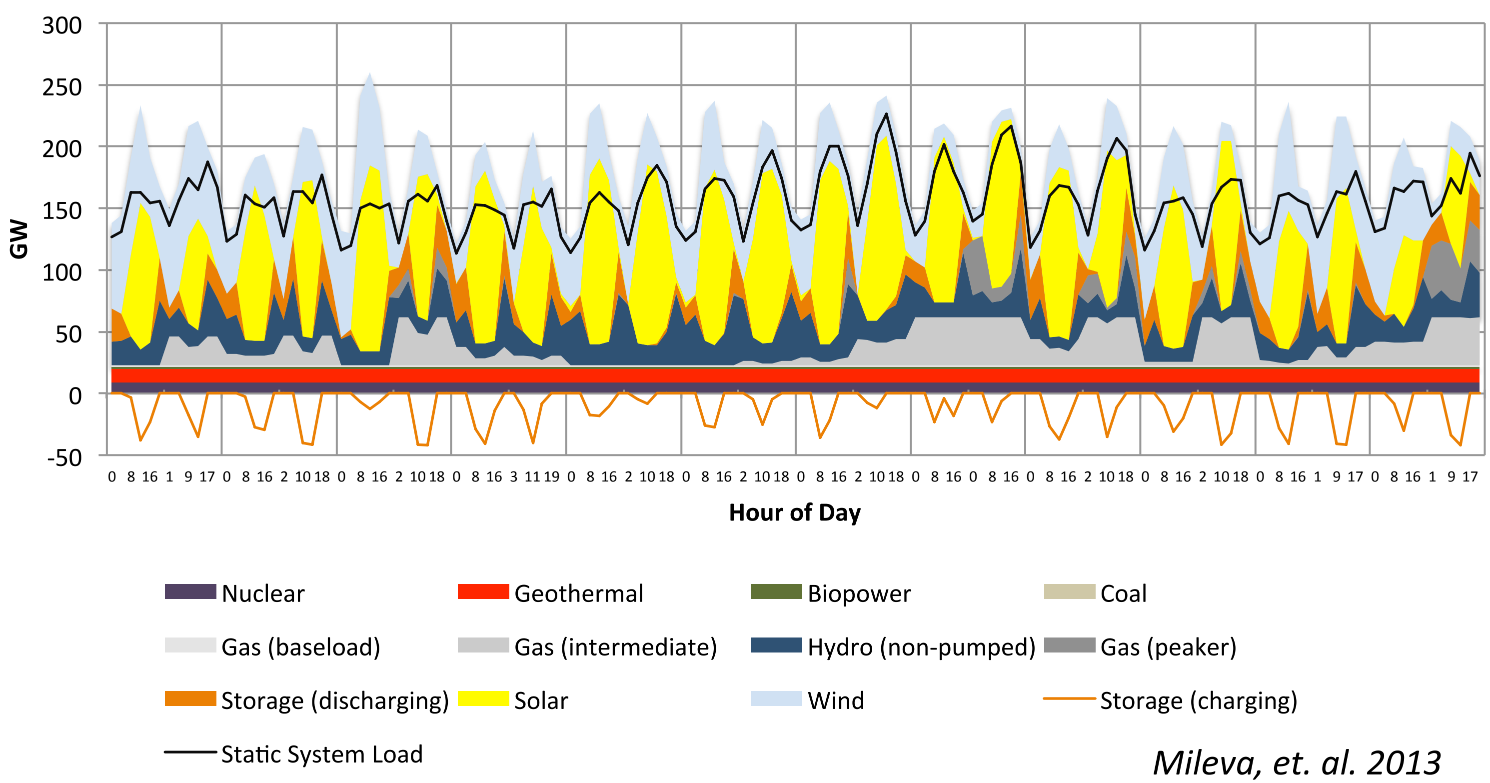
Howarth, 2010.

Methodology

- Assign emissions from supply-chain leakage to electric generation in SWITCH
- Run scenarios with a range of leakage values to understand dynamics and trade-offs
- Sensitivity: Change key factors & repeat, see how dynamics shift
  - Low-carbon baseload (CCS)
  - Cheap, low-carbon flexibility
  - Cheap renewables
  - Altered emissions cap
- Estimate value of installing leak control equipment based on system cost reduction of lower leakage rate. Compare to cost of leak control equipment (if costs are available).

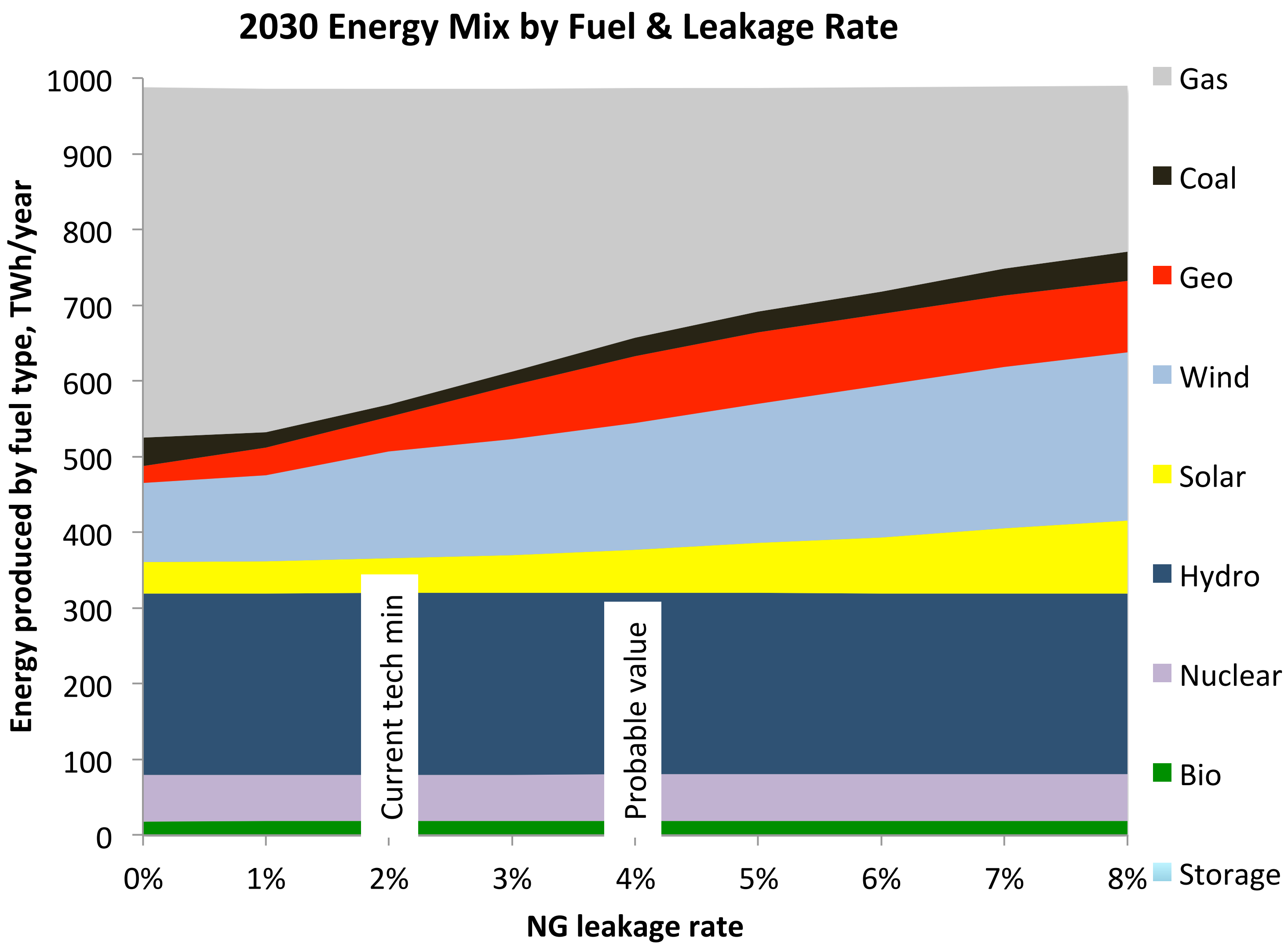
Brief review of generation roles

- Baseload – reduces magnitude of remainder
- Intermittent – Use it or lose it
- Flexible – satisfy remainder

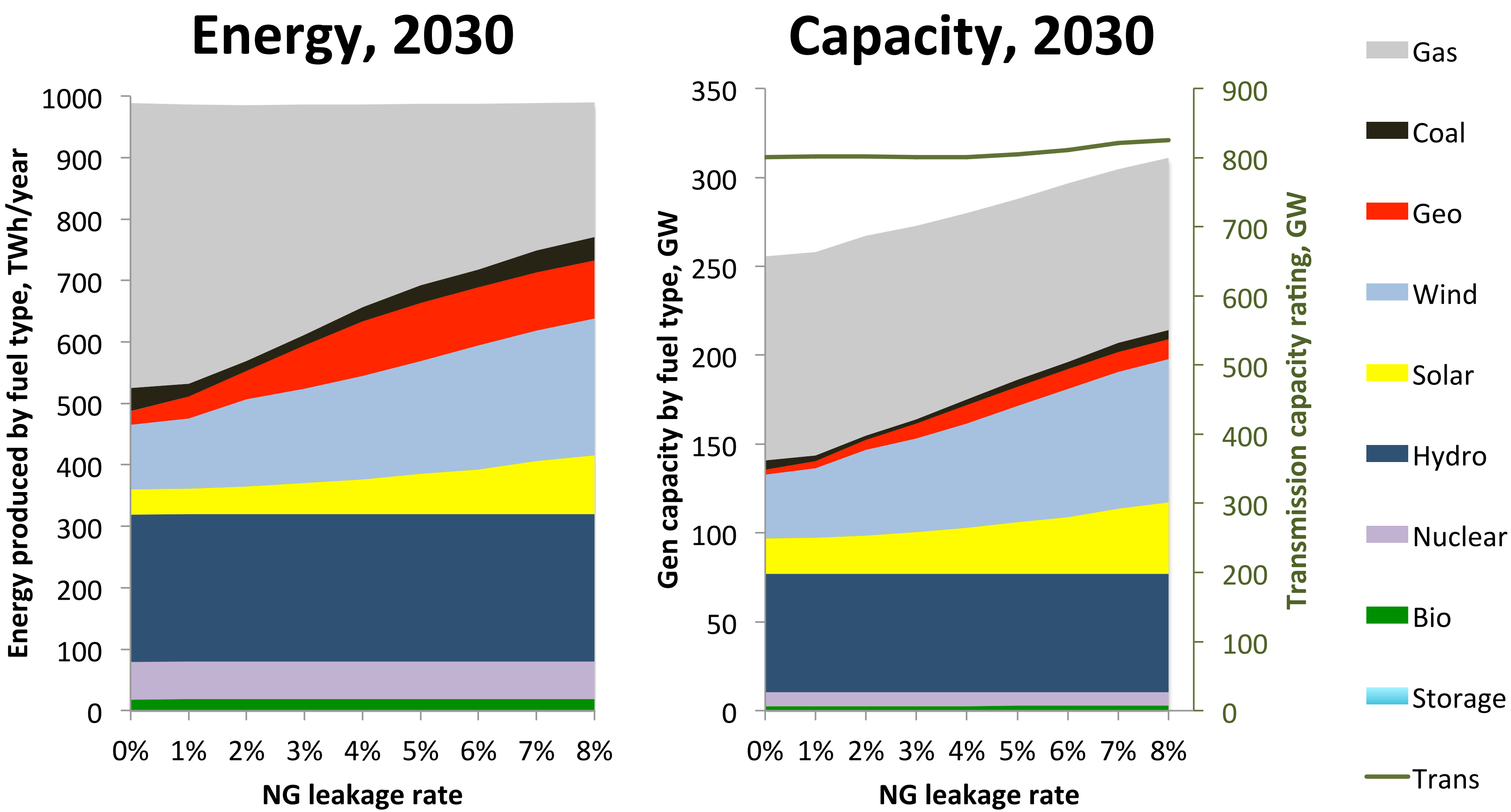


Mileva, et. al. 2013

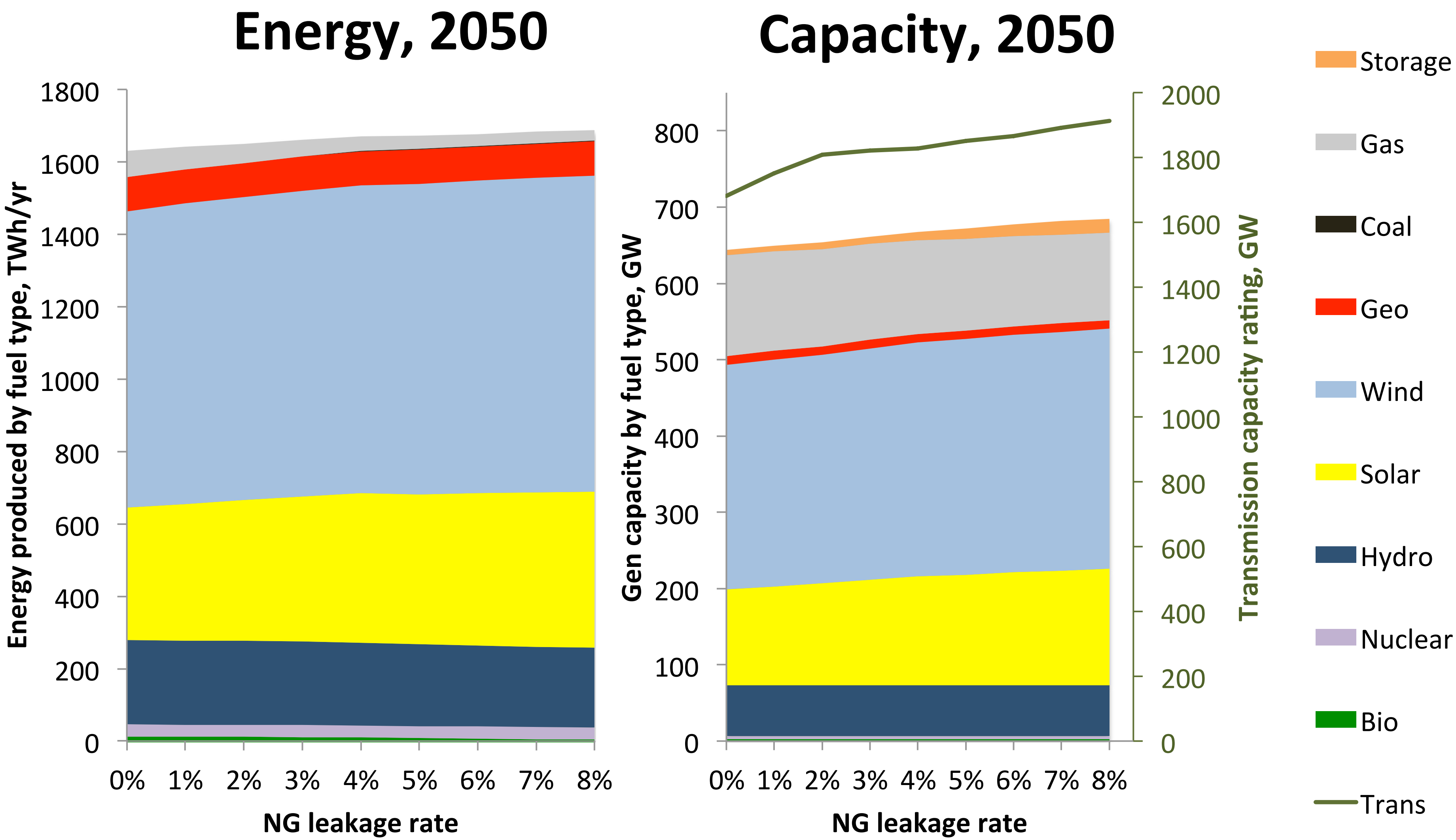
Base Results: 2030



Base Results: 2030

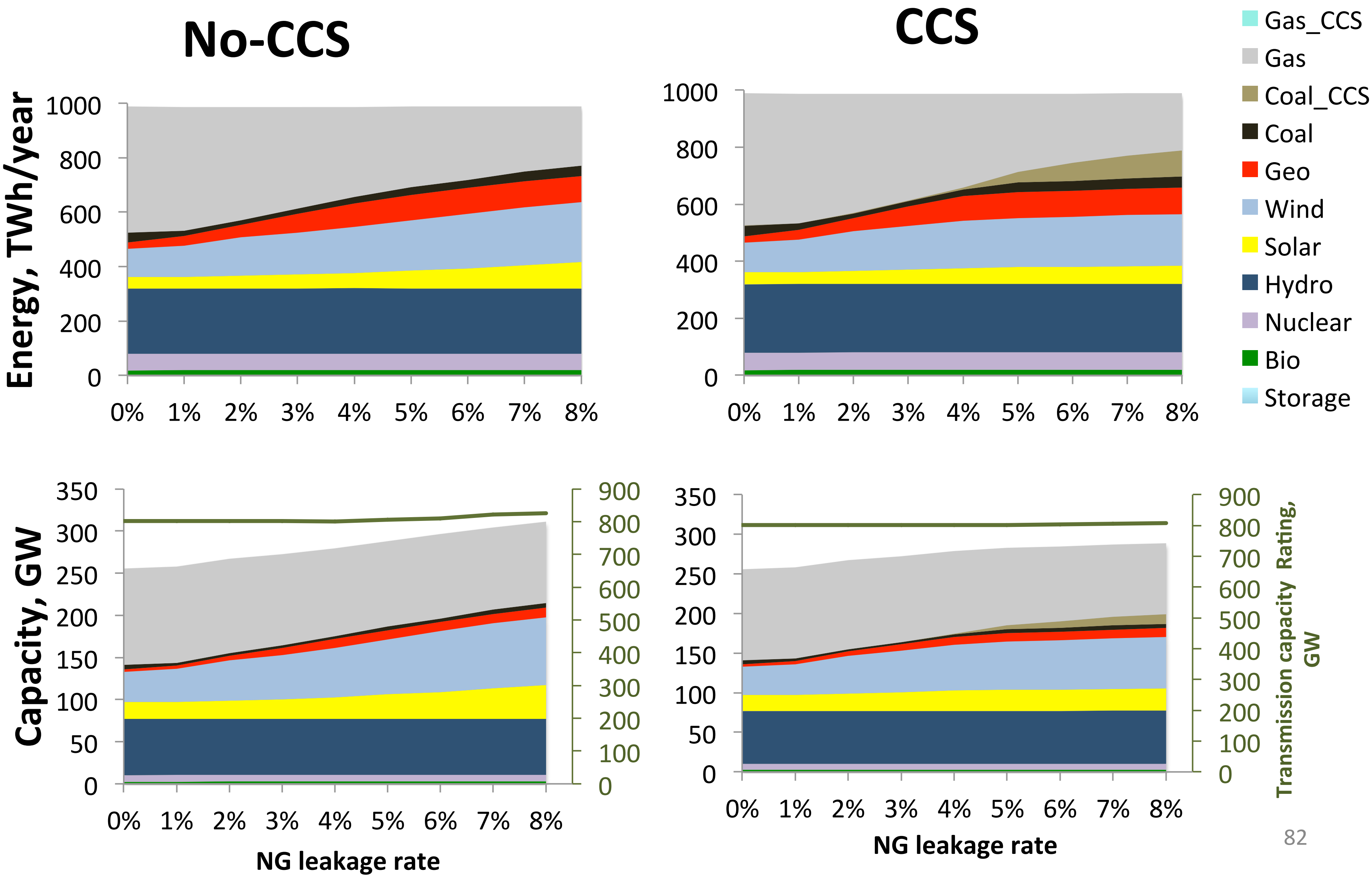


Base Results: 2050



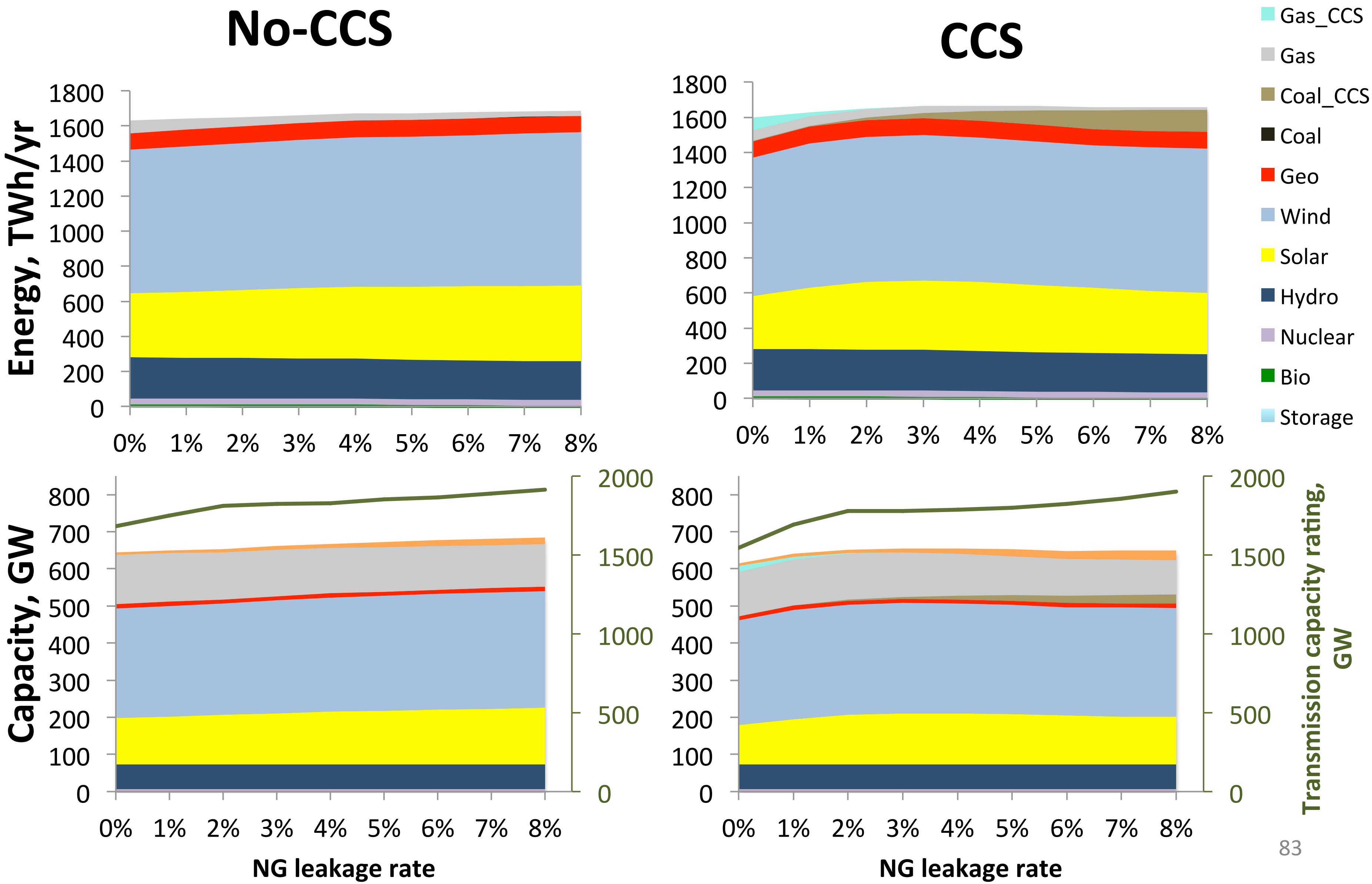
Low-Emission baseload sensitivity:

CCS Results: 2030



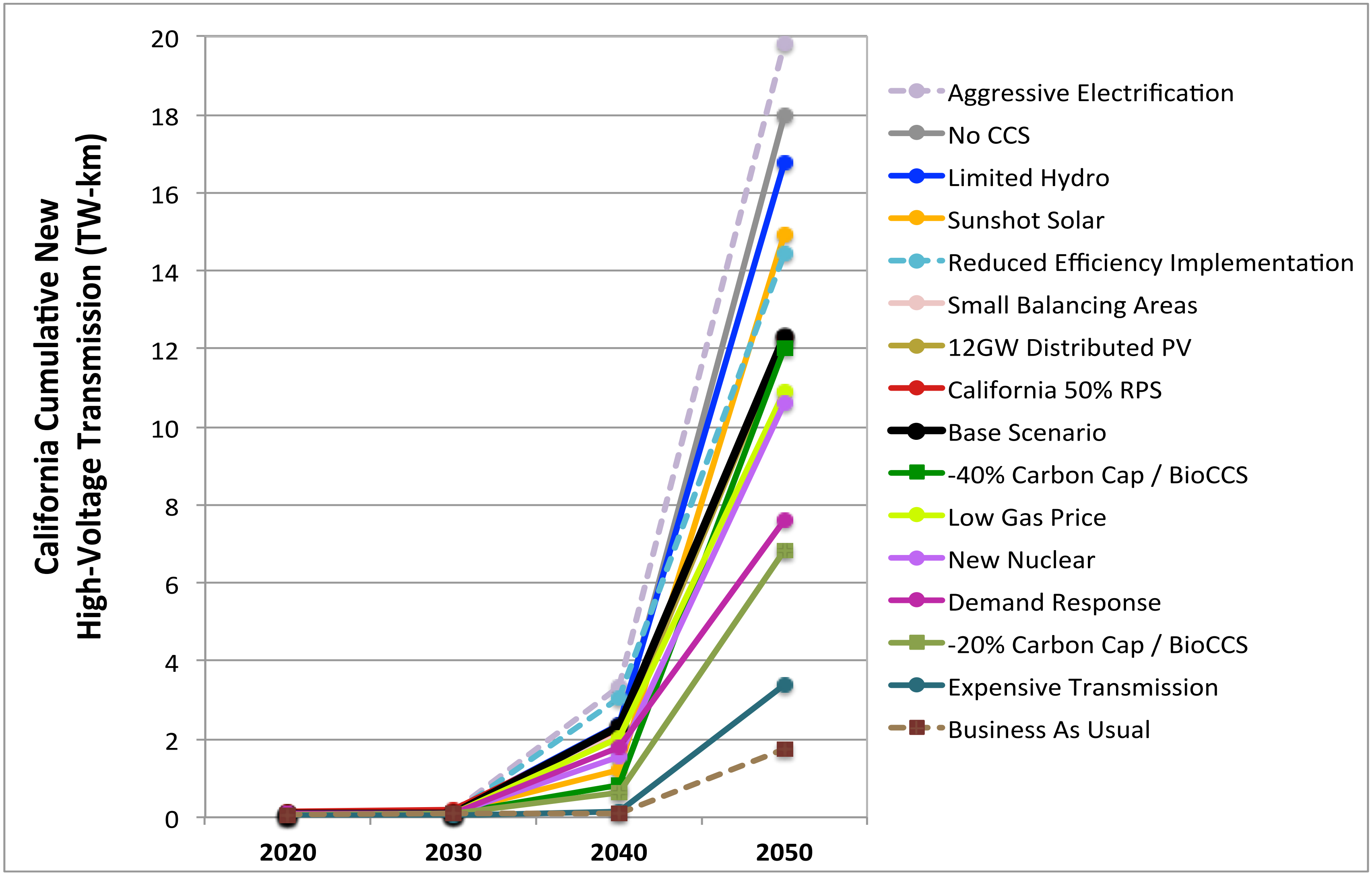
Low-Emission baseload sensitivity:

CCS Results: 2050



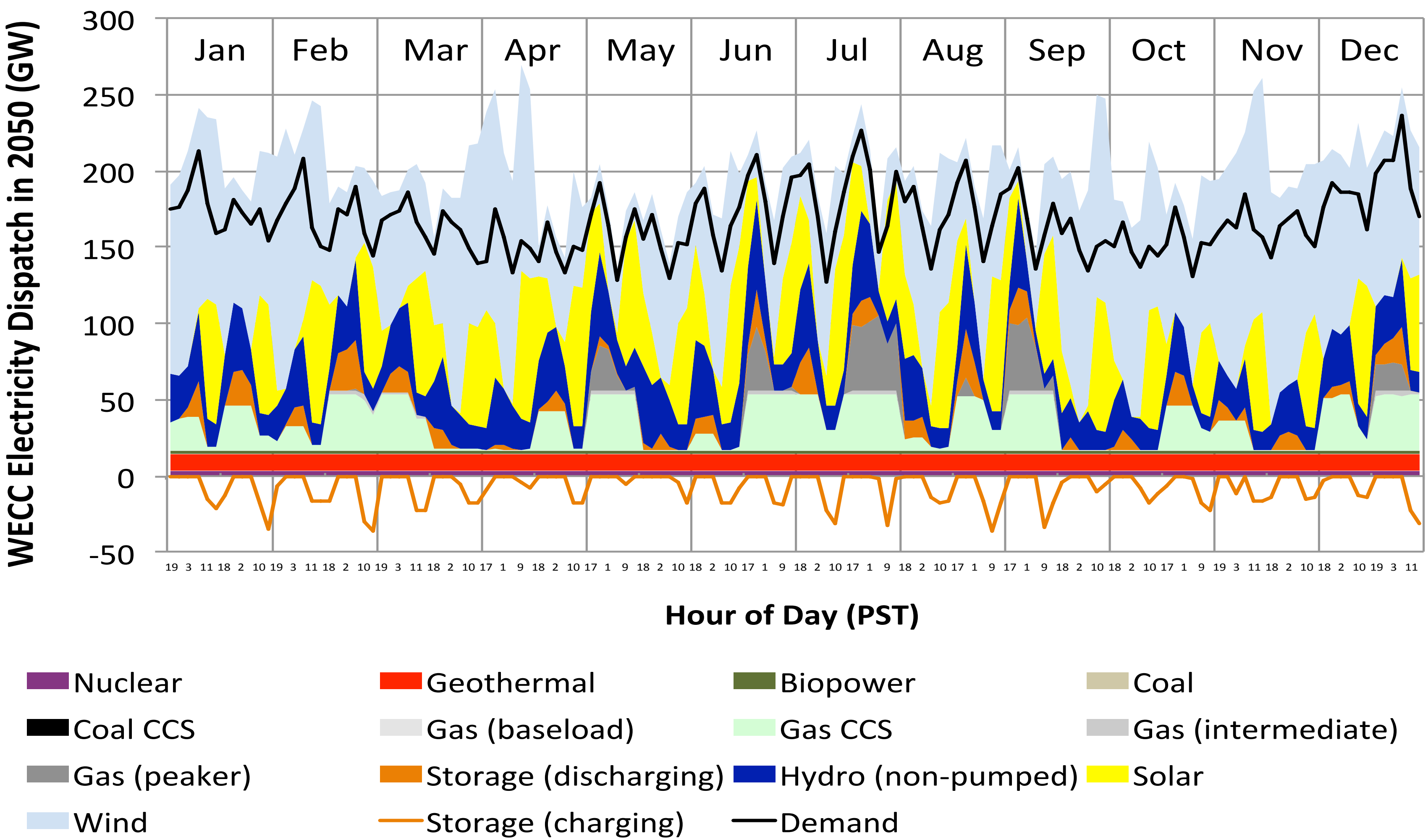
New transmission highly dependent on assumptions

- Planning under uncertainty important
- Expensive transmission increases storage and gas CCS



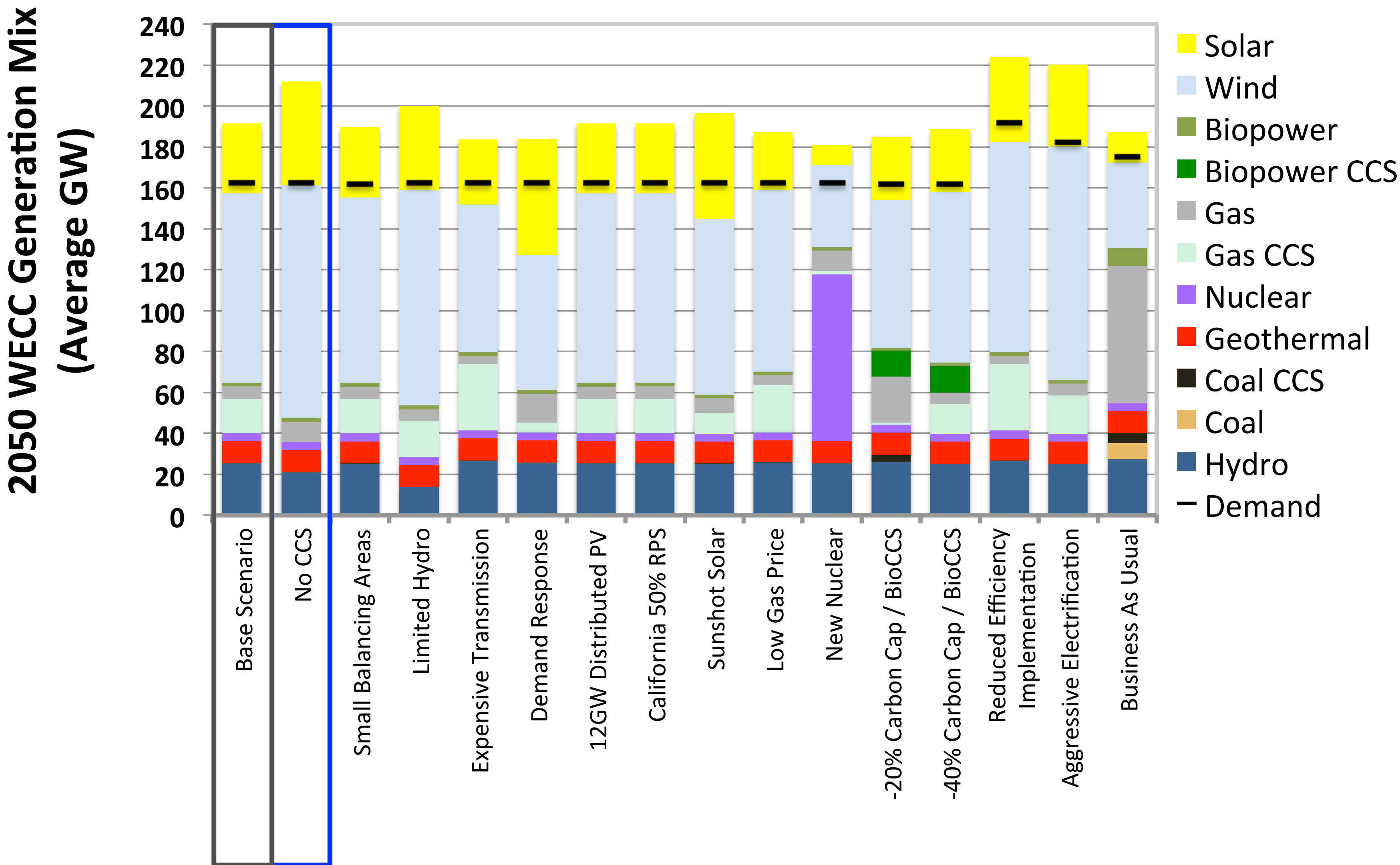
Dispatch in 2050: Flexibility and variable renewables dominate

- Storage almost exclusively moves solar to the night
- Geothermal only remaining substantial baseload



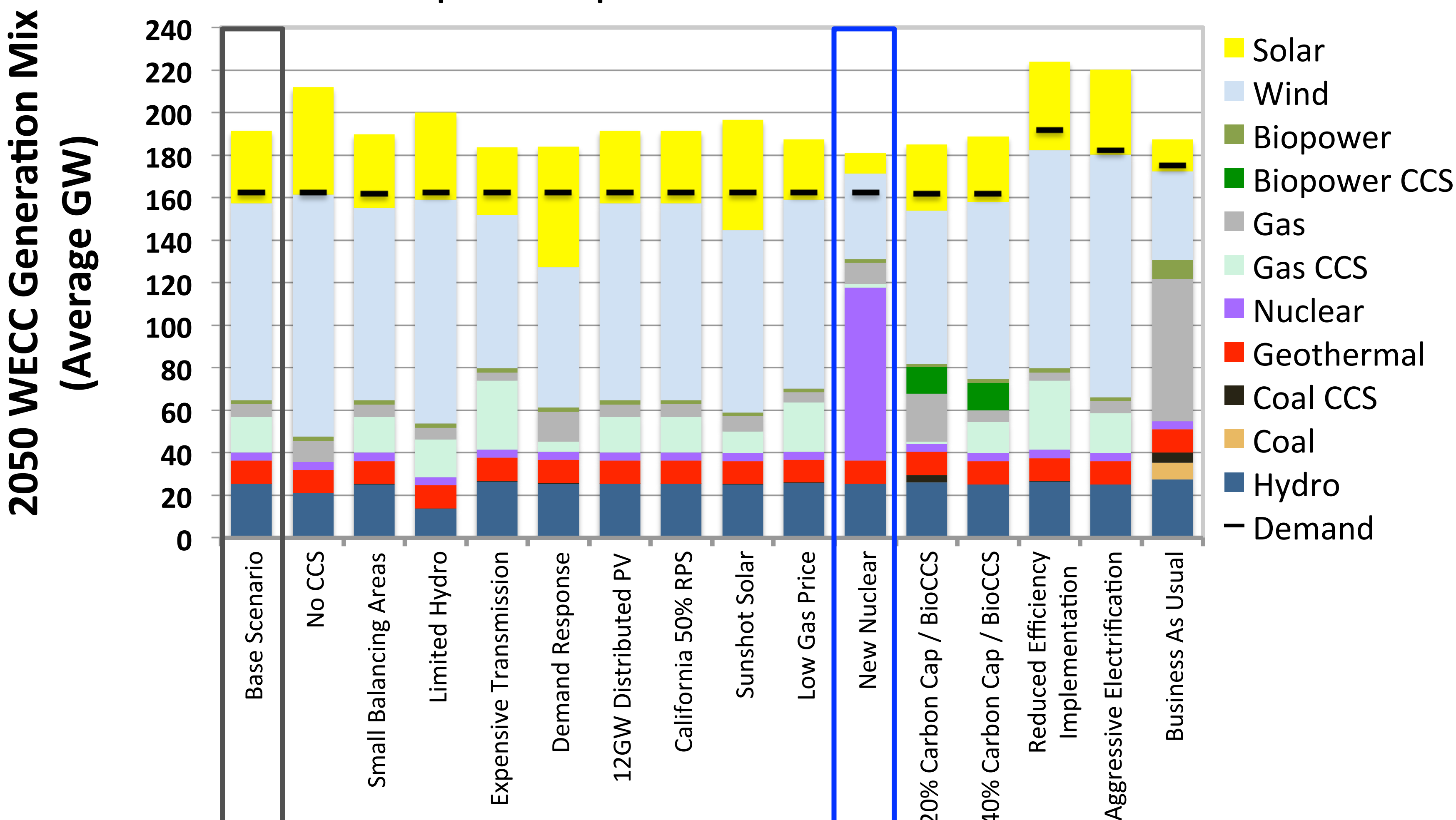
Drastic emission reductions possible without nuclear, CCS, or bioelectricity

- > 70 % of energy from wind and solar
  - Balancing and planning fundamental to keep costs reasonable



Nuclear Imports? Economical but…

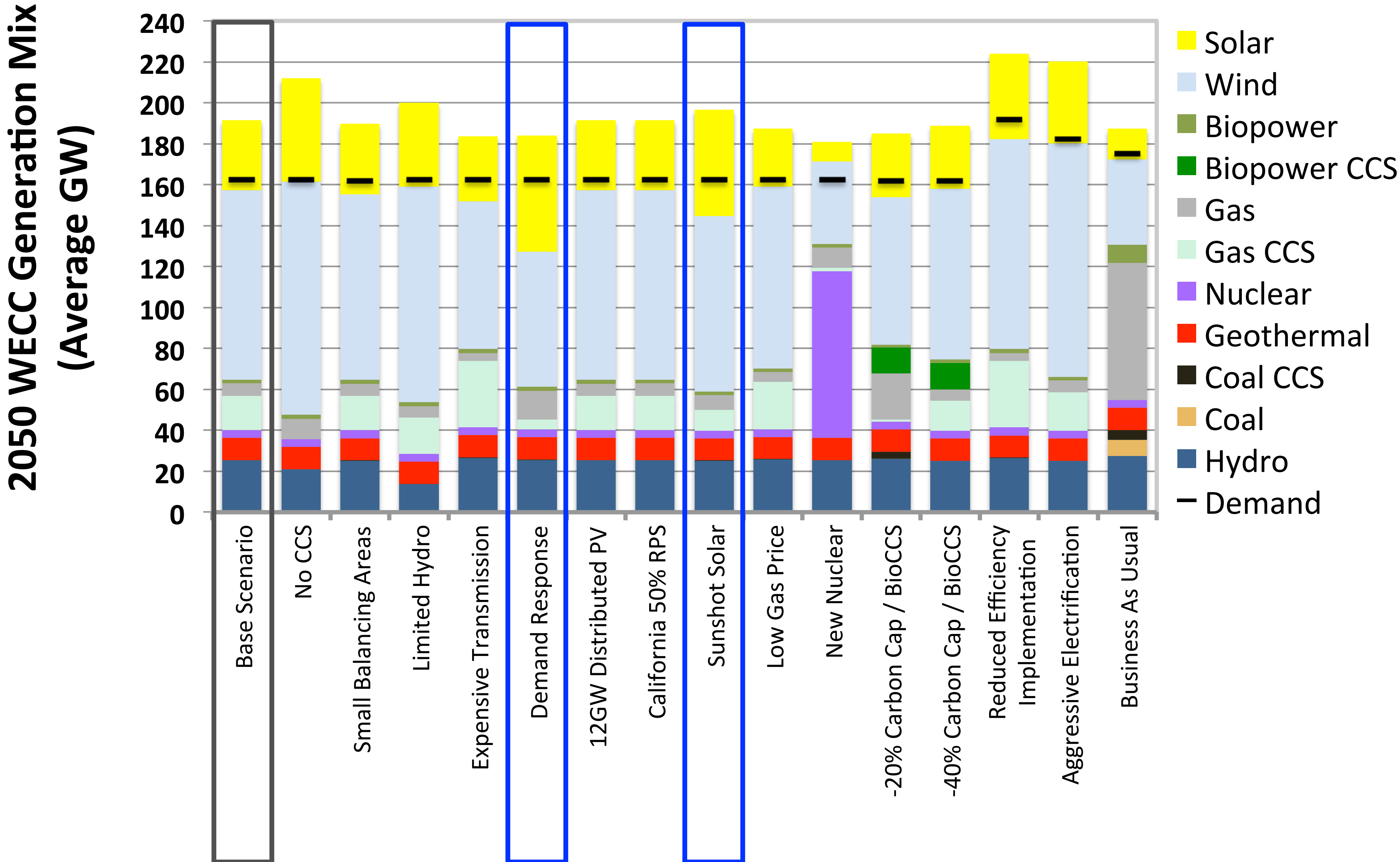
- Out-of state-nuclear economical at $6.4/W ($2013)
  - Economics not the only factor for nuclear
  - Fraction of imported power in California > 50 %



Almost all California imports are nuclear

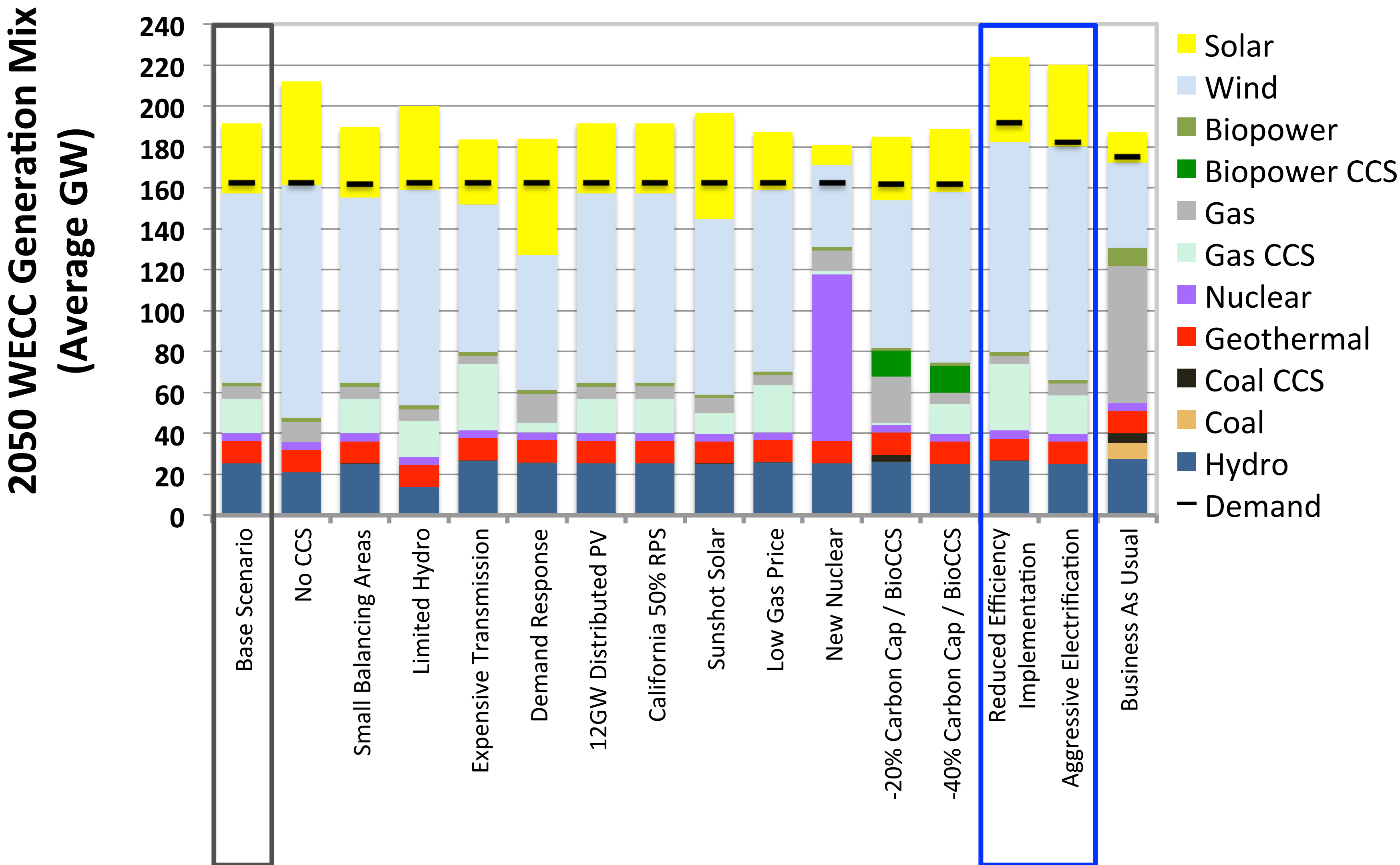
Demand response incentivizes solar… more than inexpensive solar capital costs!

- Integration costs dominate at large fractions of solar
  - Inexpensive storage (not investigated here) would likely incentivize solar



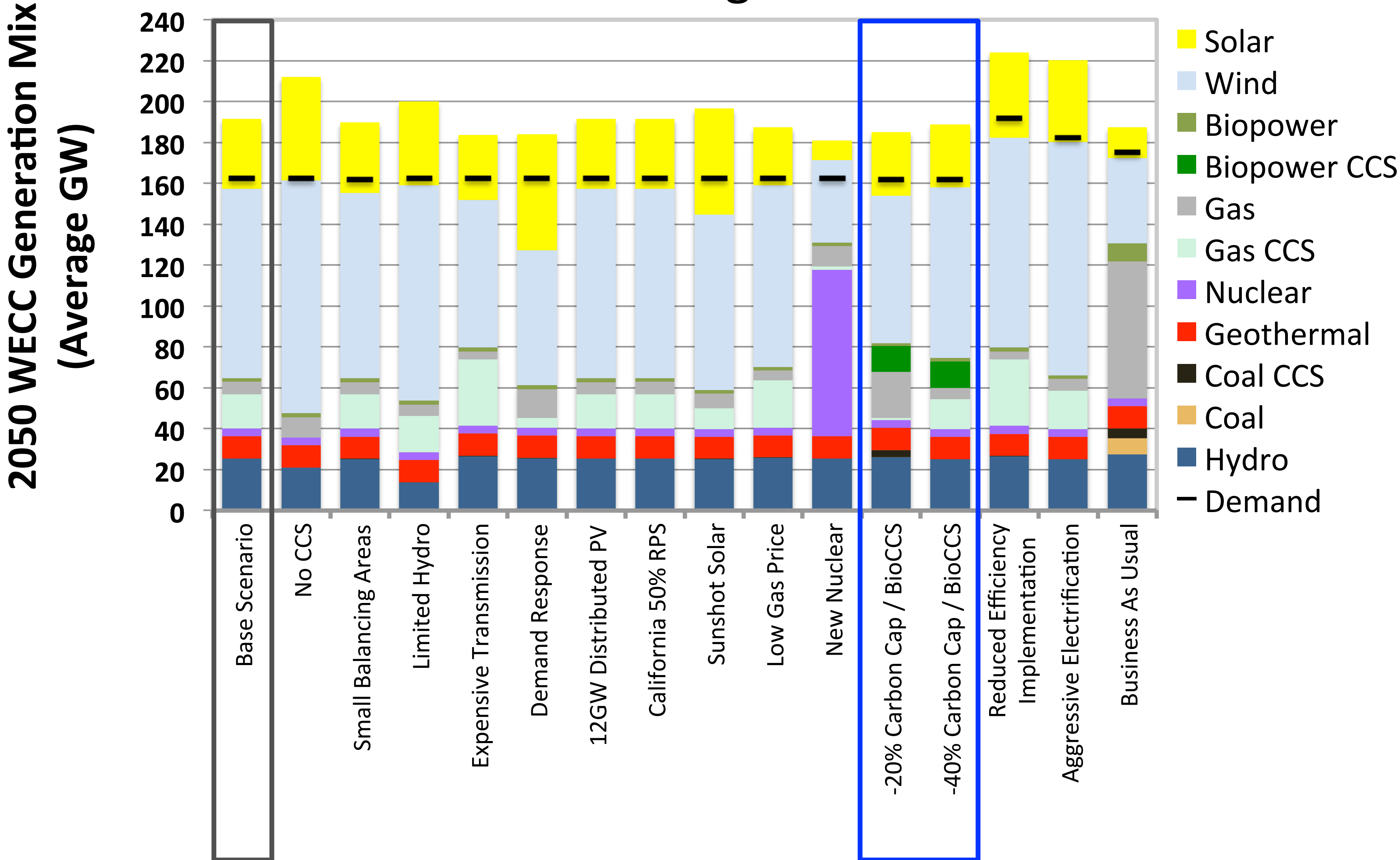
Generation mix composition relatively insensitive to demand magnitude

- Solar and wind increased to meet carbon cap

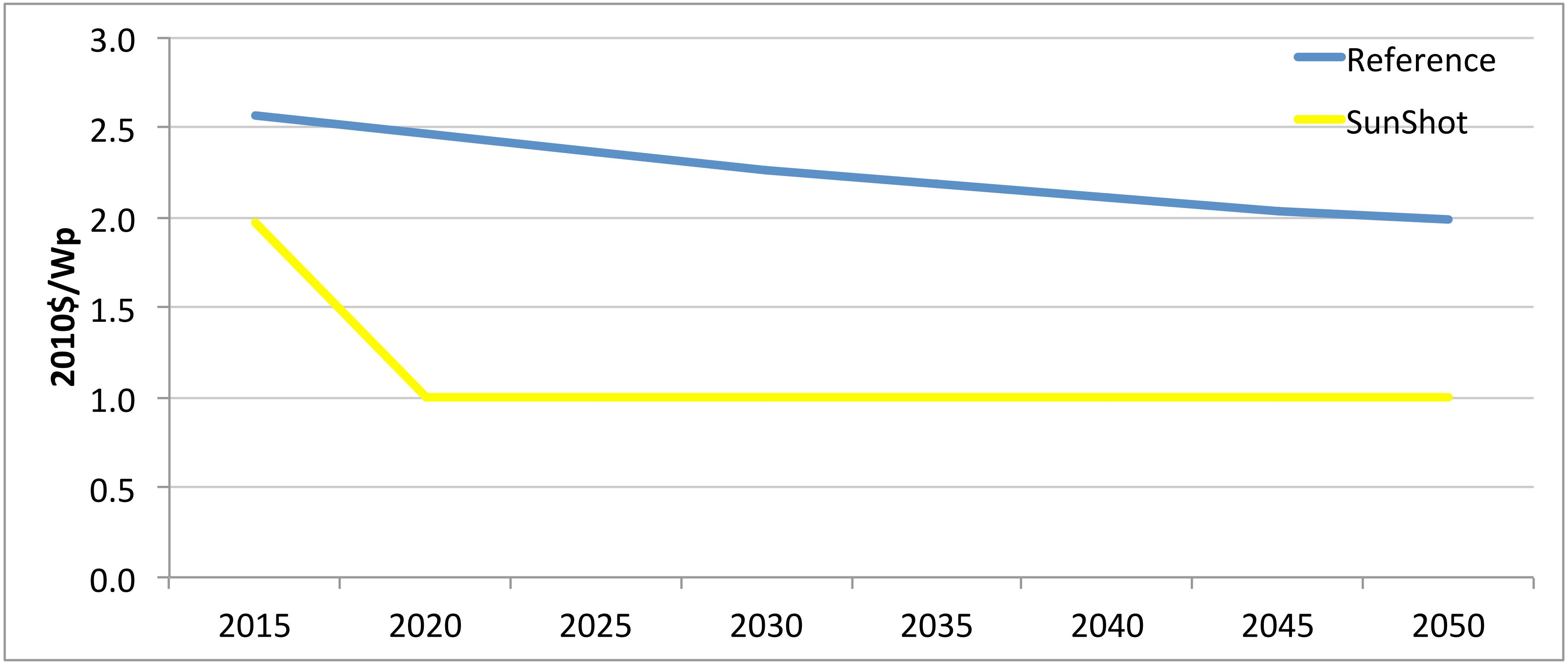


Biomass CCS can provide net negative emissions

- BioCCS increases allowable emissions in the electric power sector and/or other sectors of the economy
- Electric sector cost of reaching -40% emissions is moderate



Capital Cost of Solar Technologies



Source: Black & Veatch (Reference)
Department of Energy SunShot Program (SunShot)

SunShot Solar Deployment

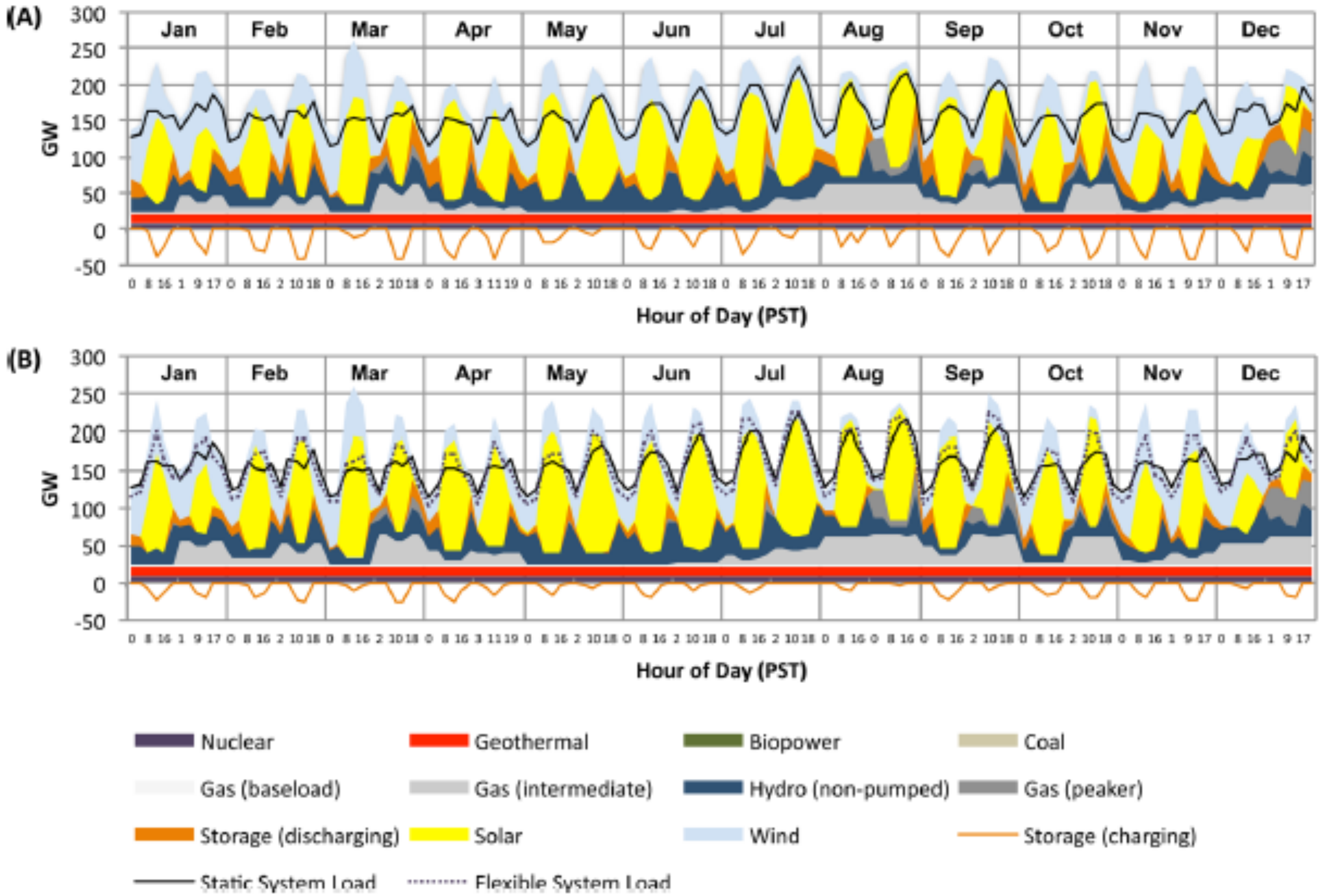
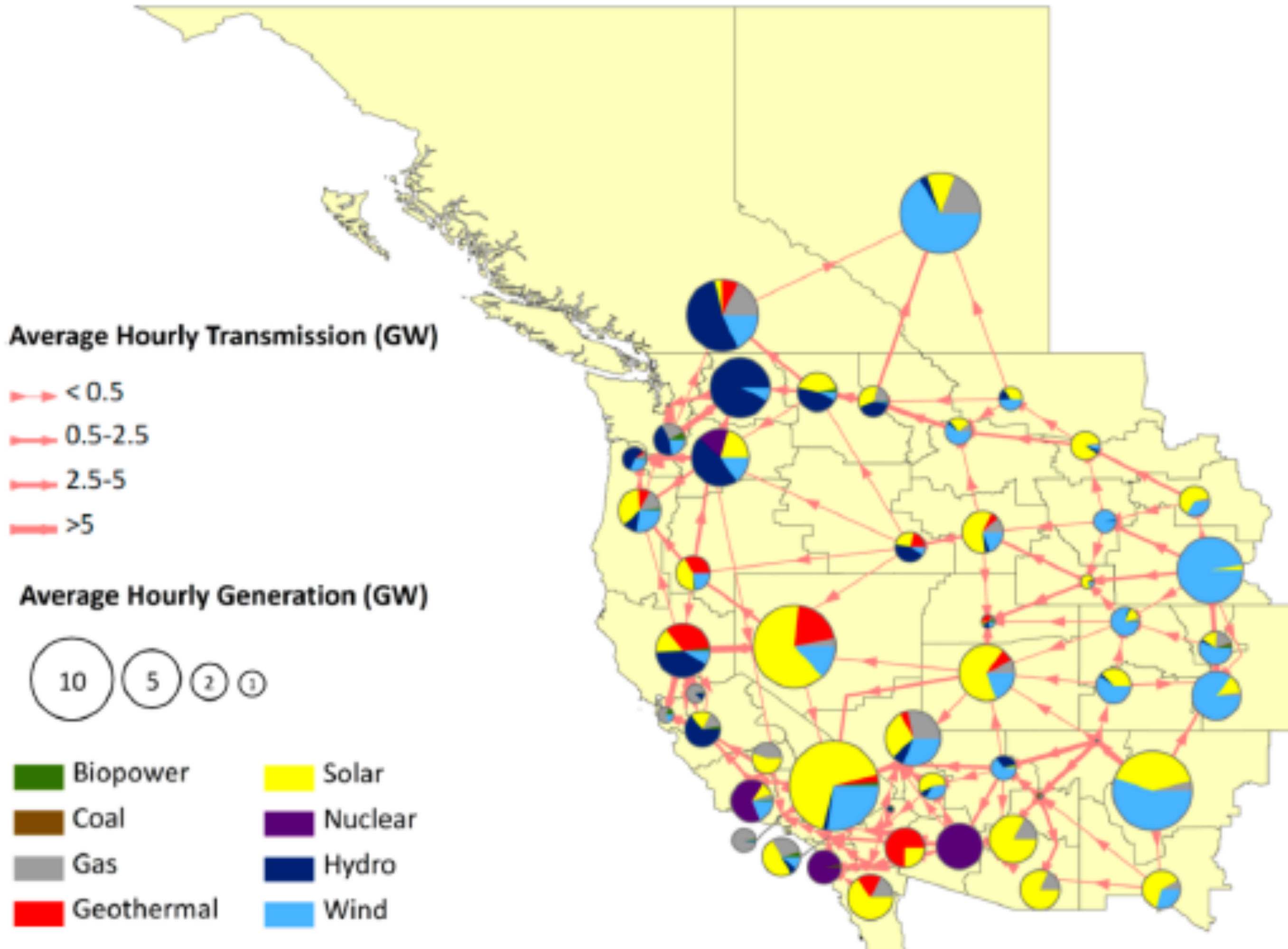
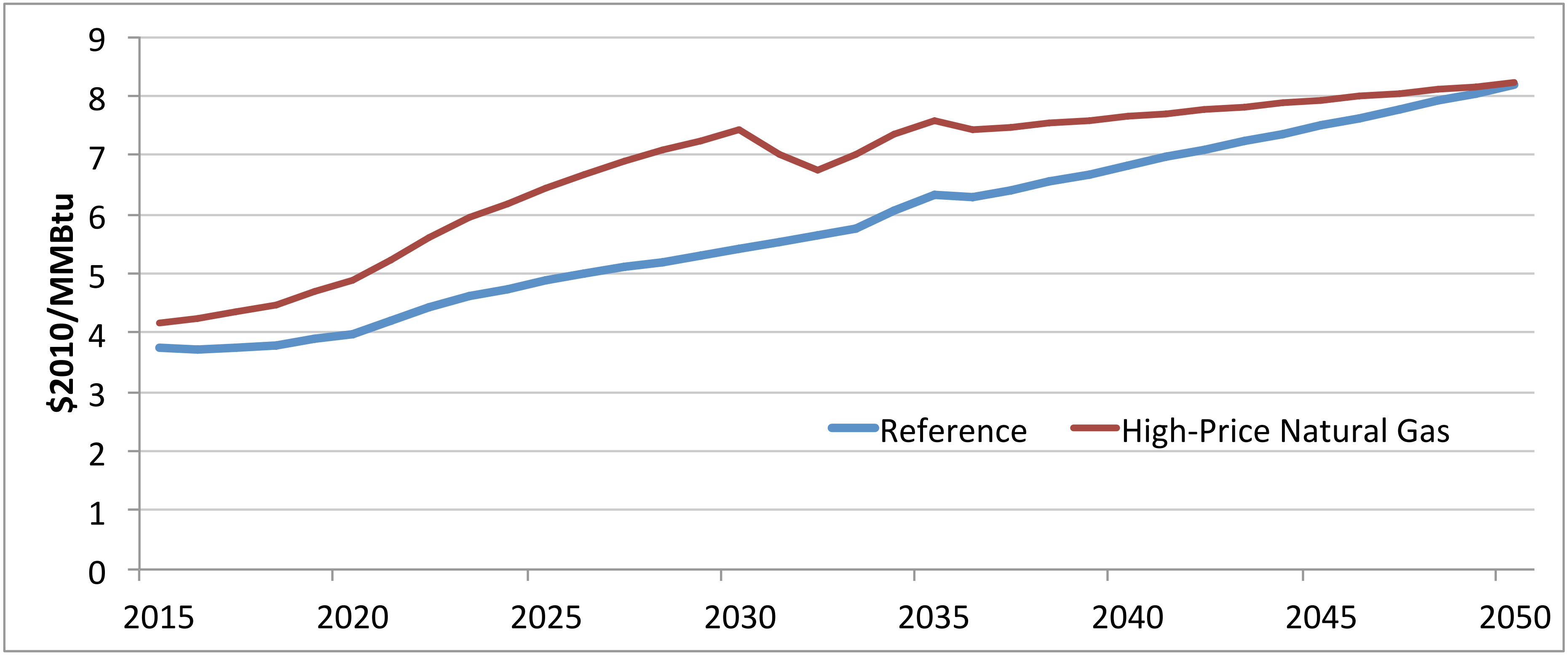


Figure 4. *System dispatch in 2050 in the (A)* Limited Technology SunShot Scenario and (B) Flexible Load Scenario. *Total generation exceeds system load because of transmission, distribution, and storage losses as well as curtailment of generation on resources.*

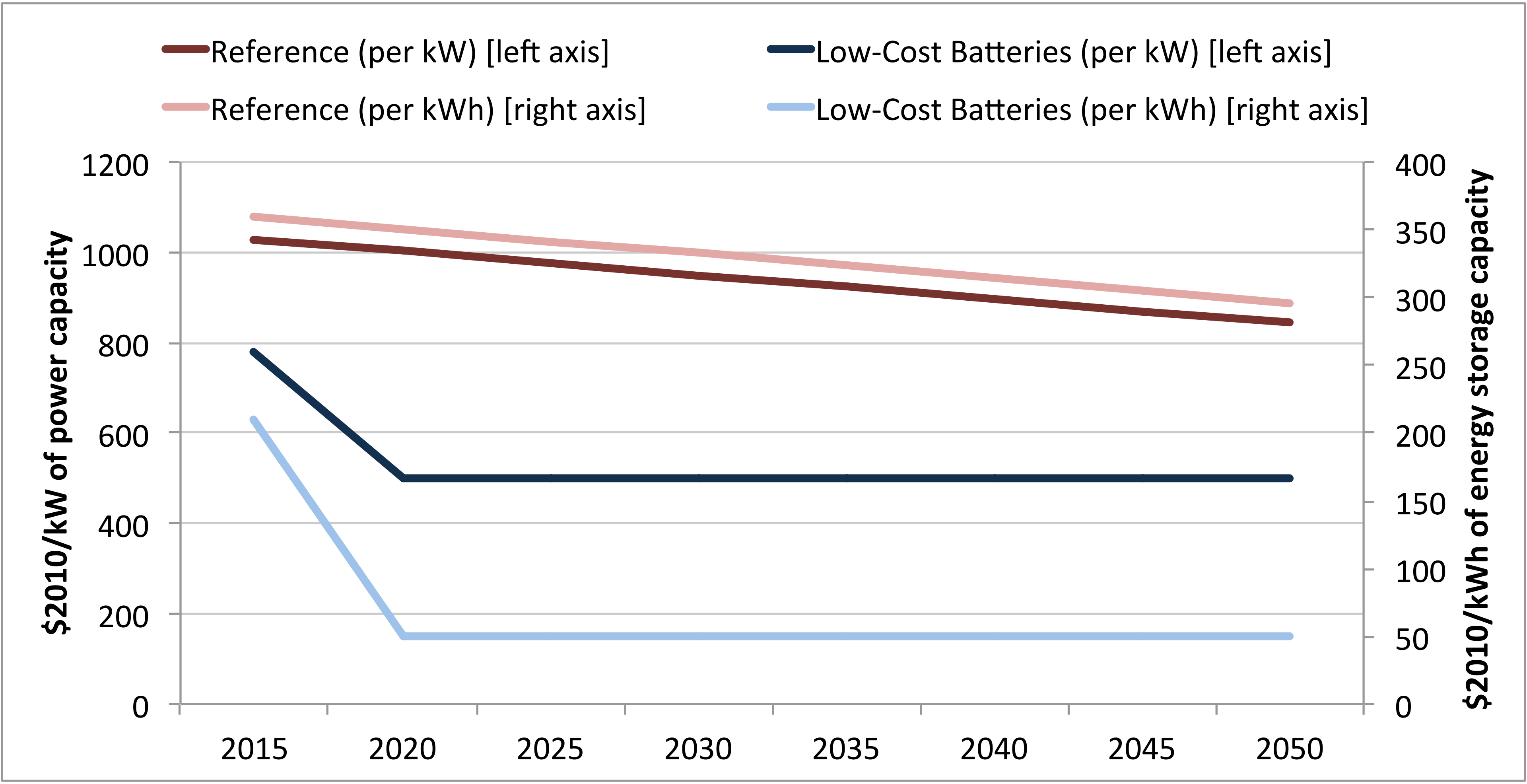
Sunshot Solar Deployment: 2050





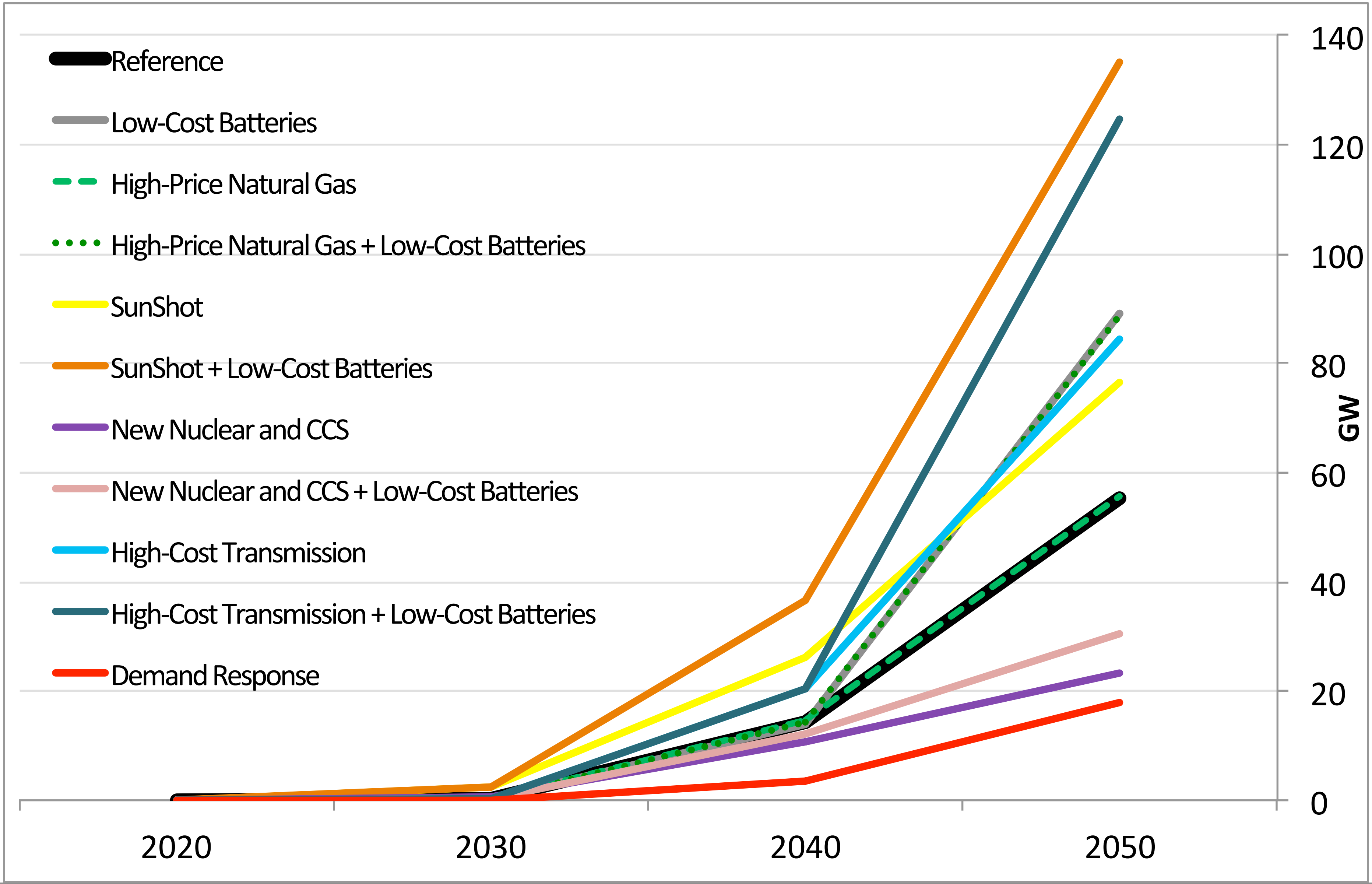
$2010/MMBtu
9
8
7
6
5
4
3
2
1
0
2015
2020
2025
2030
2035
2040
2045
2050
Reference
High-Price Natural Gas

Capital Cost of Battery Technologies

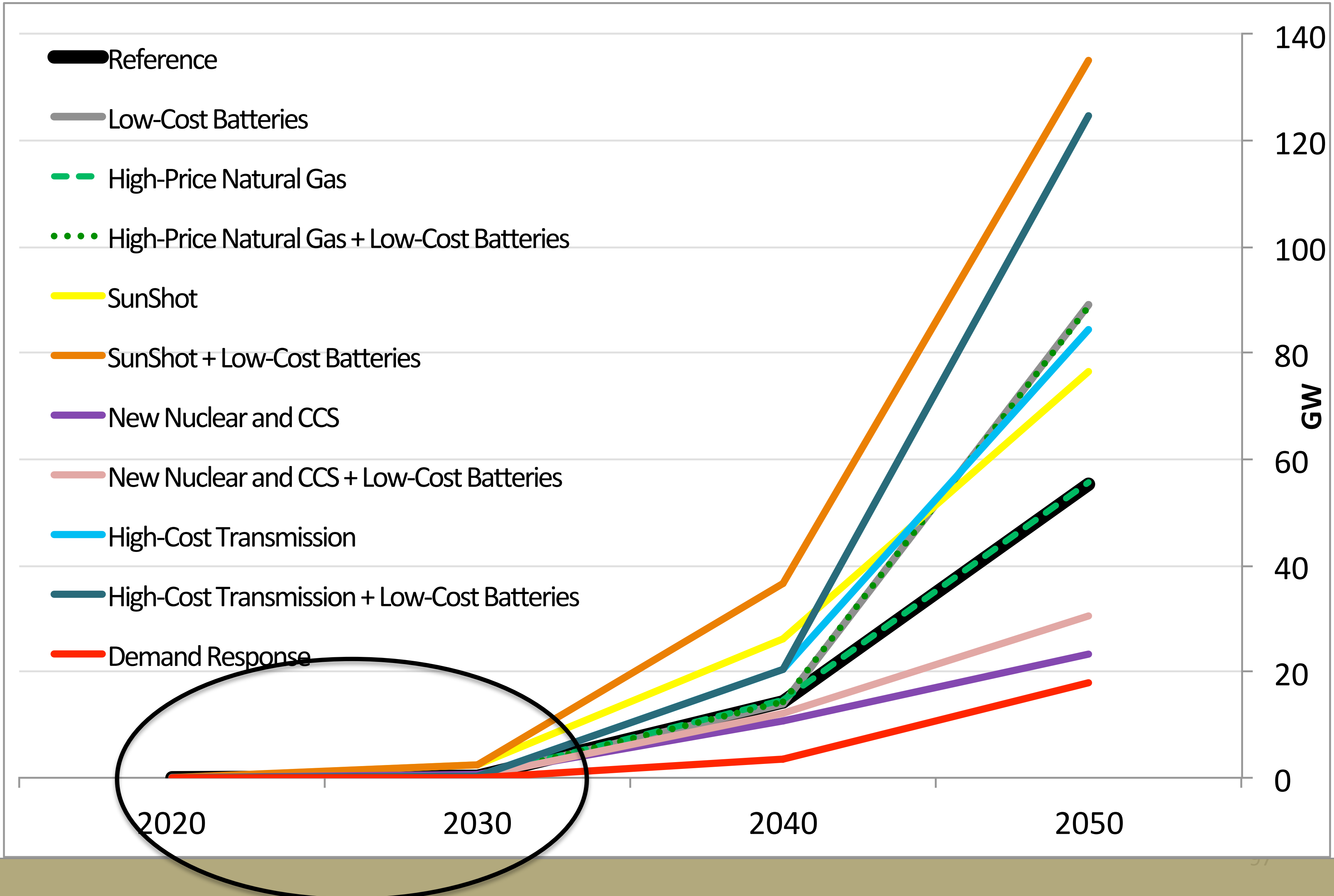


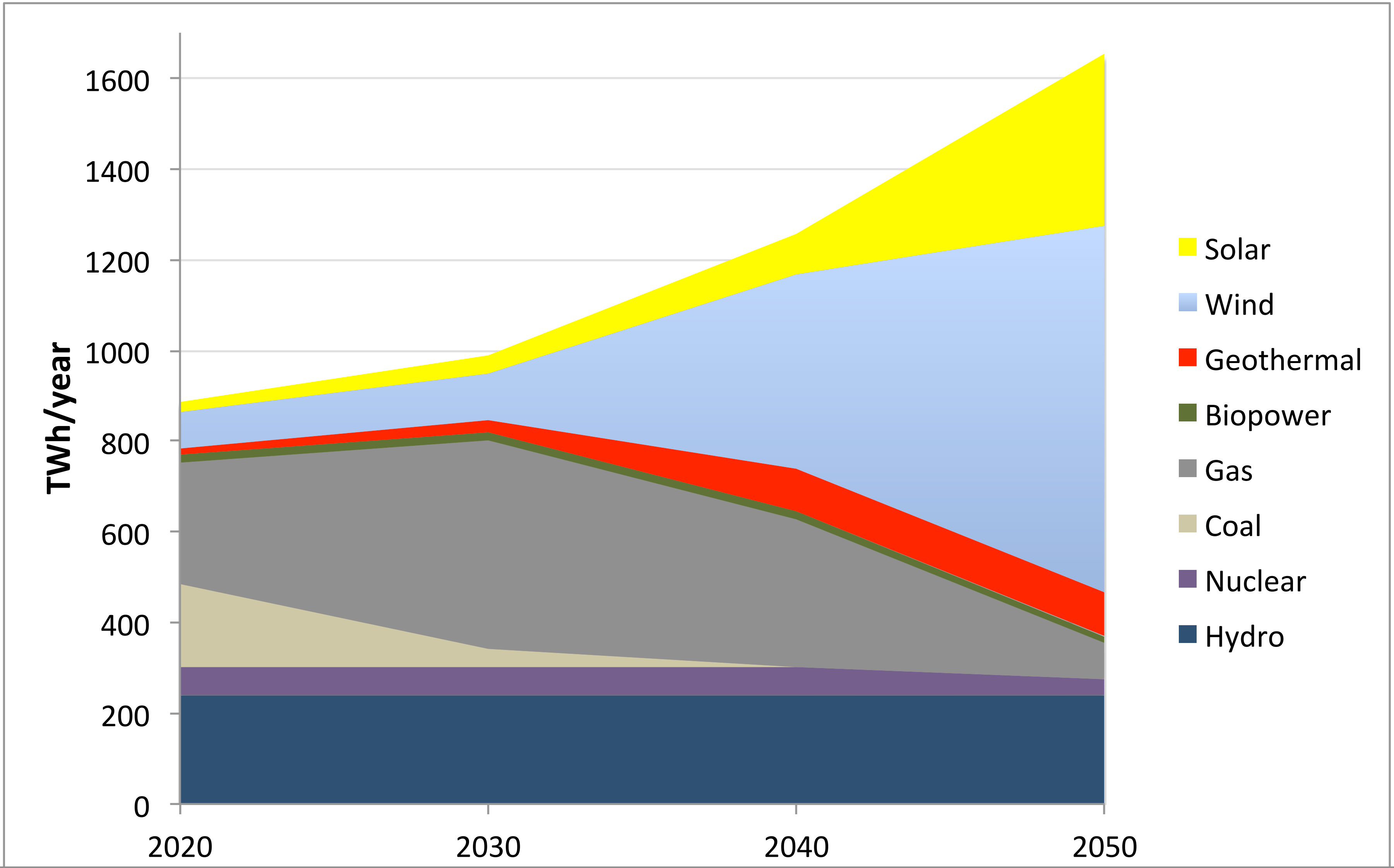
Department of Energy ARPA-E Program (Low-Cost Batteries)

WECC Storage Deployment through 2050

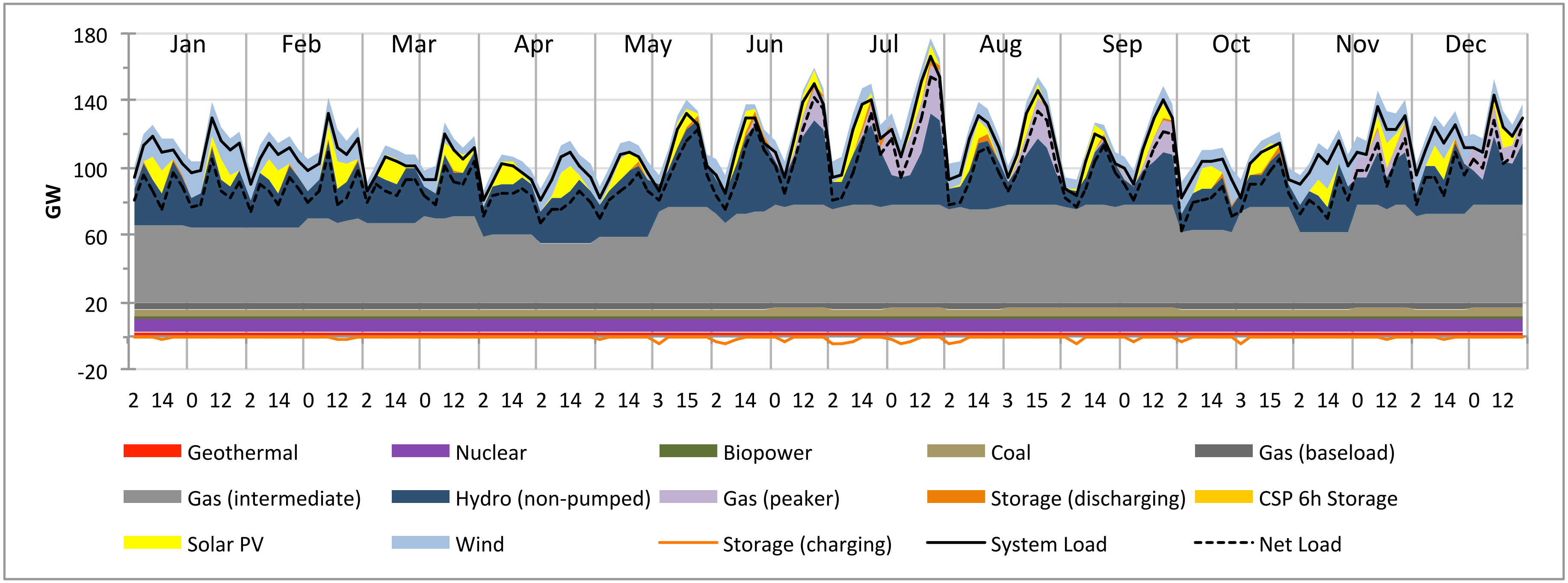


WECC Storage Deployment through 2050

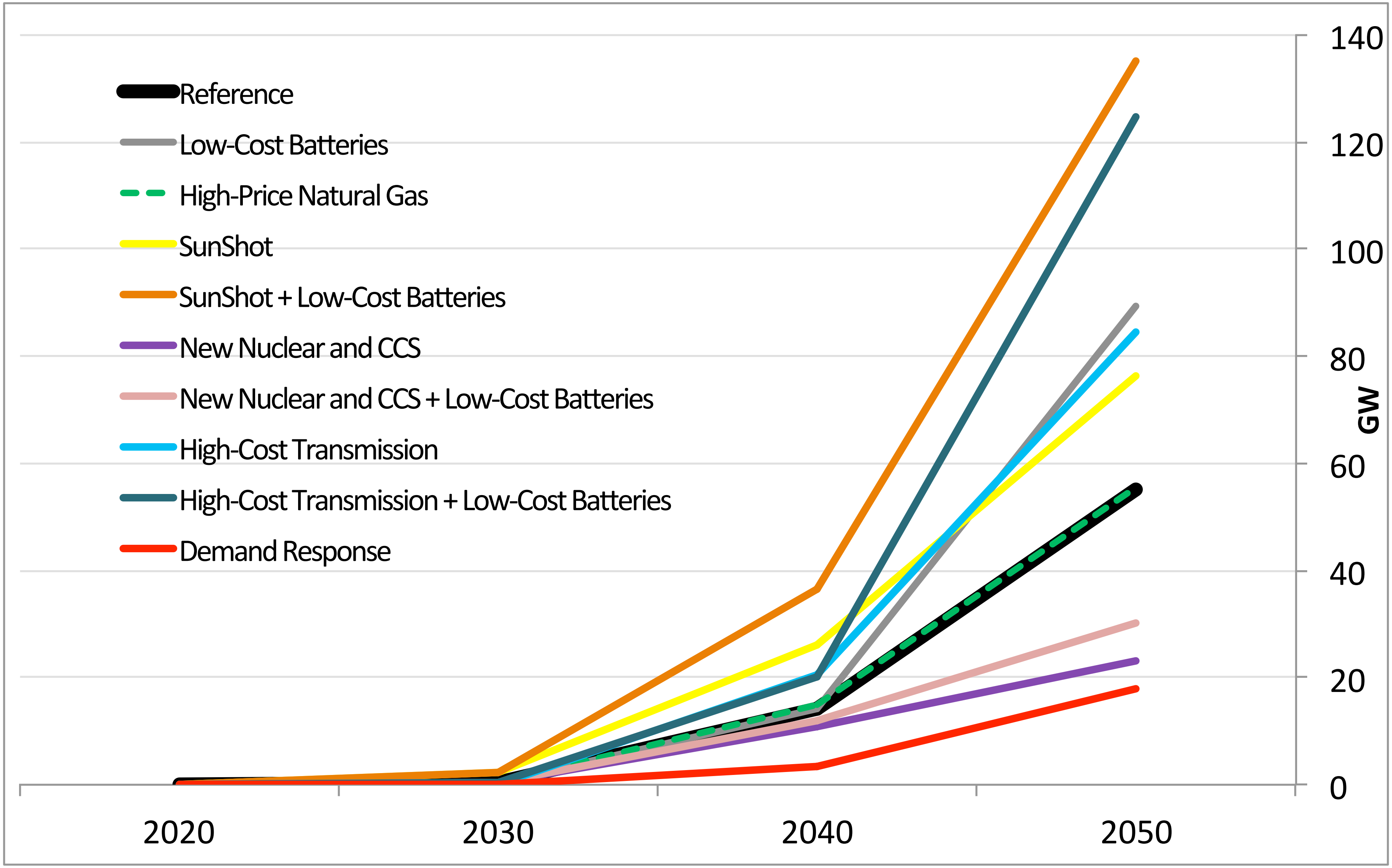


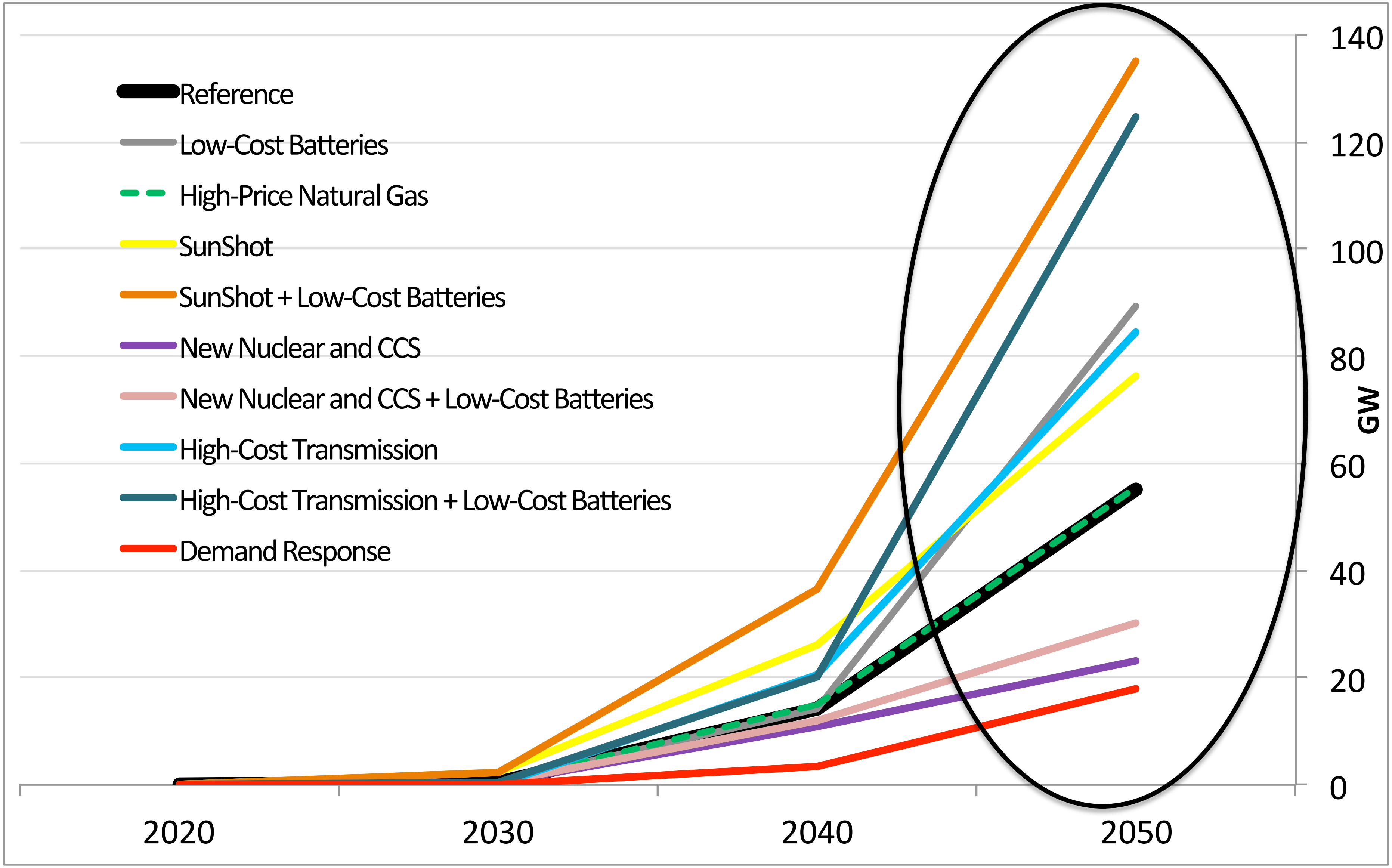

TWh/year
1600
1400
1200
1000
800
600
400
200
0
2020
2030
2040
2050
Solar
Wind
Geothermal
Biopower
Gas
Coal
Nuclear
Hydro

Reference Scenario
2030 System Dispatch



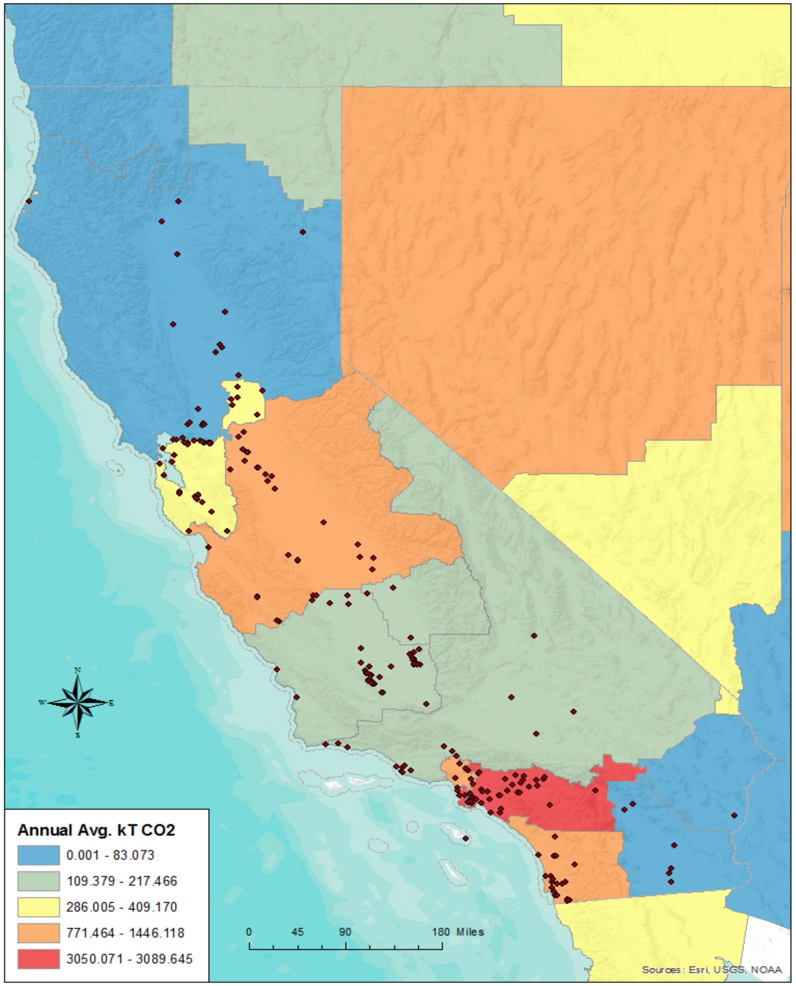
Storage Deployment through 2050



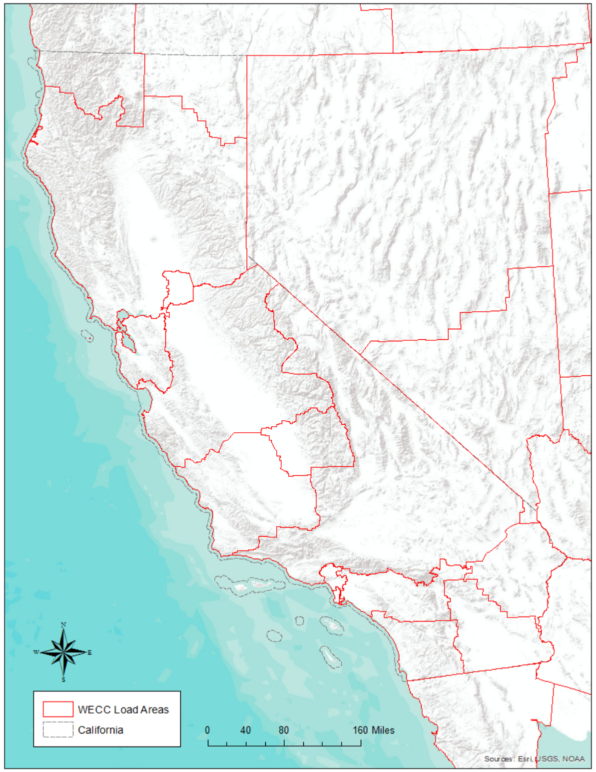

Reference
Low-Cost Batteries
High-Price Natural Gas
SunShot
SunShot + Low-Cost Batteries
New Nuclear and CCS
New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
140
120
100
80
60
40
20
0
GW
2020
2030
2040
2050

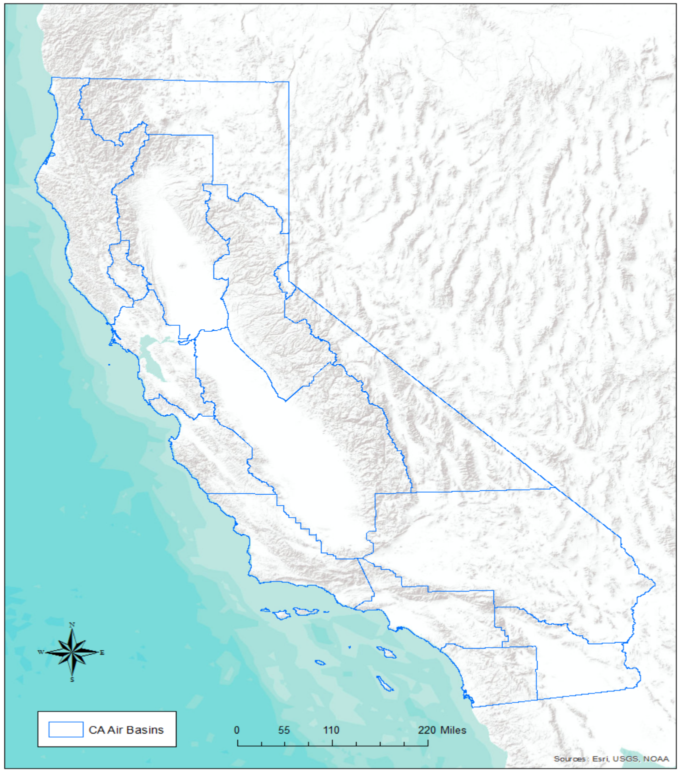
SWITCH-WECC Capabilities

CA Fossil Fuel Power Plants



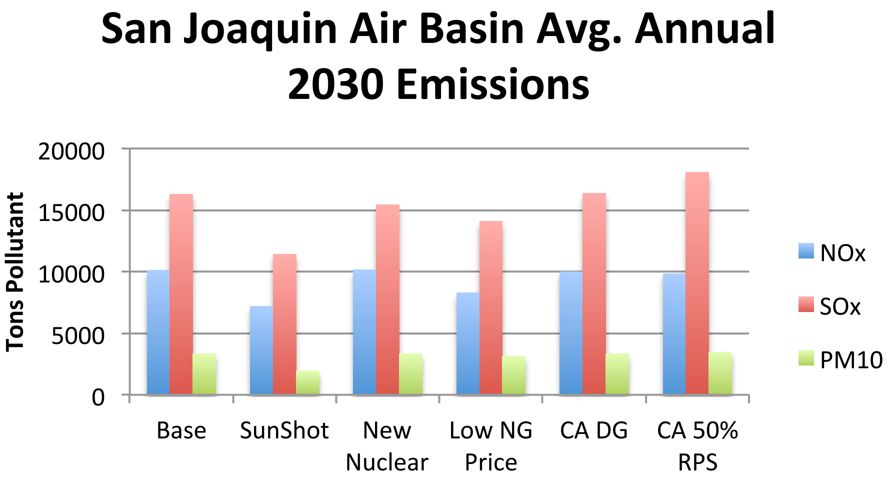
SWITCH-WECC Capabilities

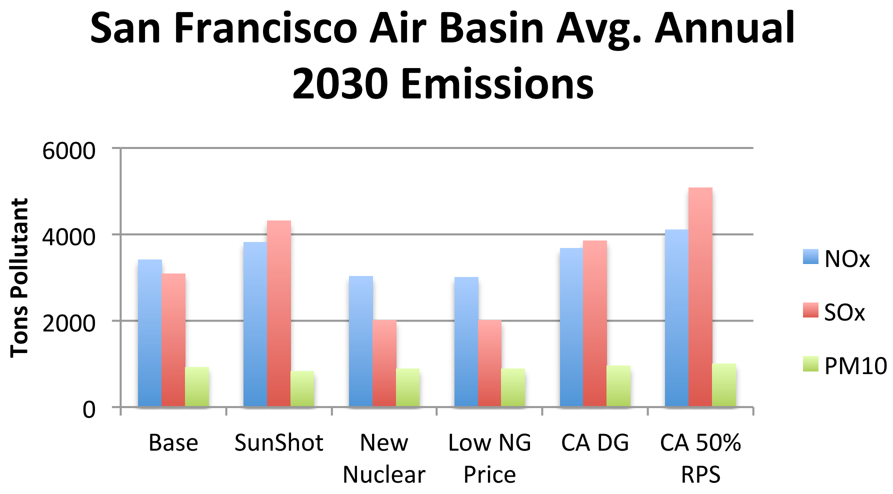


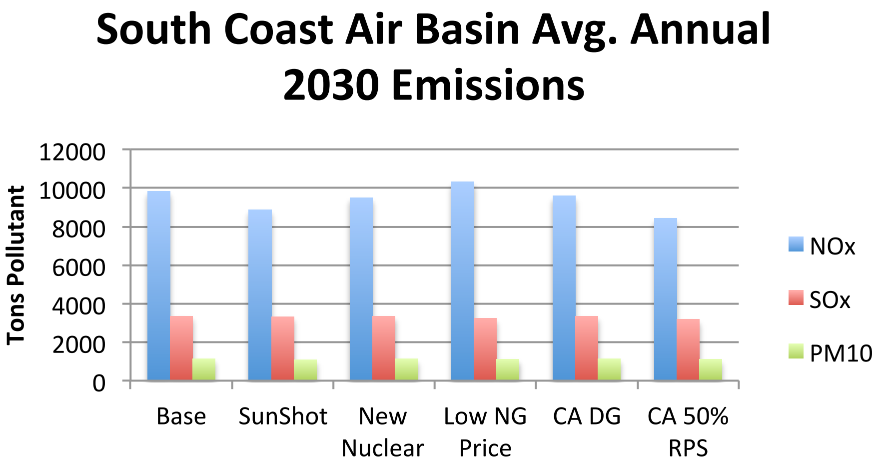


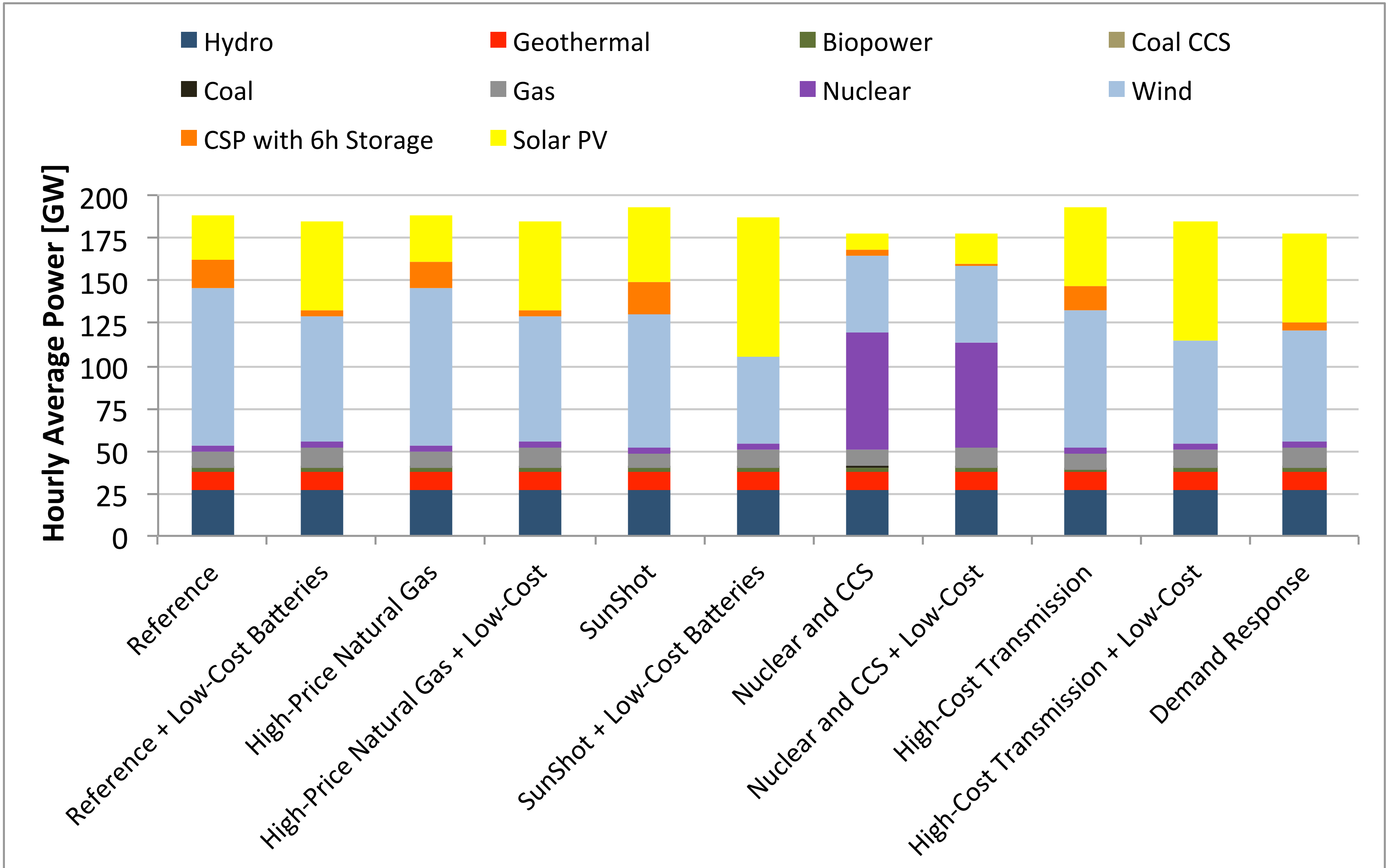
SWITCH-WECC Capabilities

SWITCH-WECC Capabilities







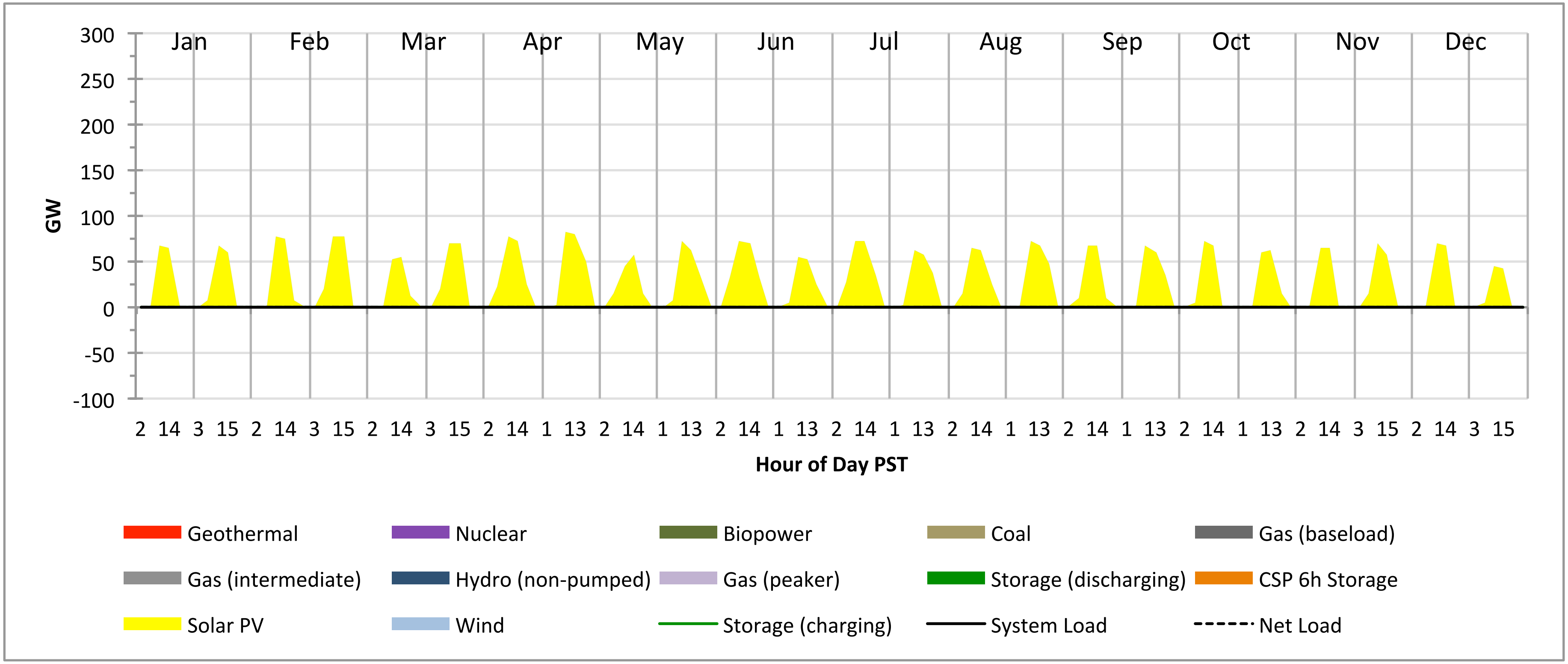

Hydro
Geothermal
Biopower
Coal CCS
Coal
Gas
Nuclear
Wind
CSP with 6h Storage
Solar PV
Hourly Average Power [GW]
200
175
150
125
100
75
50
25
0
Reference
Reference + Low-Cost Batteries
High-Price Natural Gas
High-Price Natural Gas + Low-Cost
SunShot
SunShot + Low-Cost Batteries
Nuclear and CCS
Nuclear and CCS + Low-Cost
High-Cost Transmission
High-Cost Transmission + Low-Cost
Demand Response

DR Potential Assumptions

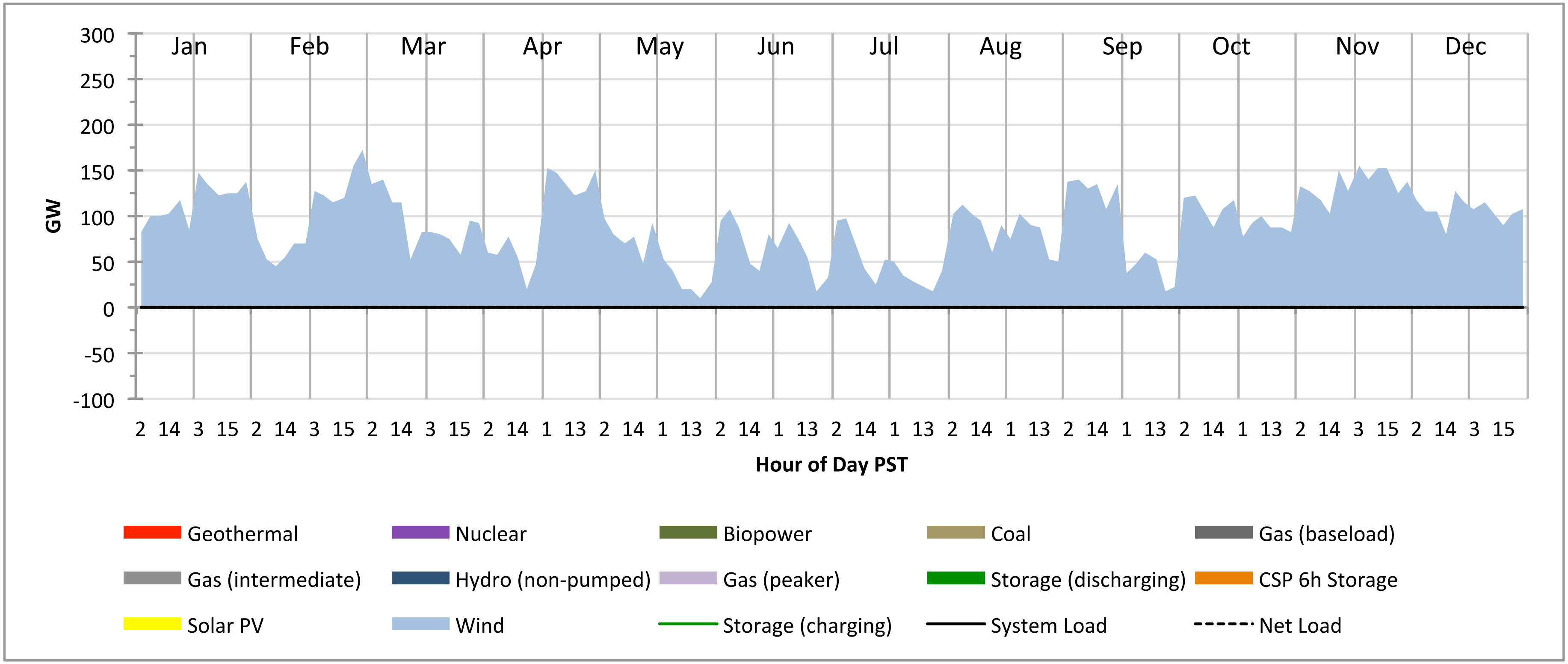
Sector	End Use	% Shiftable 2020	% Shiftable 2030	% Shiftable 2040	% Shiftable 2050
Residential	Space heating	2%	20%	40%	60%
	Water heating	20%	40%	60%	80%
	Cooling	2%	20%	40%	60%
	Dryer	2%	20%	60%	80%
Commercial	Space heating	2%	20%	40%	60%
	Water heating	20%	40%	60%	80%
	Cooling	2%	20%	40%	60%

- Potentials estimated based on above DR penetration levels applied to Itron hourly load projections by end-use for California
  - Rest of WECC assumed to be at same levels a decade after California

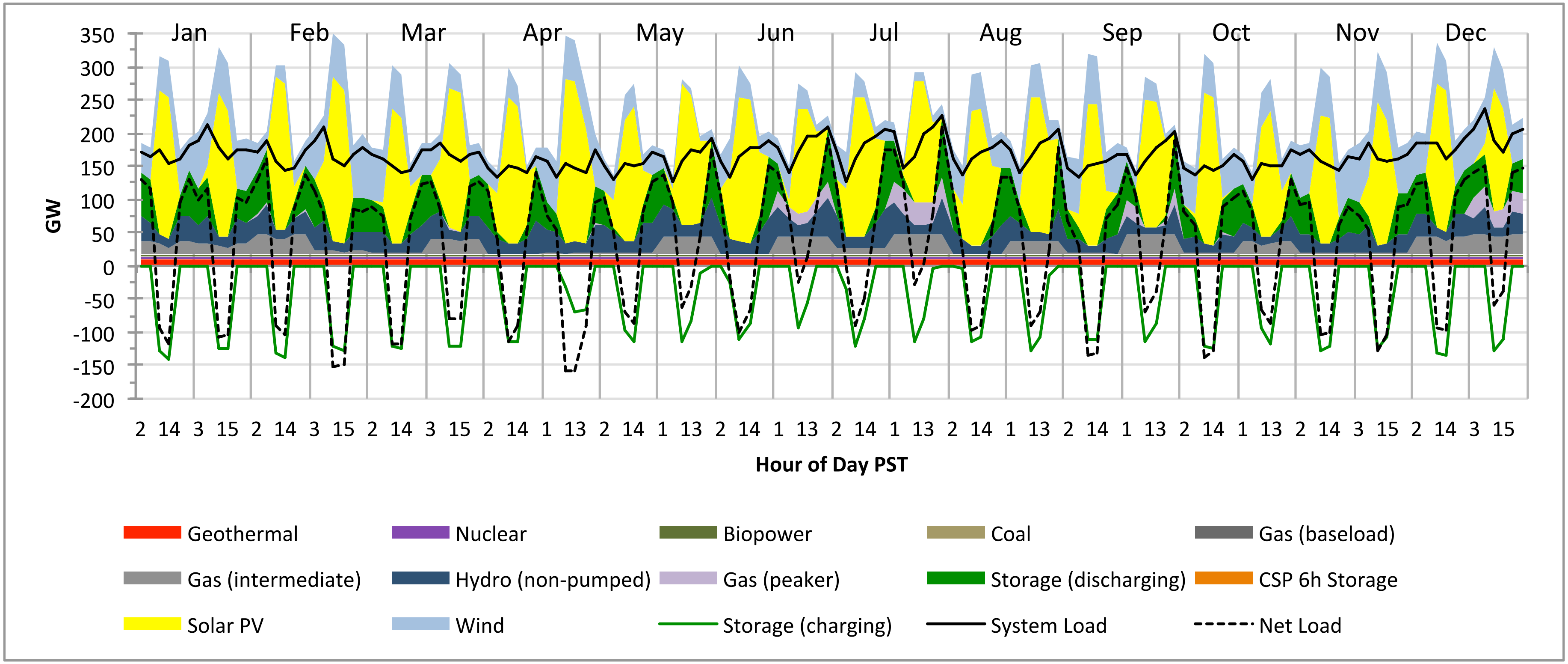
Reference Scenario
2050 Solar Output



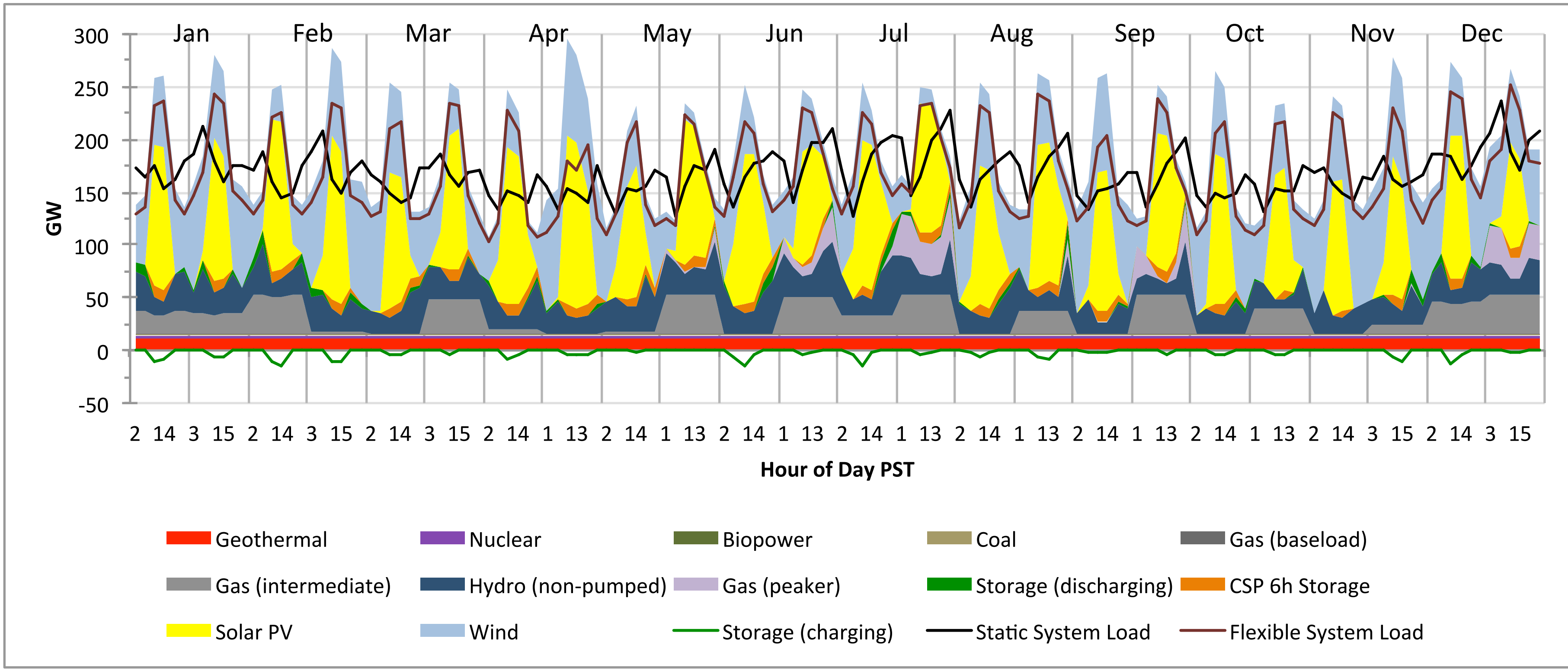
Reference Scenario
2050 Wind Output



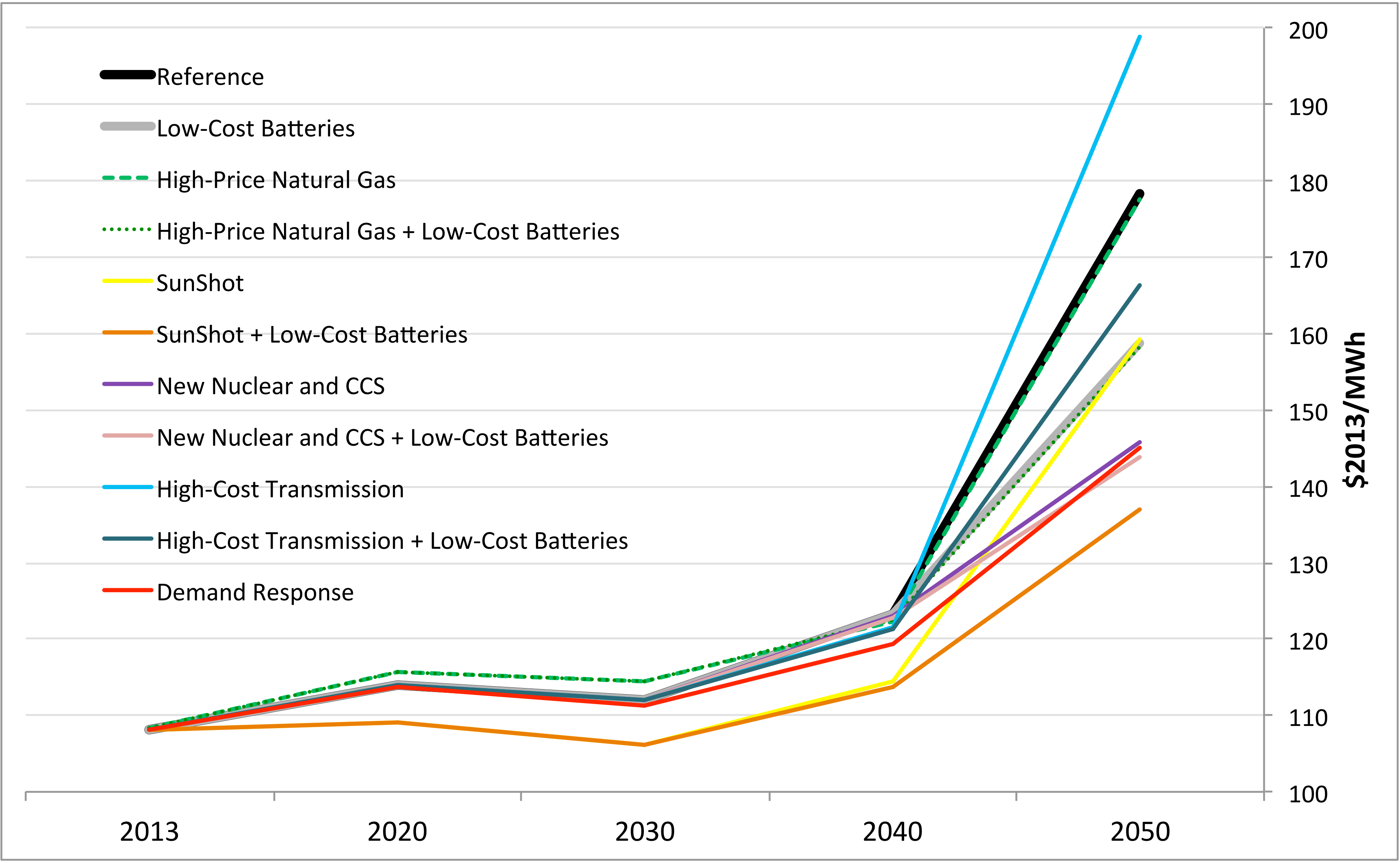
SunShot + Low-Cost Batteries Scenario
2050 System Dispatch



Demand Response Scenario
2050 System Dispatch



Cost


Reference
Low-Cost Batteries
High-Price Natural Gas
High-Price Natural Gas + Low-Cost Batteries
SunShot
SunShot + Low-Cost Batteries
New Nuclear and CCS
New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
200
190
180
170
160
150
140
130
120
110
100
$2013/MWh
2013
2020
2030
2040
2050

SWITCH-WECC Capabilities

Category	Currently, SWITCH can:	Currently, SWITCH cannot:	Planned capability:
Model uses	Create long-term investment plans that meet load, reliability requirements, operational constraints, and policy goals using projected technology costs. A simplified hourly dispatch algorithm within the investment framework captures aspects of wind and solar variability and mitigation measures for such variability	Perform detailed unit commitment and economic dispatch to simulate day-to-day grid operations	Check feasibility and performance of investment plans with an industry standard security-constrained unit commitment and economic dispatch model such as PLEXOS
Geographic extent and resolution	Model the Western Electricity Coordinating Council (WECC): California, Oregon, Washington, Idaho, Montana, Utah, Wyoming, Nevada, Colorado, Arizona, New Mexico, Baja Mexico Norte, British Columbia, Alberta		Expand to the electric power system of the entire continental United States and Canada
	Model 50 load areas or "zones" in the WECC within which demand must be met and between which power is sent	Perform bus or substation level analysis	
Technology options	Operate the existing generation within operational lifetimes		
	Retire existing generation infrastructure		
	Install and operate conventional and renewable generation capacity using projected fuel and technology costs. Natural gas fuel costs can be modeled with price elasticity	Determine economy-wide fuel prices	
	Install and operate storage technologies with multiple hours of storage duration for power management services		Install and operate storage technologies with shorter storage duration
	Use supply curve for biomass to deploy bioelectricity plants	Determine the optimal ratio of biomass allocation between electricity and other end uses	Determine the optimal ratio of biomass allocation between electricity and transportation
Transmission network	Install new transmission lines and operate them as a transportation network subject to transmission path limits	Enforce AC power flow, stability, and N-1 contingency constraints for the transmission network in the investment optimization	Enforce DC power flow, stability, and N-1 contingency constraints in PLEXOS
	Operate existing transmission lines subject to transmission path limits		Enforce DC power flow for the existing transmission network and limit power flow of existing network via phase angle in the investment optimization
Demand	Detailed hourly demand forecasts for 50 load area throughout WECC through 2050, including energy efficiency, electric vehicles, and heating electrification	Evaluate optimal energy efficiency installation or electrification decisions	

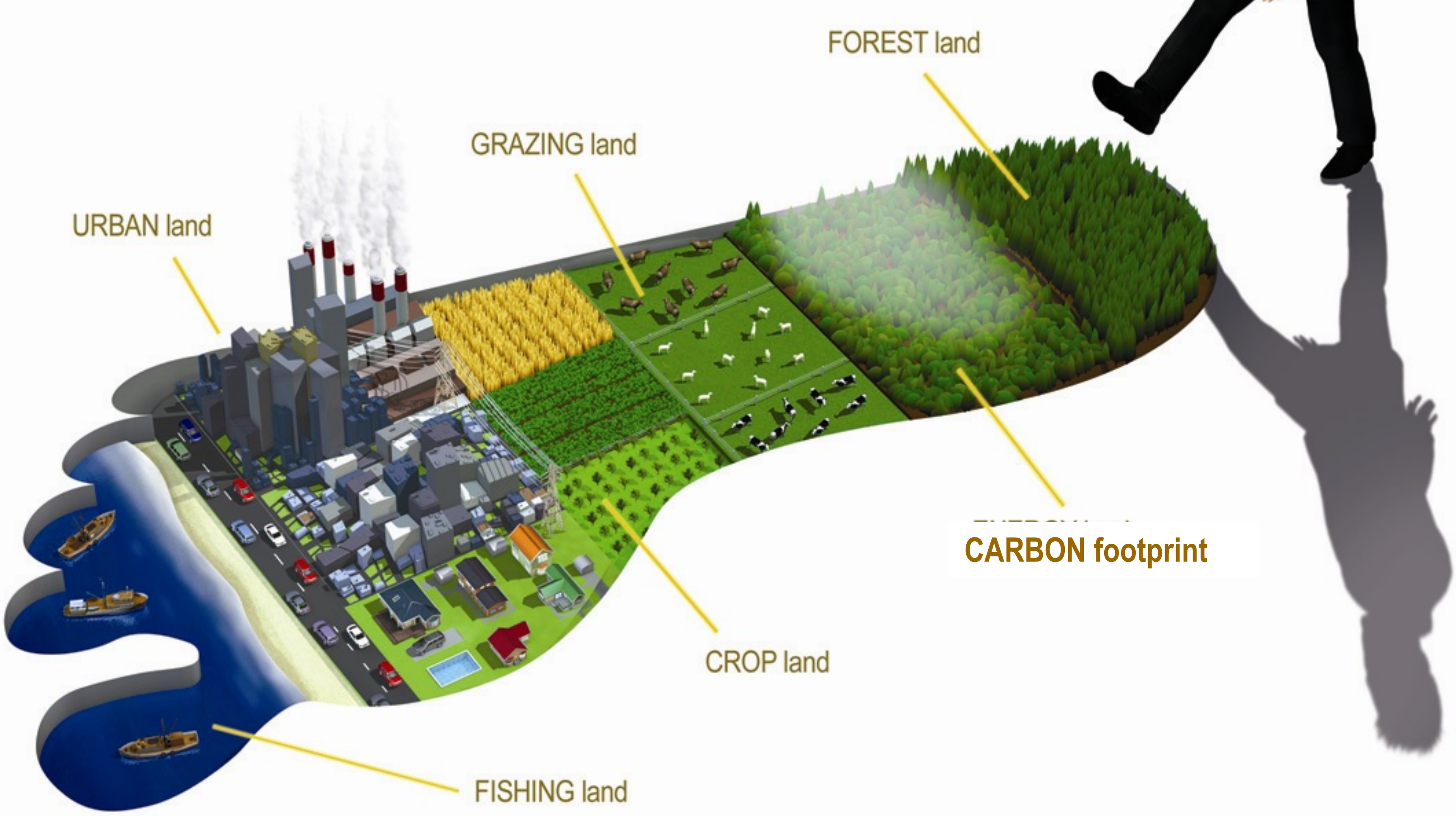
SWITCH-WECC Capabilities

Category	Currently, SWITCH can:	Currently, SWITCH cannot:	Planned capability:
Reliability	Ensure load is met on an hourly basis in all load areas	Account for sub-optimal unit-commitment due to forecast error; include treatment of electricity market structures	
	Maintain spinning and non-spinning reserves in each balancing area in each hour to address contingencies	Explicitly balance load and generation on the sub-hourly timescale; model system inertia or Automatic Generation Control (AGC)	Maintain regulation reserves
	Maintain a capacity reserve margin in each load area in each hour		
Operations	Cycle baseload coal and biomass generation on a daily basis and enforce heat-rate penalties for operation below full load		Enforce ramping constraints
	Enforce startup costs and part-load heat-rate penalties for intermediate generation such as combined cycle gas turbines (CCGTs)	Perform detailed unit-commitment in the investment optimization	Perform unit-commitment in PLEXOS
	Enforce startup costs for peaker combustion turbines		
	Shift loads within a day using projections of demand response potential		
	Operate hydroelectric generators within water flow limits	Model detailed dam-level water flow or environmental constraints	
Policy	Enforce Renewable Portfolio Standards (RPS) at the load-serving entity level using bundled Renewable Energy Certificates (RECs)	Model unbundled RECs	Enforce NOx and SOx caps
	Enforce a WECC-wide carbon cap or carbon price that escalates over time	Provide global equilibrium carbon price or warming target; assess leakage or reshuffling from carbon policies	
	Enforce the California Solar Initiative (CSI) and other distributed generation targets	Assess incentives for distributed generation	
Environmental Impacts	No capabilities currently	Enforce localized criteria air pollutant, water use, land use, and wildlife constraints	Tabulate regional criteria air pollutant, water use, and land use values for each scenario
Uncertainty	Perform deterministic, scenario-based planning	Perform stochastic planning	Develop robust optimization plans using multiple scenarios

Does not model markets – but could design markets around these results

The Ecological Footprint:

coolclimate.berkeley.edu



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WELCOME TO COOLCALIFORNIA.org, our goal is to provide resources to all Californians in order to reduce their environmental impact and take action to stop climate change. Realizing local governments, businesses, schools and individuals have different needs, we have customized pages for each audience. Click the tabs above to find:

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- Carbon footprint and greenhouse gas emissions calculation tools
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10
8
6
4
2
0
Metric tons CO2/year
Reduction
Air Travel
Car MFG
Car Fuel
Construction
Water
Natural Gas
Electricity
Cereals
Produce
Meat
Other Goods
Furniture
Clothing
Services
Travel
Home
Food
Goods
Services
Reset Axis
Total Reductions
1.6
tons CO2/year
$/yr saved: $706
Upfront cost: $2030
Total Footprint
33.5
tons CO2/year
43.6% Better
than the average household in Davis, California with 2 people and similar income.
Assumptions
Transportation
Housing
Shopping
Offset
Save to my profile
Category
Tons Saved mtCO2e/yr
Dollars Saved $/yr
Upfront Cost $/yr
Pledge Telecommute to Work 0.61 $405 $0
Pledge Carpool to Work 0.85 $323 $0
Pledge Practice Eco-Driving 0.95 $256 $0
Pledge Maintain My Vehicles 0.75 $201 $0
Pledge Buy a More Efficient Vehicle 0.64 $171 $2000
Pledge Go on a low carbon diet -0.01 $97 $0
Pledge Reduce Air Travel 0.42 $94 $0
Pledge Ride my Bike 0.33 $89 $0
Pledge Take Public Transportation 0.22 $89 $0
Pledge Line-dry Clothing 0.13 $76 $0

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Intro | Travel | Housing | Food | Shopping | Take Action

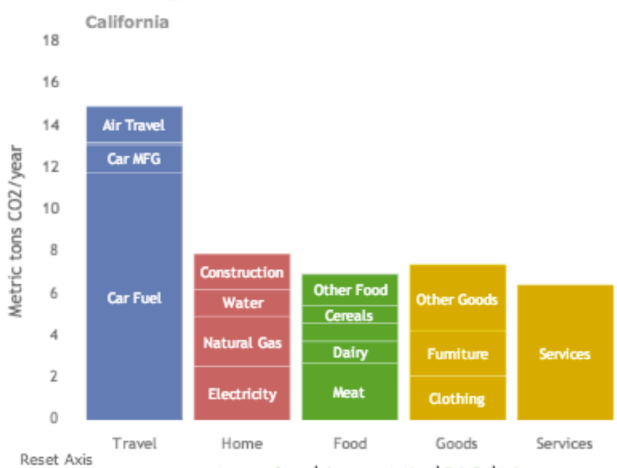
Start with a quick footprint estimate

Zipcode | City | County | State

California (CA), United States

How Many people live in your household?
Average

What is your gross annual household income?
Average



Total

43.9

tons CO_2/year

The footprint of the average household in California with average size and similar income.

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INTRODUCTION | TRANSPORTATION | HOUSING | SHOPPING | SUMMARY | TAKE ACTION

Carbon Footprint Summary (tons CO_2e / year)

Transportation	14
Housing	2
Food	6
Goods	7
Services	7
Total	36

Footprint Offsets Pledged reductions

Climate Action Plan Summary

MY CURRENT FOOTPRINT	41	100%
Pledged reductions	5	12%
Offsets	0	0%
MY NEW FOOTPRINT	36	88%
financial savings per yr	$2223	
10 year net savings	$20321	
Payback	0.9	

1) Click view / hide 2) Pledge 3) Save

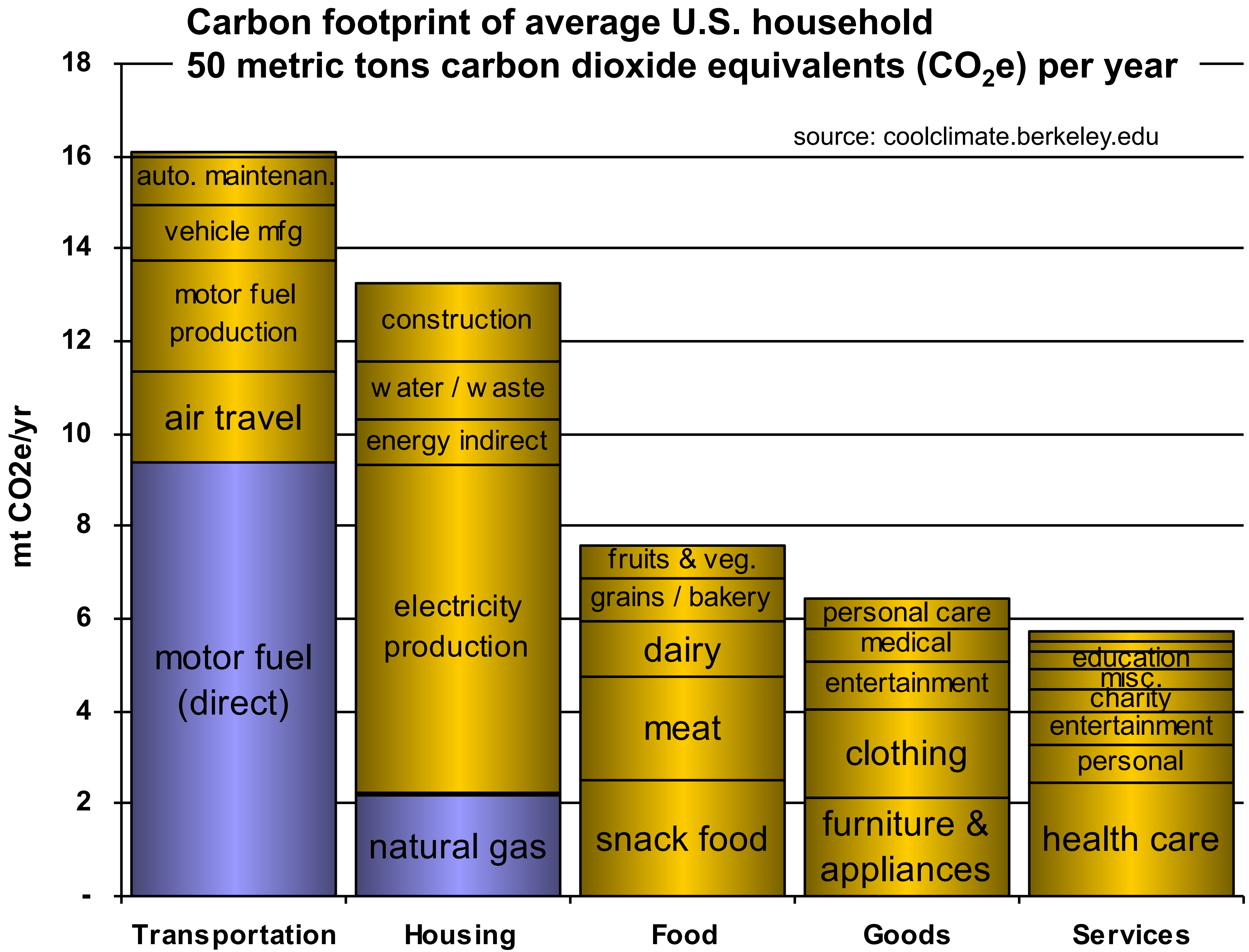
Assumptions

Pledge all

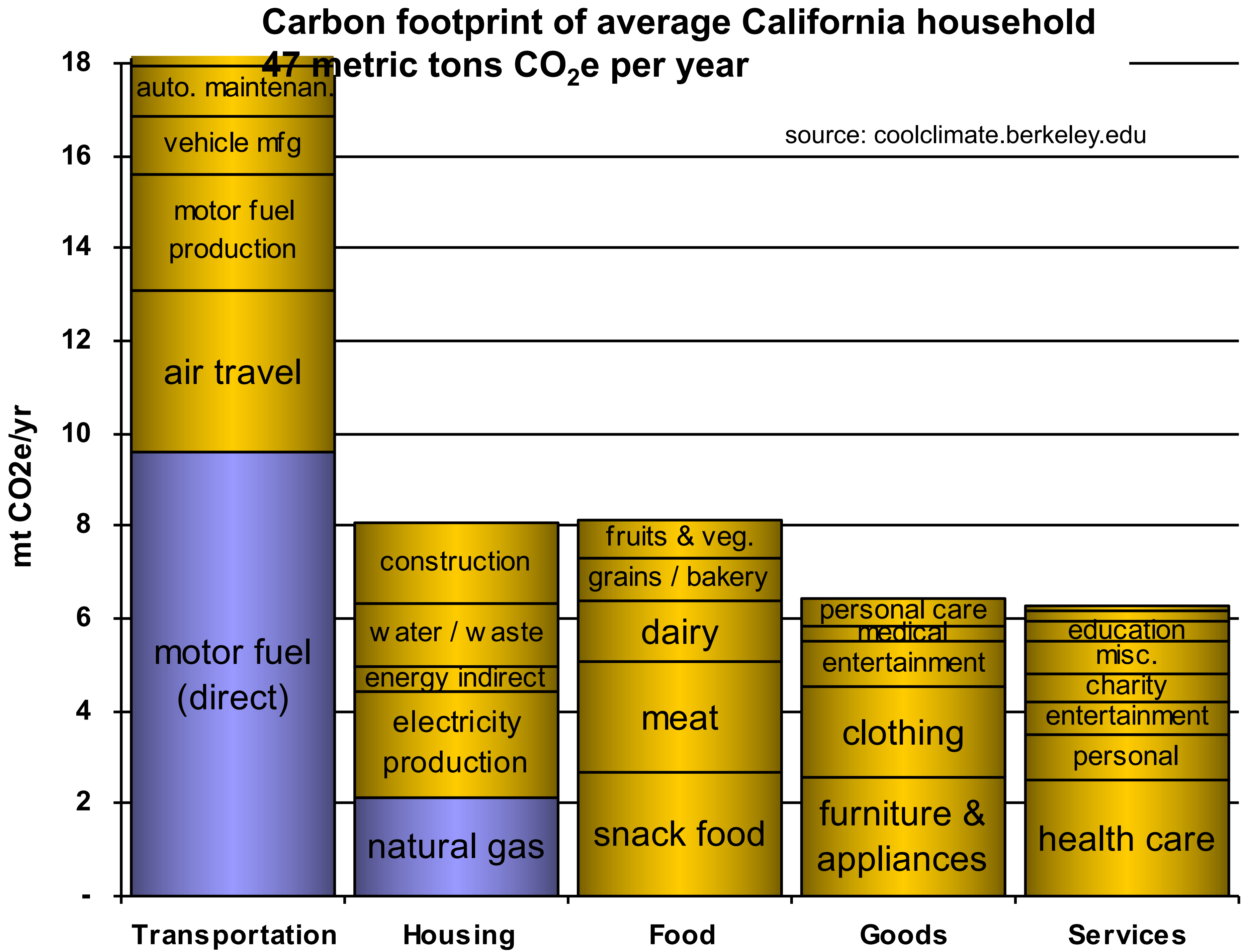
Pledged		Action	mt CO2e/yr reduced	$ / yr saved	10 year net savings
✓	view	Buy a More Efficient Vehicle	1.86	$500	$3000
✓	view	Telecommute to Work	1.07	$528	$5280
	view	Ride my Bike	0.58	$156	$1560
	view	Take Public Transportation	0.47	$156	$1560
	view	Practice Eco-Driving	0.93	$249	$2490
	view	Maintain my Vehicles	0.71	$190	$1900
	view	Reduce Air Travel	0.45	$100	$1000
	view	Offset Remaining Transportation Footprint	13.07	$-261	$-2610
✓	view	Switch to CFLs	0.18	$63	$721
	view	Turn Down Thermostat in Winter	0.52	$95	$950
	view	Turn up Thermostat in Summer	0.15	$54	$540
	view	Choose an Energy Star Refrigerator	0.05	$17	$140
	view	Dry your Clothes on the Line	0.22	$75	$750
	view	Purchase Green Electricity	0	$0	$0

Greenhouse gas and sustainability calculators:

http://coolclimate.berkeley.edu
http://coolclimate.berkeley.edu/maps
&
http://www.coolcalifornia.org



Carbon footprint of average U.S. household
50 metric tons carbon dioxide equivalents (CO_2e) per year
source: coolclimate.berkeley.edu
mt CO2e/yr
18
16
14
12
10
8
6
4
2
-
auto. maintenan.
vehicle mfg
motor fuel production
air travel
motor fuel (direct)
construction
w ater / w aste
energy indirect
electricity production
natural gas
fruits & veg.
grains / bakery
dairy
meat
snack food
personal care
medical
entertainment
clothing
furniture & appliances
education
misc.
charity
entertainment
personal
health care
Transportation
Housing
Food
Goods
Services



Carbon footprint of average California household
47 metric tons CO_2e per year
source: coolclimate.berkeley.edu
mt CO2e/yr
18
16
14
12
10
8
6
4
2
-
auto. maintenan.
vehicle mfg
motor fuel production
air travel
motor fuel (direct)
construction
w ater / w aste
energy indirect
electricity production
natural gas
fruits & veg.
grains / bakery
dairy
meat
snack food
personal care
medical
entertainment
clothing
furniture & appliances
education
misc.
charity
entertainment
personal
health care
Transportation
Housing
Food
Goods
Services

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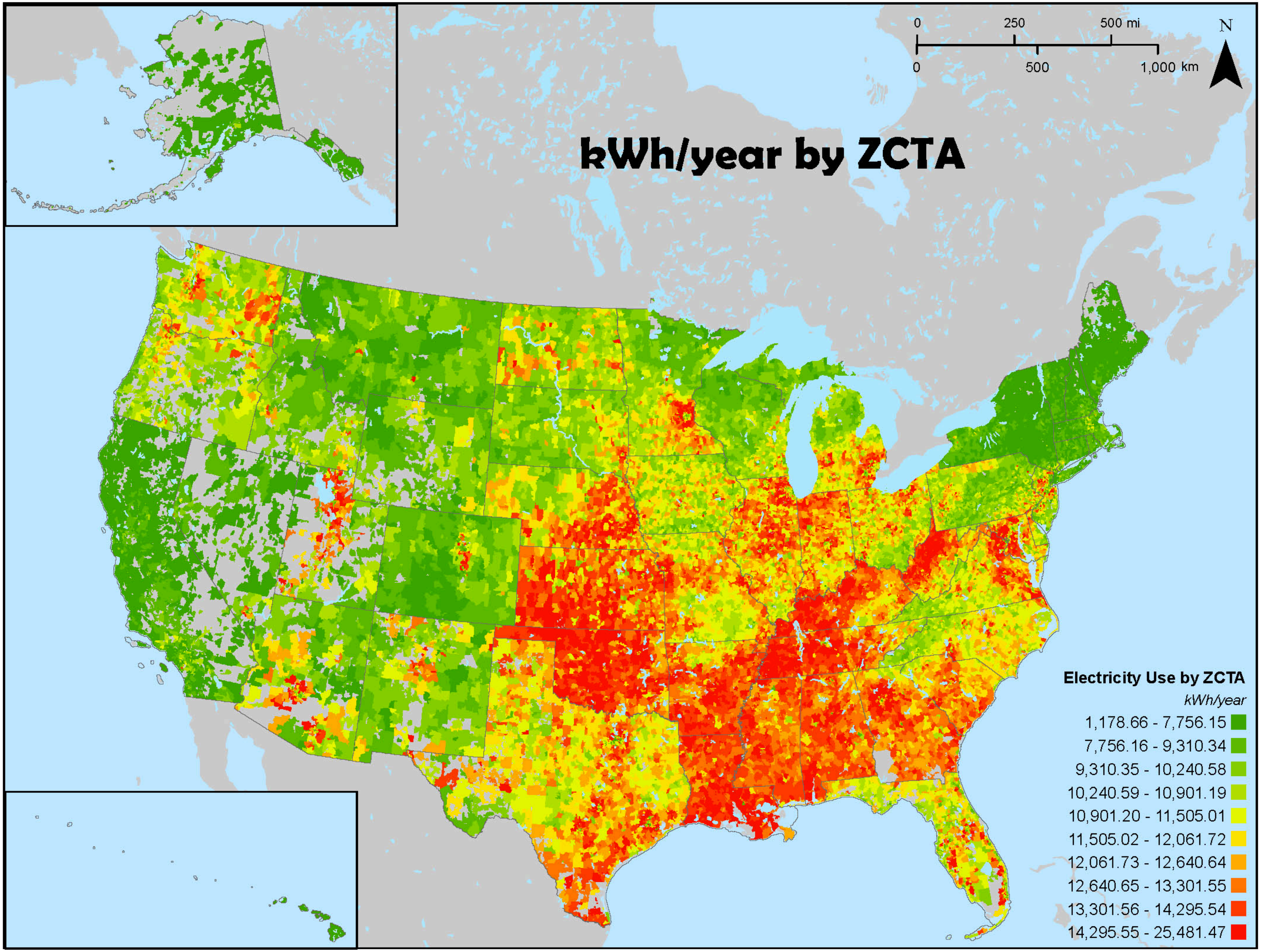
Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density

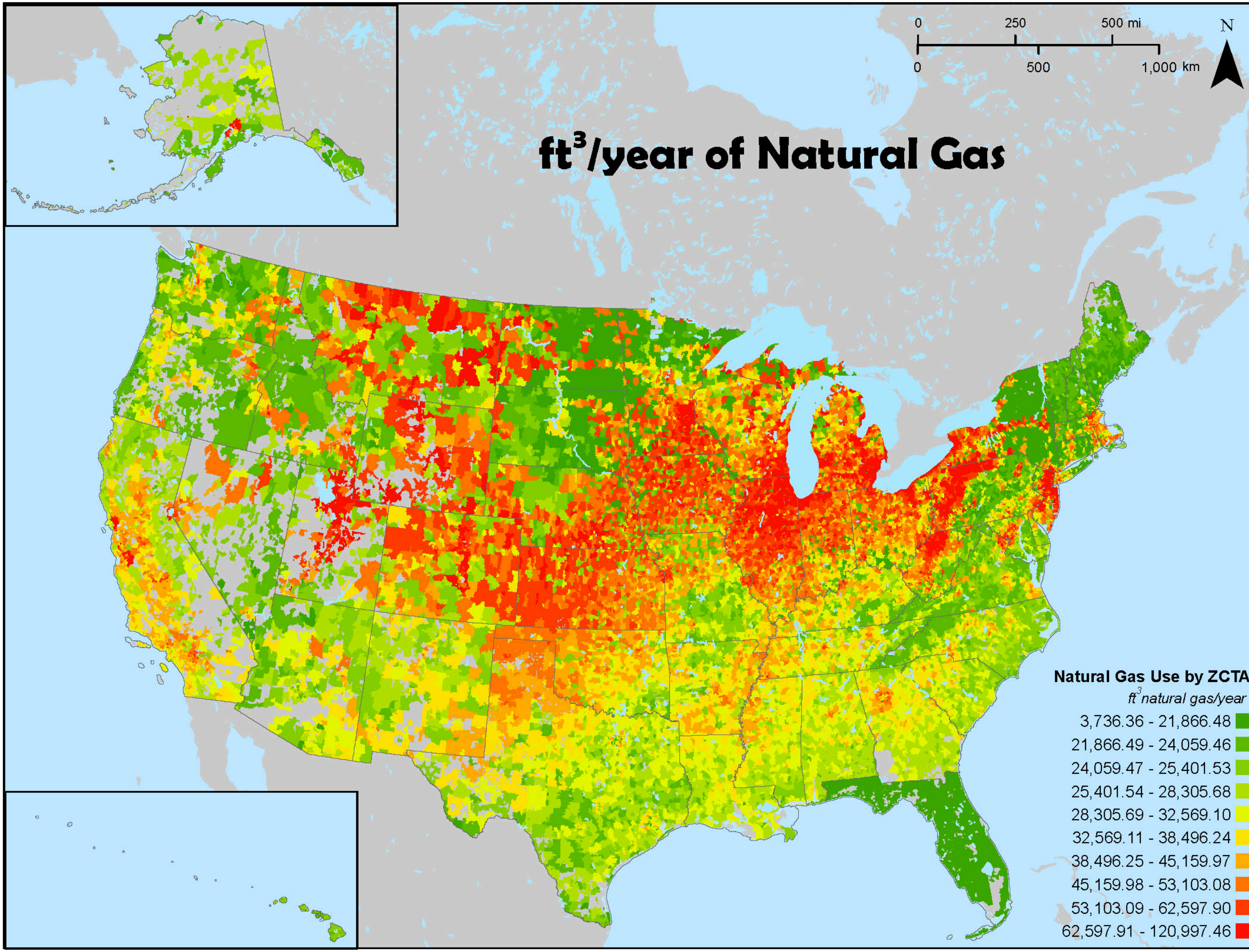
Christopher Jones*,† and Daniel M. Kammen*,†,‡,§

†Energy and Resources Group, ‡Goldman School of Public Policy, and §Department of Nuclear Engineering, University of California, Berkeley, California 94720, United States

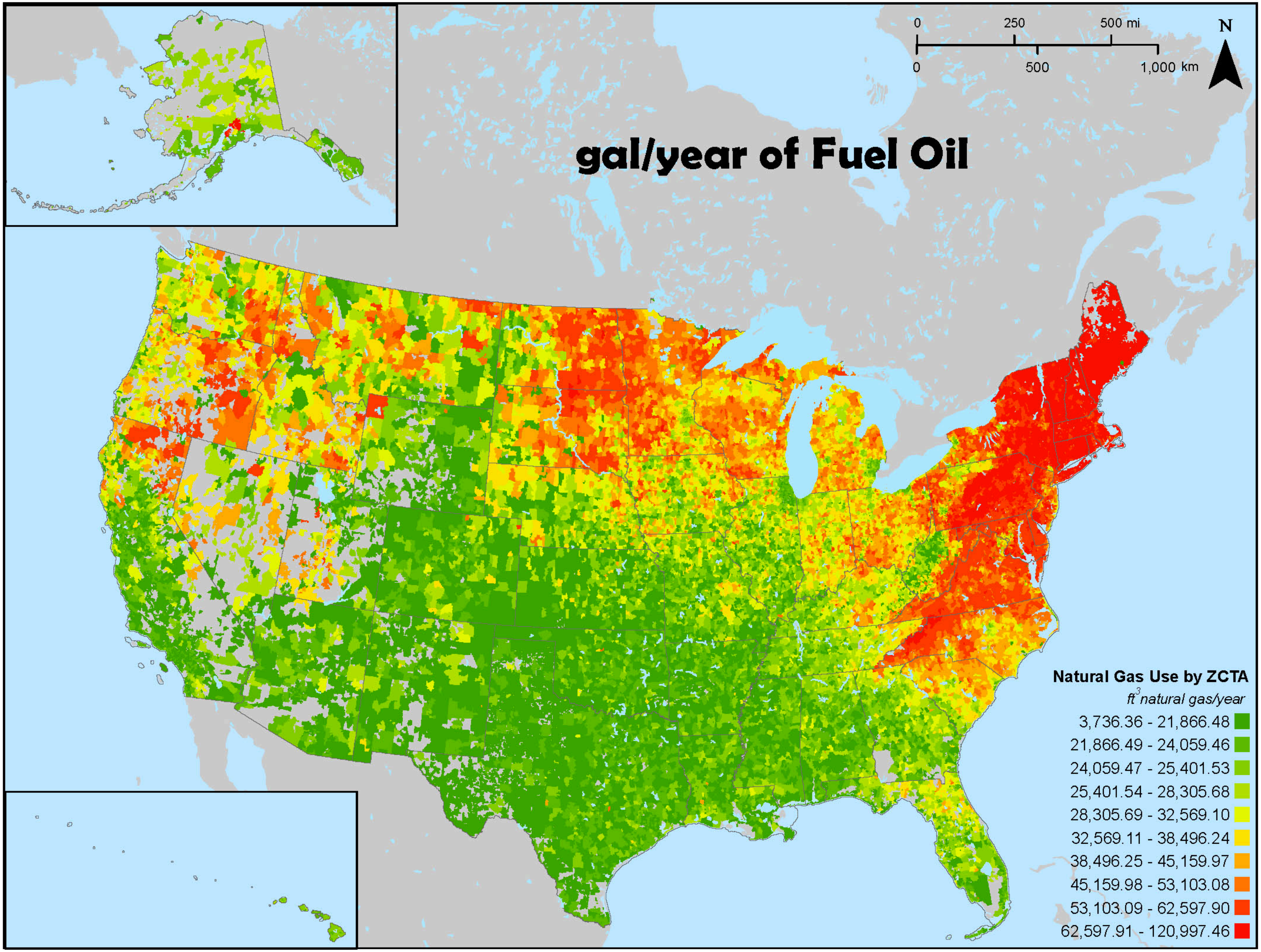
http://coolclimate.berkeley.edu/maps

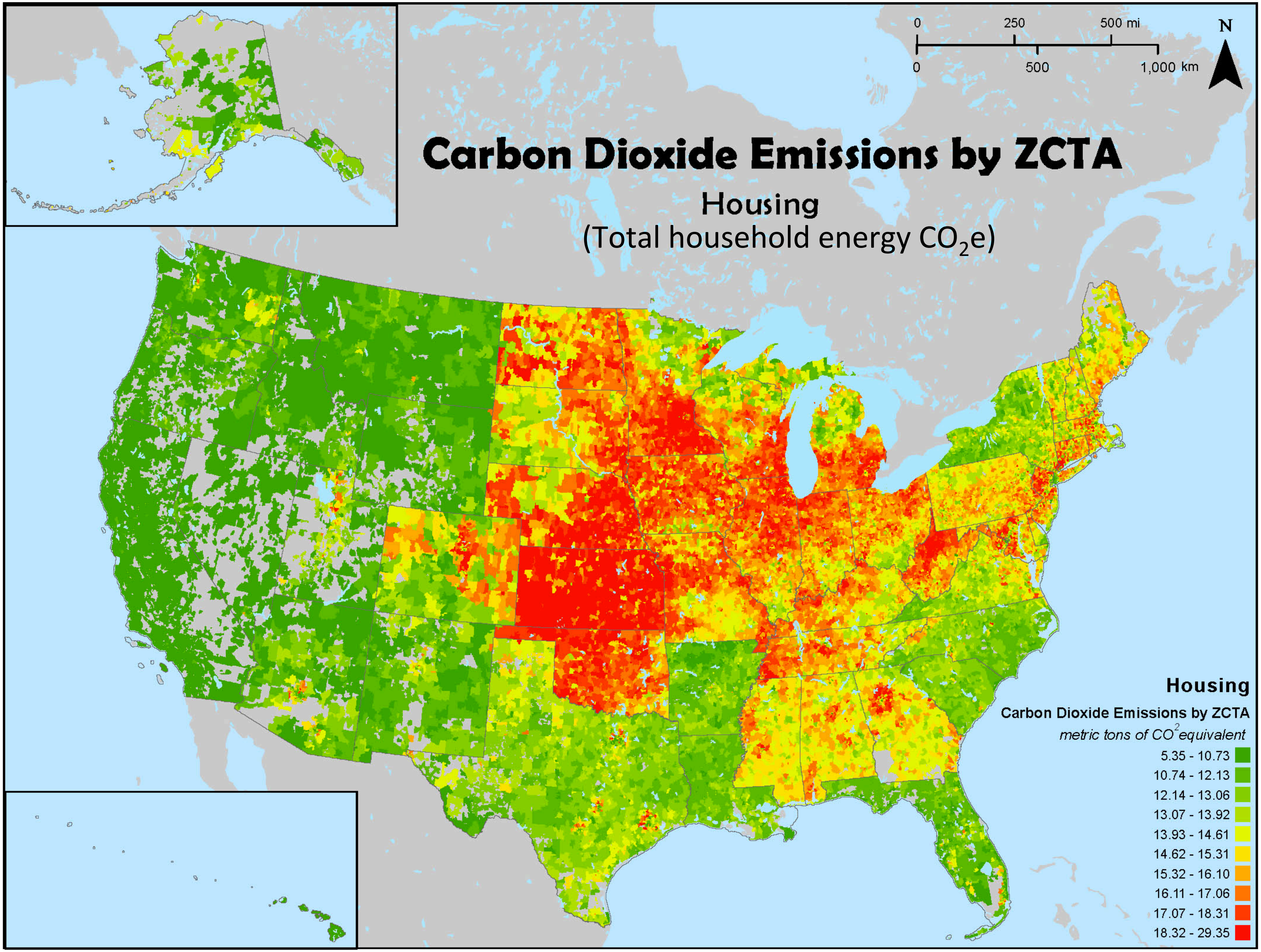


kWh/year by ZCTA
0
250
500 mi
0
500
1,000 km
N
Electricity Use by ZCTA
kWh/year
1,178.66 - 7,756.15
7,756.16 - 9,310.34
9,310.35 - 10,240.58
10,240.59 - 10,901.19
10,901.20 - 11,505.01
11,505.02 - 12,061.72
12,061.73 - 12,640.64
12,640.65 - 13,301.55
13,301.56 - 14,295.54
14,295.55 - 25,481.47

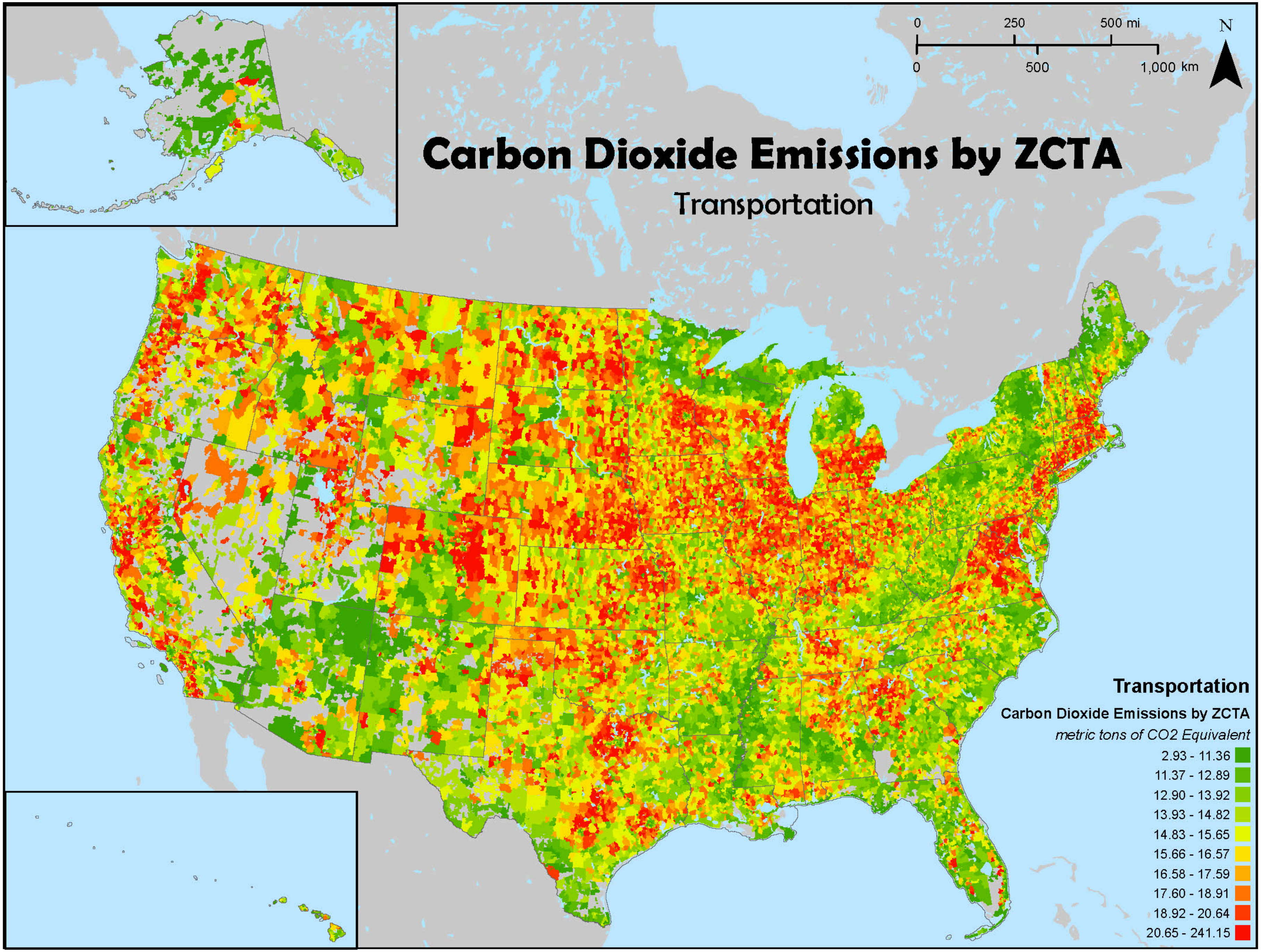


ft³/year of Natural Gas
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft³ natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46

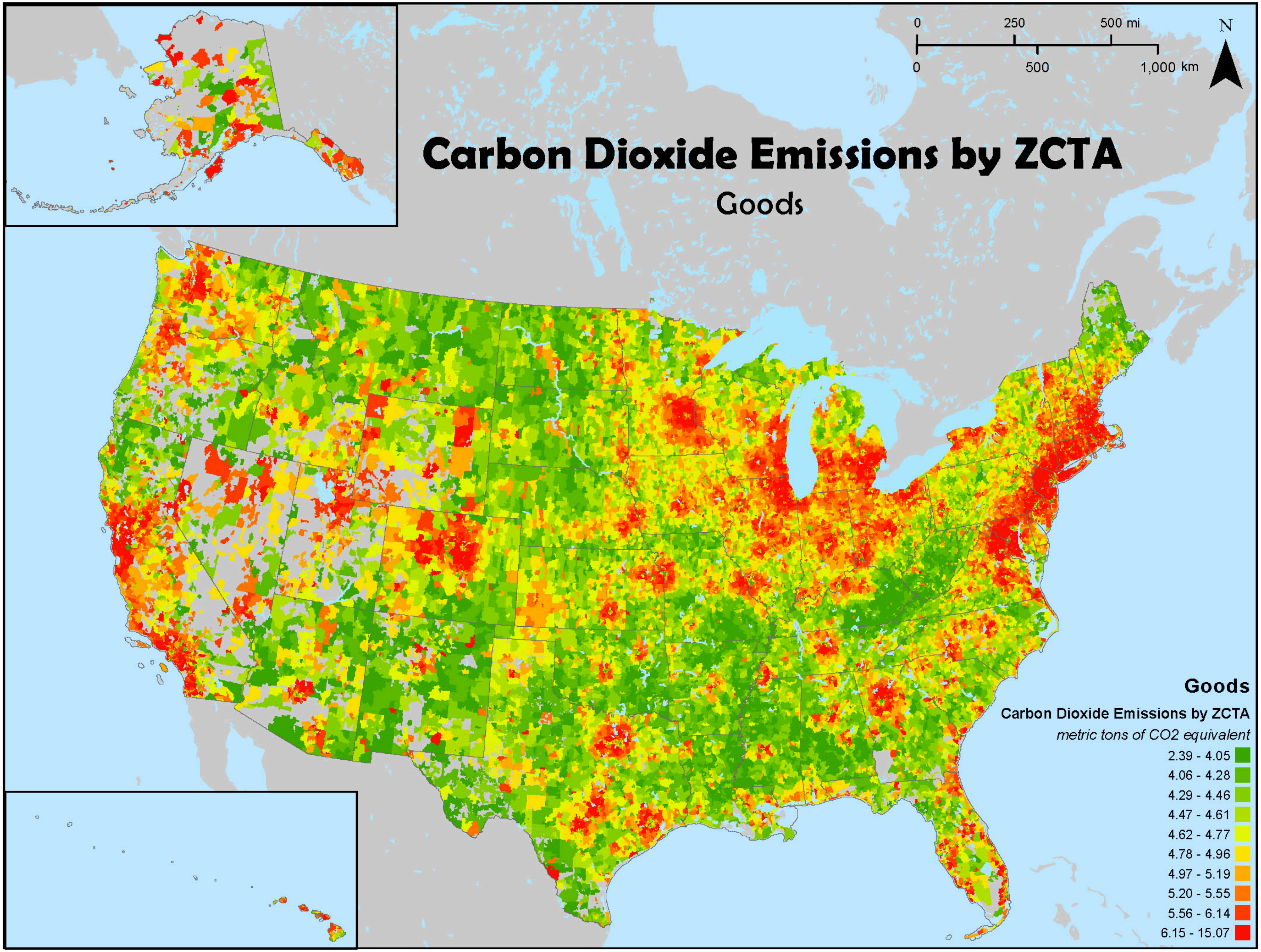

gal/year of Fuel Oil
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft³ natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46

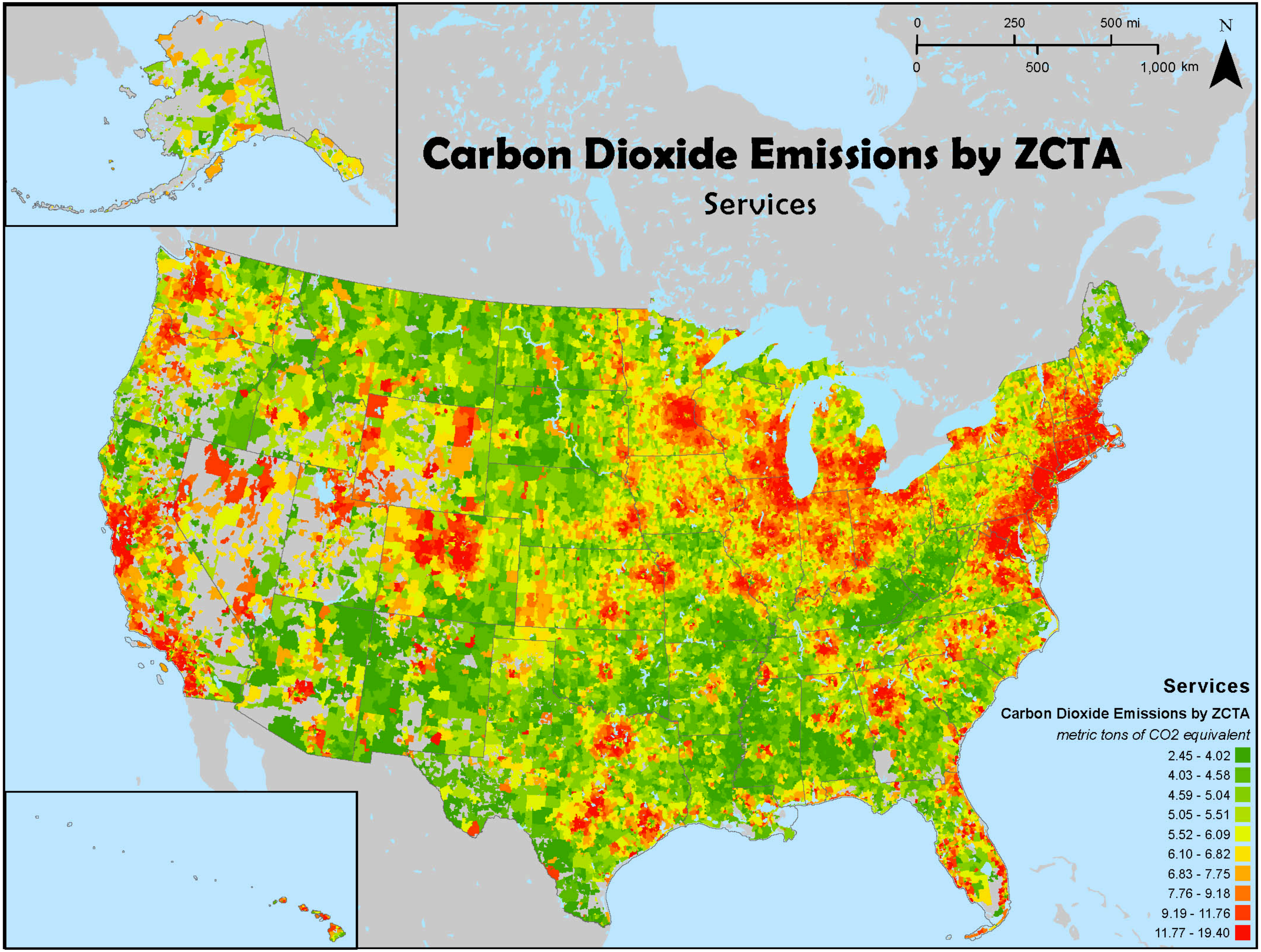


Carbon Dioxide Emissions by ZCTA
Housing
(Total household energy CO_2e)
0
250
500 mi
0
500
1,000 km
N
Housing
Carbon Dioxide Emissions by ZCTA
metric tons of CO^2 equivalent
5.35 - 10.73
10.74 - 12.13
12.14 - 13.06
13.07 - 13.92
13.93 - 14.61
14.62 - 15.31
15.32 - 16.10
16.11 - 17.06
17.07 - 18.31
18.32 - 29.35

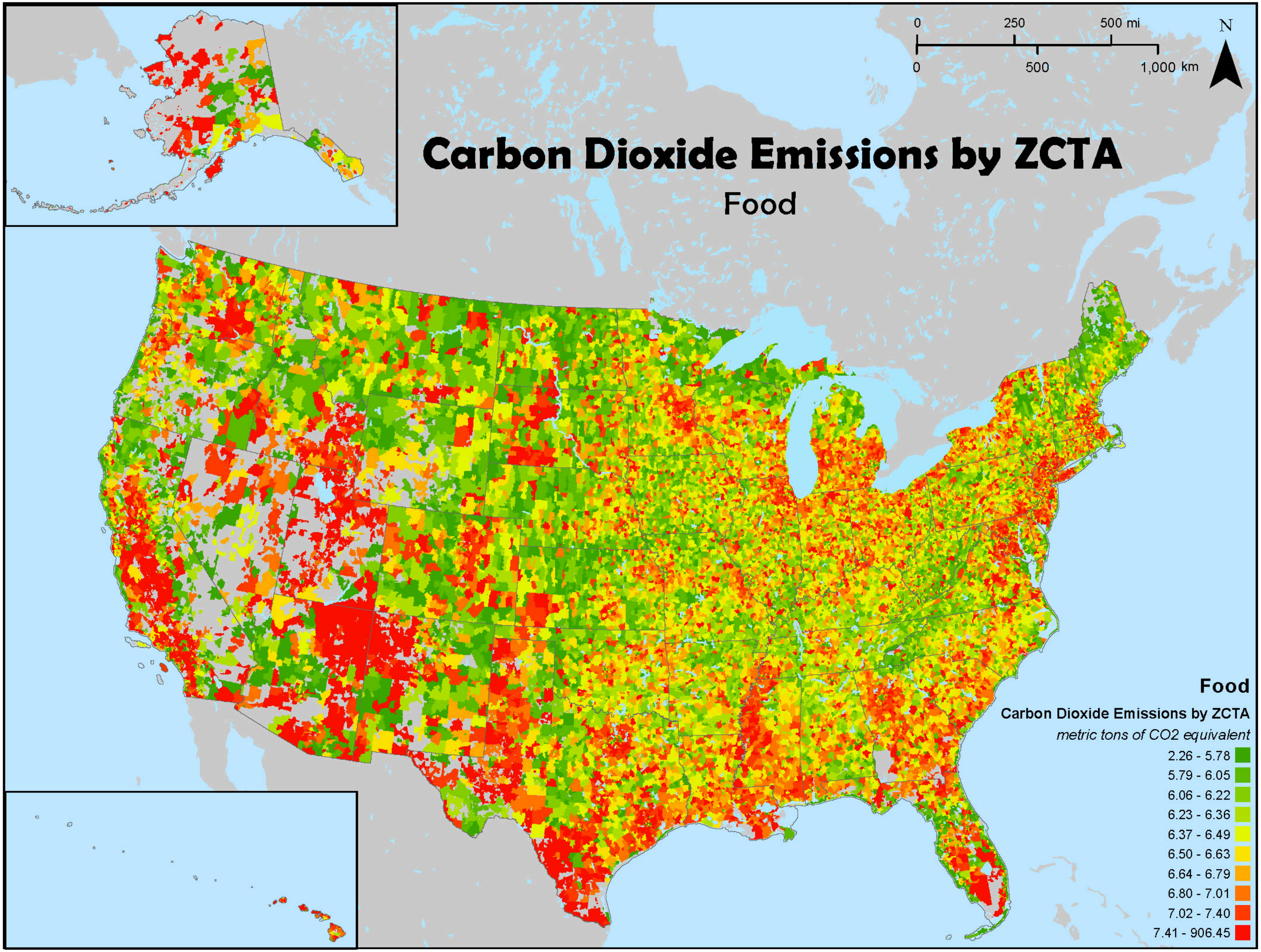


Carbon Dioxide Emissions by ZCTA
Transportation
0
250
500 mi
0
500
1,000 km
N
Transportation
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 Equivalent
2.93 - 11.36
11.37 - 12.89
12.90 - 13.92
13.93 - 14.82
14.83 - 15.65
15.66 - 16.57
16.58 - 17.59
17.60 - 18.91
18.92 - 20.64
20.65 - 241.15

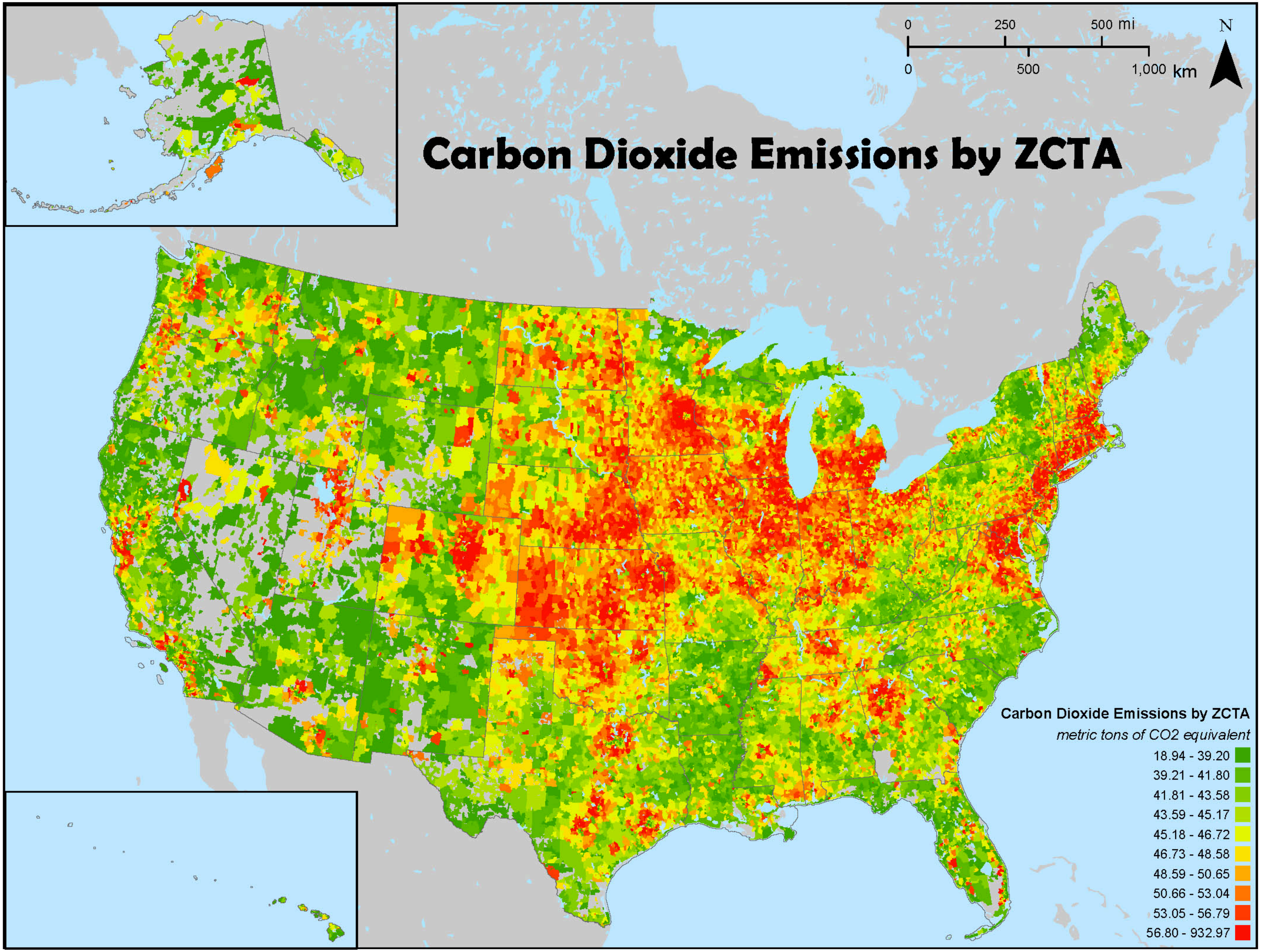

Carbon Dioxide Emissions by ZCTA
Goods
0
250
500 mi
0
500
1,000 km
N
Goods
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
2.39 - 4.05
4.06 - 4.28
4.29 - 4.46
4.47 - 4.61
4.62 - 4.77
4.78 - 4.96
4.97 - 5.19
5.20 - 5.55
5.56 - 6.14
6.15 - 15.07



Carbon Dioxide Emissions by ZCTA
Services
0
250
500 mi
0
500
1,000 km
N
Services
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
2.45 - 4.02
4.03 - 4.58
4.59 - 5.04
5.05 - 5.51
5.52 - 6.09
6.10 - 6.82
6.83 - 7.75
7.76 - 9.18
9.19 - 11.76
11.77 - 19.40

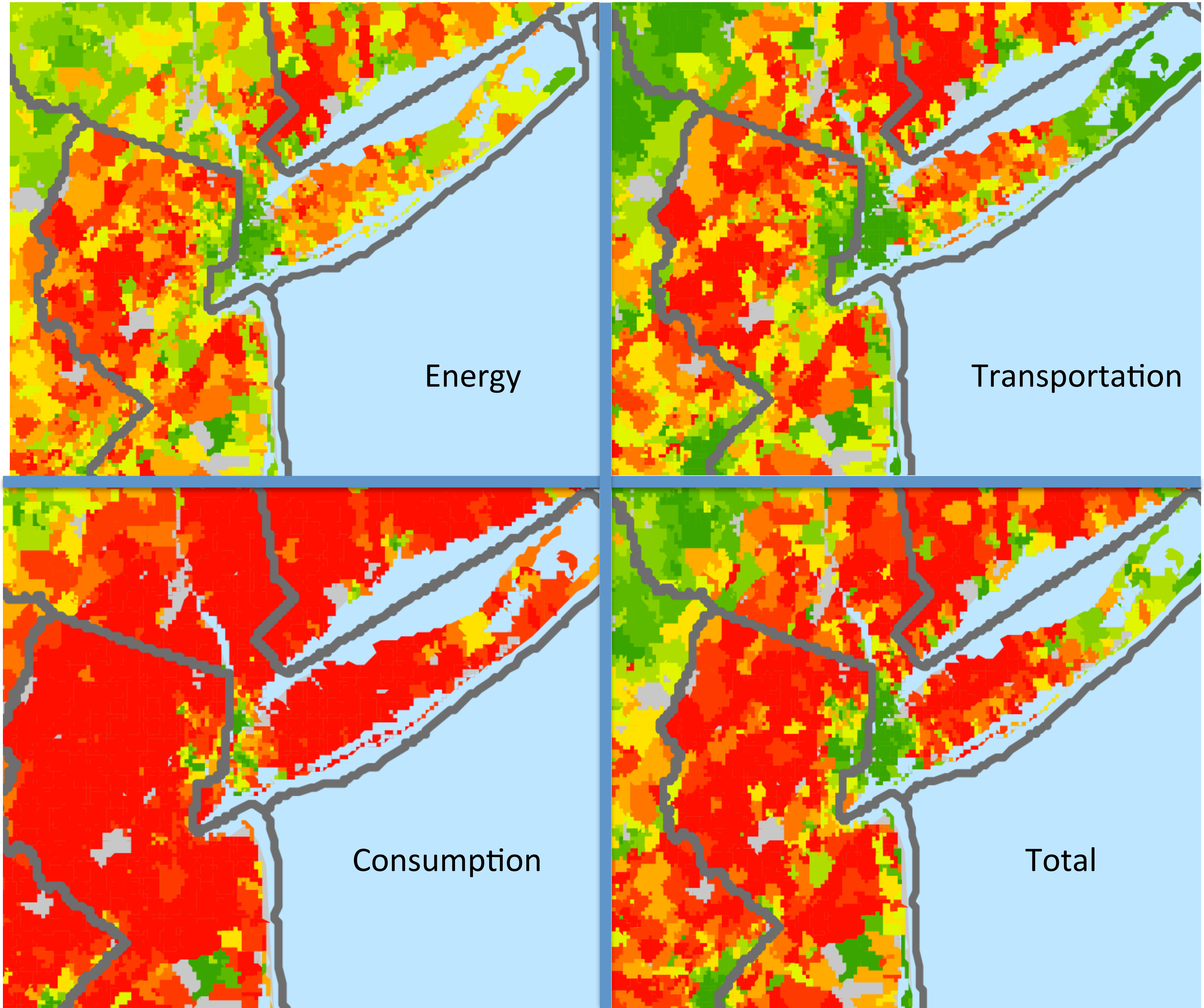


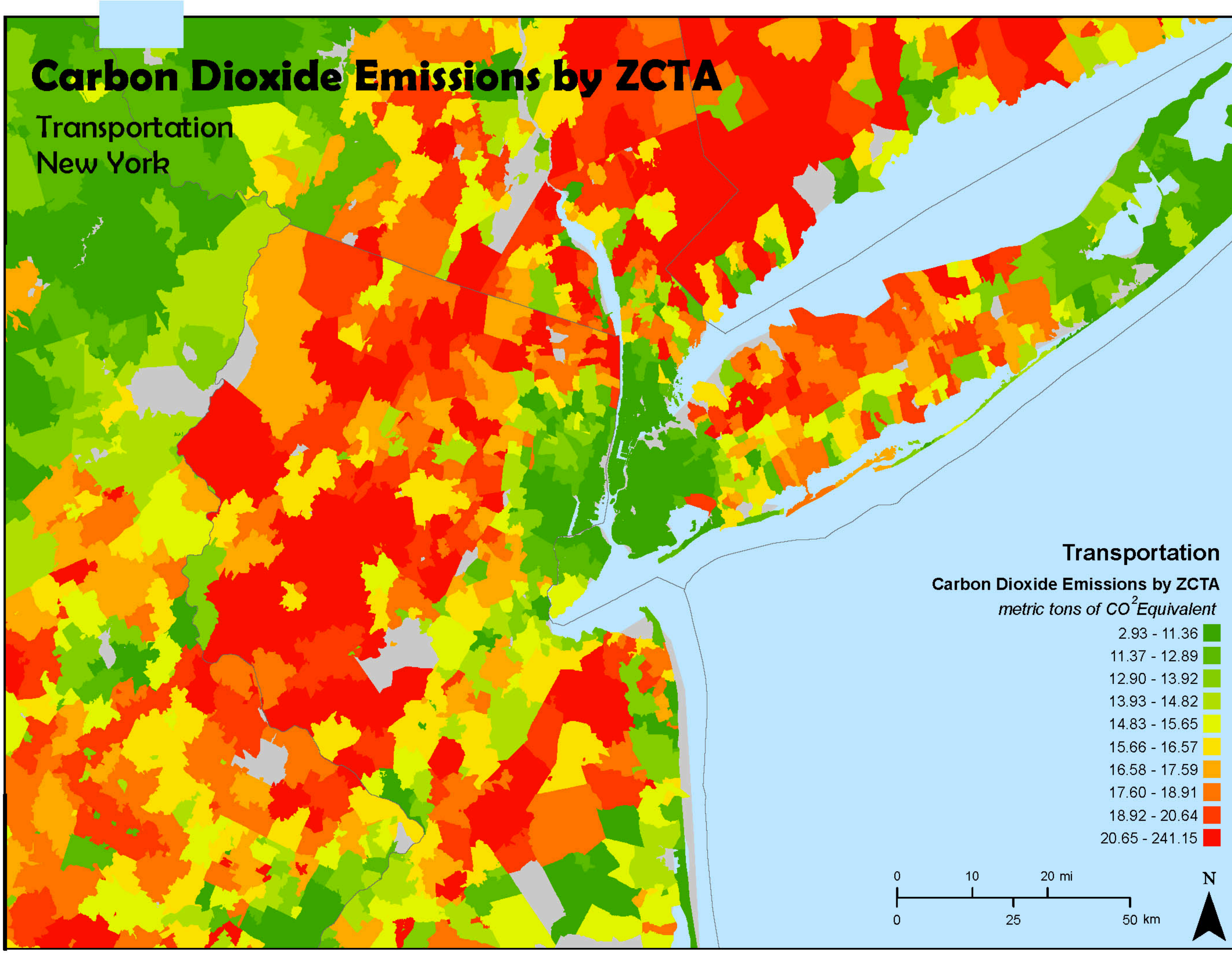
Carbon Dioxide Emissions by ZCTA
Food
0
250
500 mi
0
500
1,000 km
N
Food
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
2.26 - 5.78
5.79 - 6.05
6.06 - 6.22
6.23 - 6.36
6.37 - 6.49
6.50 - 6.63
6.64 - 6.79
6.80 - 7.01
7.02 - 7.40
7.41 - 906.45



Carbon Dioxide Emissions by ZCTA
0
250
500 mi
0
500
1,000 km
N
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
18.94 - 39.20
39.21 - 41.80
41.81 - 43.58
43.59 - 45.17
45.18 - 46.72
46.73 - 48.58
48.59 - 50.65
50.66 - 53.04
53.05 - 56.79
56.80 - 932.97

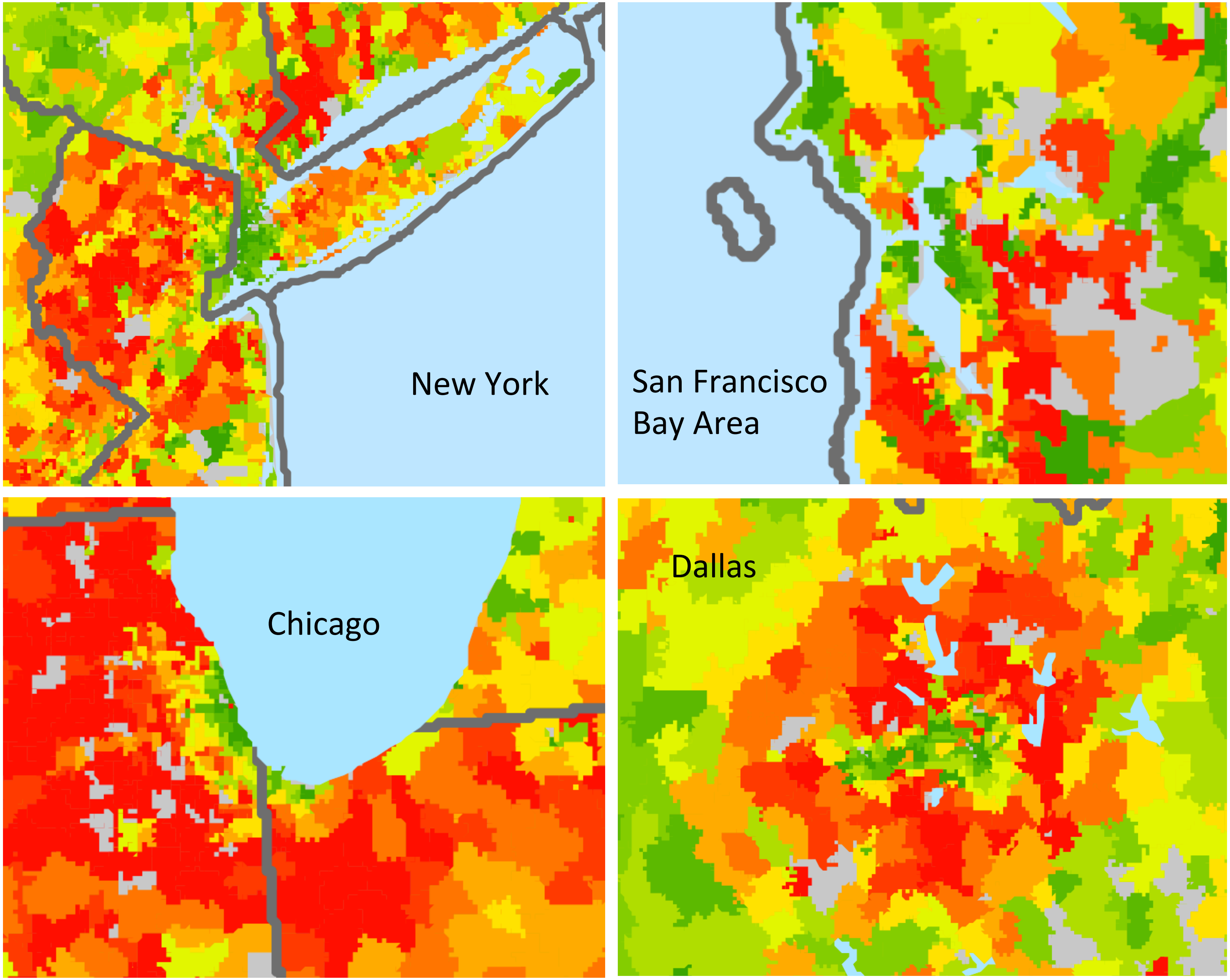
Household GHG emissions in New York Metro Region





Carbon Dioxide Emissions by ZCTA
Transportation
New York
Transportation
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 Equivalent
2.93 - 11.36
11.37 - 12.89
12.90 - 13.92
13.93 - 14.82
14.83 - 15.65
15.66 - 16.57
16.58 - 17.59
17.60 - 18.91
18.92 - 20.64
20.65 - 241.15
0 10 20 mi
0 25 50 km
N

Household GHG emissions in four metro regions



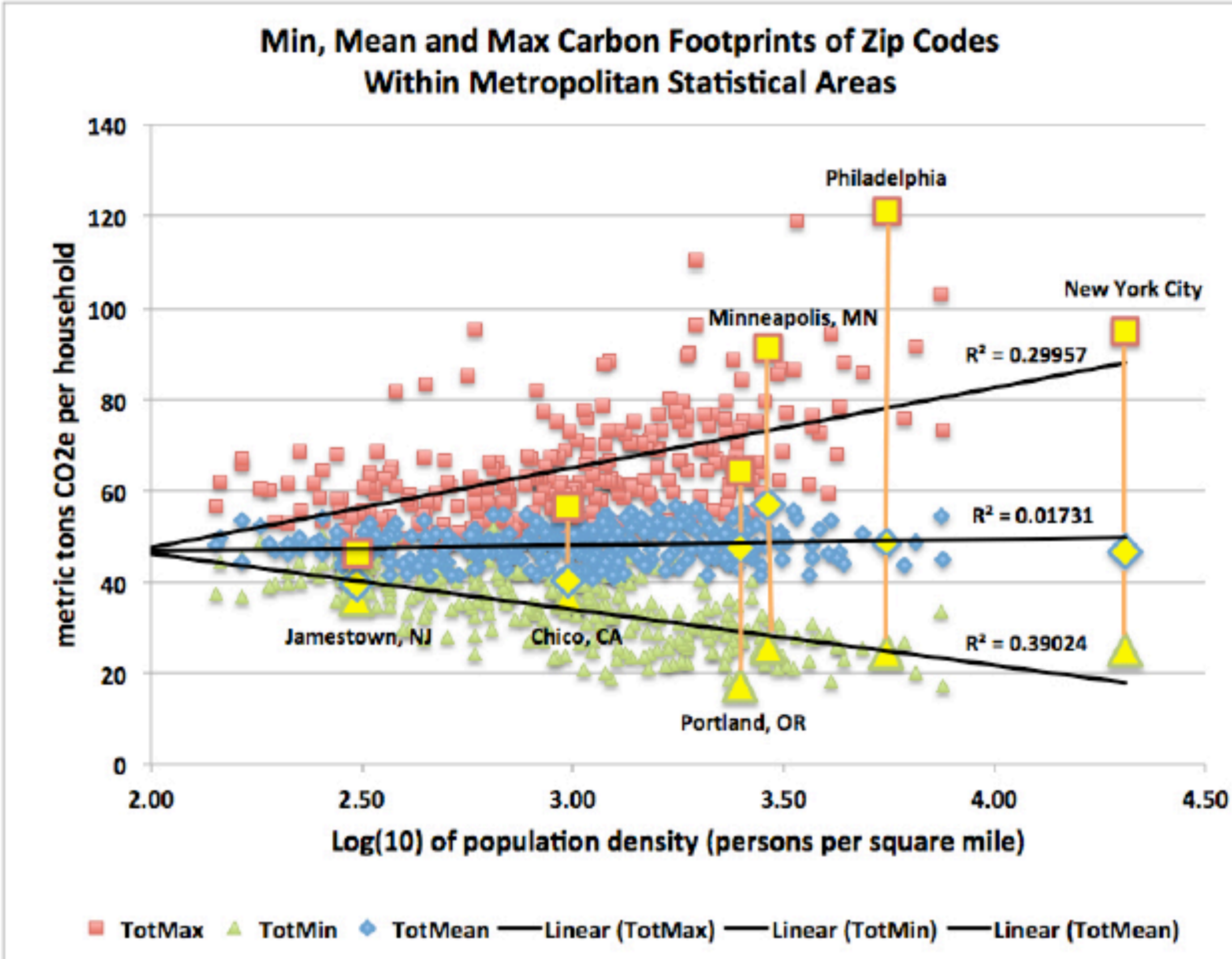


Figure S-4. Min, mean and max carbon footprints of zip codes within metropolitan statistical areas, ordered by log of population density (x-axis). Linear goodness of fit lines are drawn between min, mean and max values, including R-squared for each line. Results from six metropolitan regions are labeled, including Jamestown NJ (lowest mean HCF), Chico, CA (second lowest mean HCF), Portland, OR (includes zip code with lowest HCF), Minneapolis, MN (highest mean HCF), Philadelphia, PA (includes zip code with highest HCF), and New York, NY (highest population density).

California Climate Action Support Tool (CCAST)

RAEL — Renewable & Appropriate Energy Laboratory | California Environmental Protection Agency AIR RESOURCES BOARD | CoolCalifornia.org — Simple steps for a sustainable future

Introduction:
This tool is intended to help California local governments identify cost-effective and feasible greenhouse gas (GHG) reduction strategies and policies, which can be incorporated into a jurisdiction's climate action plan.

Instructions:
1) Introduction page: Adjust any cells in yellow on the introduction page. "Smart default" values are provided for each all cells in the tool.
2) Review information on supporting tabs and make any desired changes to assumptions for measures.
3) Consult documentation: link to documentation
4) Review results on introduction page

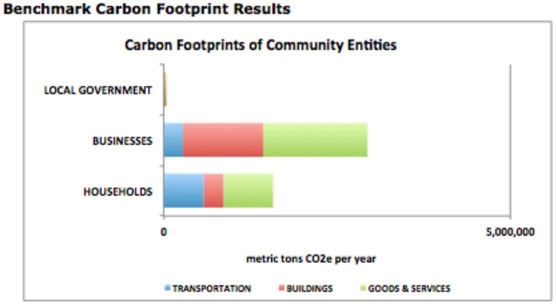
This tool does NOT:
1) Give credit, as defined in a cap and trade program;
2) Assume the greenhouse gas reductions, if implemented, will occur precisely at the value reported with this tool (e.g., if 50 MTCO2E reduction is reported with the tool, the ACTUAL reductions may or may not occur at this value);
3) Give guidance on how to verify emission values reported within this tool. (This work is done by the Local Government Toolkit & Local Government Operations Protocol)
4) Guarantee GHG emission reduction compliance with the California Environmental Quality Act (CEQA).

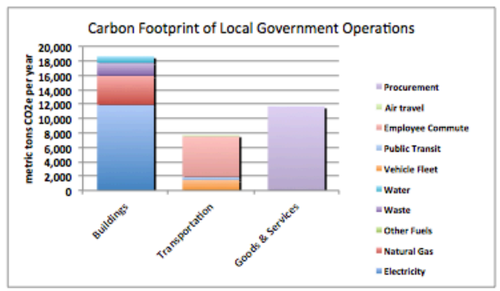
1. Select your County	Example CA County
2. Select your municipality	Example CA City
3. Year of assessment	2012

4. Critical assumptions based on your municipality

Population	100,000	Daytime Electricity Rate ($/kWh)	$0.14	Inflation Rate	3.0%	Community MSW (tons/yr)	96,000
# of Municipal Employees	3,100	Night time Electricity Rate ($/kWh)	$0.12	Electricity Inflation Rate	3.0%	MSW Diversion Rate	55.1%
Sq.ft. of Government Facilities	2,659,000	Residential Nat. Gas Rate ($/kcu.ft.)	$10.12	Natural Gas Inflation Rate	2.0%	Waste Region	Not Applicable
Electric Utility	SMUD	Commercial Nat. Gas Rate ($/kcu.ft.)	$8.44	Gasoline Inflation Rate	3.0%	Air District	SOUTH COAST
Natural Gas Utility	PG&E	Waste Disposal Rate ($/short ton)	$257.73	Nominal Discount Rate (without inflation)	8.0%	Res. Water Rate ($/gallon)	0.0020
Climate Zone	9	Price of Gasoline ($/gallon)	$4.20	Electricity Emissions Factor (tCO2/kWh)	0.000324	Hydro Zone	South Coast
		Price of Diesel ($/gallon)	$4.40			% homes built before 1980	63%

Benchmark Carbon Footprint Results





GHG Mitigation Measures Results

	Measure Type	Actor paying upfront cost, Actor receiving savings	Measure	Adoption rate	Lifetime of measure (years)	metric tons CO2e saved over lifetime	Upfront Cost	Annual net savings	Simple payback (years)	Annual Levelized Cost (Savings)	$/metric ton CO2e saved	NPV
1	BUILDING & FACILITIES	Households, Household	Exceed Title 24 for Residential Construction		10	50,544	$5,100,000	$484,045	10.5	-$113,536	-$22	$1,562,800
2	BUILDING & FACILITIES	puchasing policy	Purchase Energy-Efficient Heating		10	3,884	$87,000	$20,160	4.3	-$8,340	-$21	$61,380
3	BUILDING & FACILITIES	puchasing policy	Purchase Energy-Efficient Cooling		10	789	$295,528	$22,704	13.0	$3,061	$39	-$35,115
4	BUILDING & FACILITIES		Install Reflective Roofing		30	183	$178,000	$140,399	1.3	-$127,467	-$20,845	$1,754,567
5	BUILDING & FACILITIES	Local Government	Recommissioning of existing buildings	50%	20	22,014	$398,850	$454,612	0.9	-$422,607	-$384	$5,266,618
6	BUILDING & FACILITIES	puchasing policy	Use Energy-Efficient Computers		10	172	0.0	$20,203	N/A	-$20,203	-$1,172	$156,000
7	BUILDING & FACILITIES	puchasing policy	Use Energy-Efficient Copiers		10	6	0.0	$528	N/A	-$528	-$831	$4,077
8	BUILDING & FACILITIES	puchasing policy	Use Energy-Efficient Printers		10	32	0.0	$3,168	N/A	-$3,168	-$986	$24,464
9	BUILDING & FACILITIES		Replace T12 with T-8 fluorescent lamps		10	1,078	$1,705,711	$495,567	3.4	-$263,816	-$2,447	$1,941,705

Data for Figures

Carbon Footprint of municipal actors

	HOUSEHOLDS	BUSINE
TRANSPORTATION	578,823	27
BUILDINGS	286,840	1,15
GOODS & SERVICES	711,569	1,50
TOTAL	1,577,232	2,93
Units	35,714	

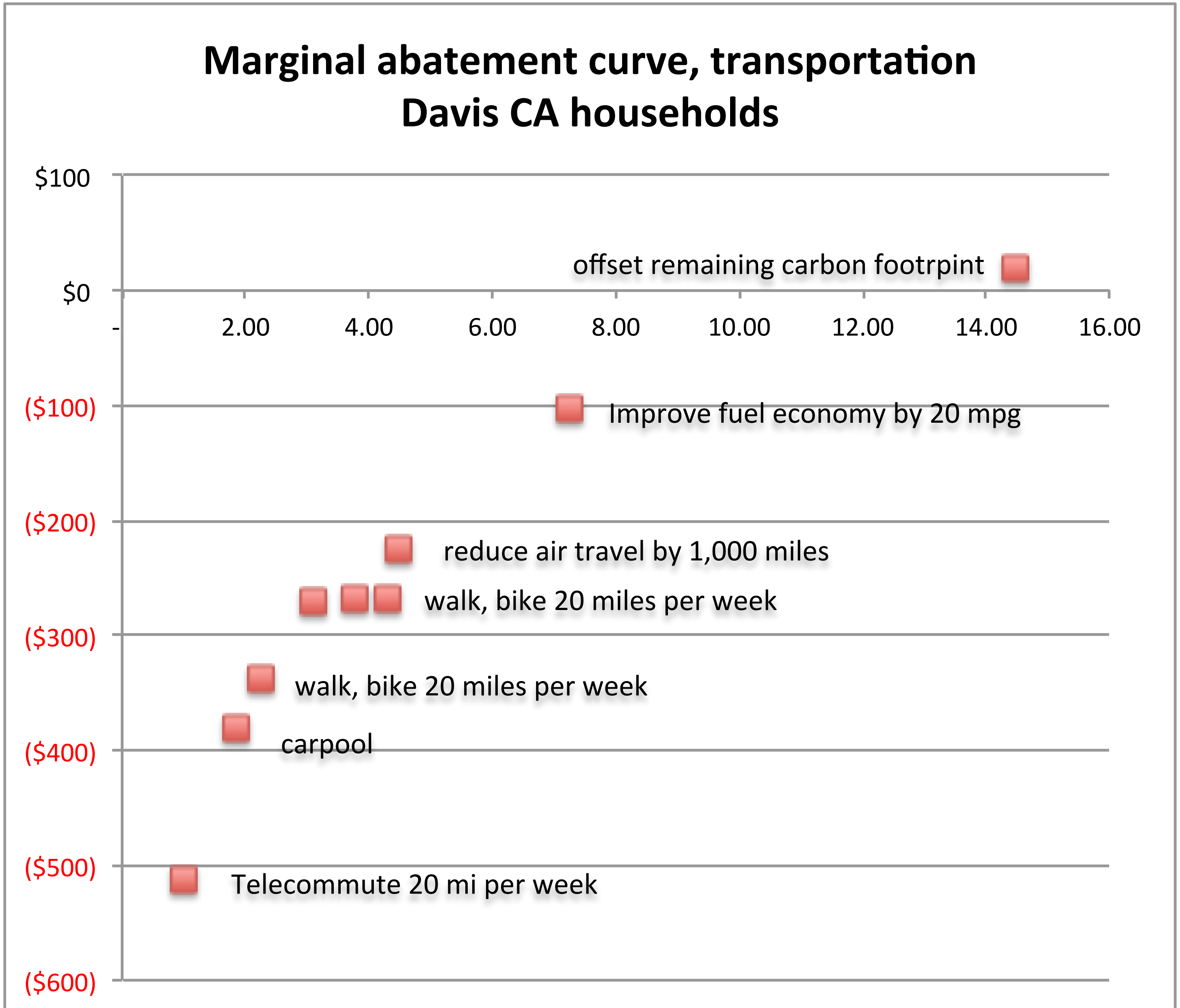
MUNICIPAL GOVERNMENT FOOTPRINT

	Buildings	Transport
Electricity	11,939	
Natural Gas	4,038	
Other Fuels		
Waste	1,801	
Water	901	
Vehicle Fleet		
Public Transit		
Employee Commute		
Air travel		
Procurement		
TOTAL	18,679	

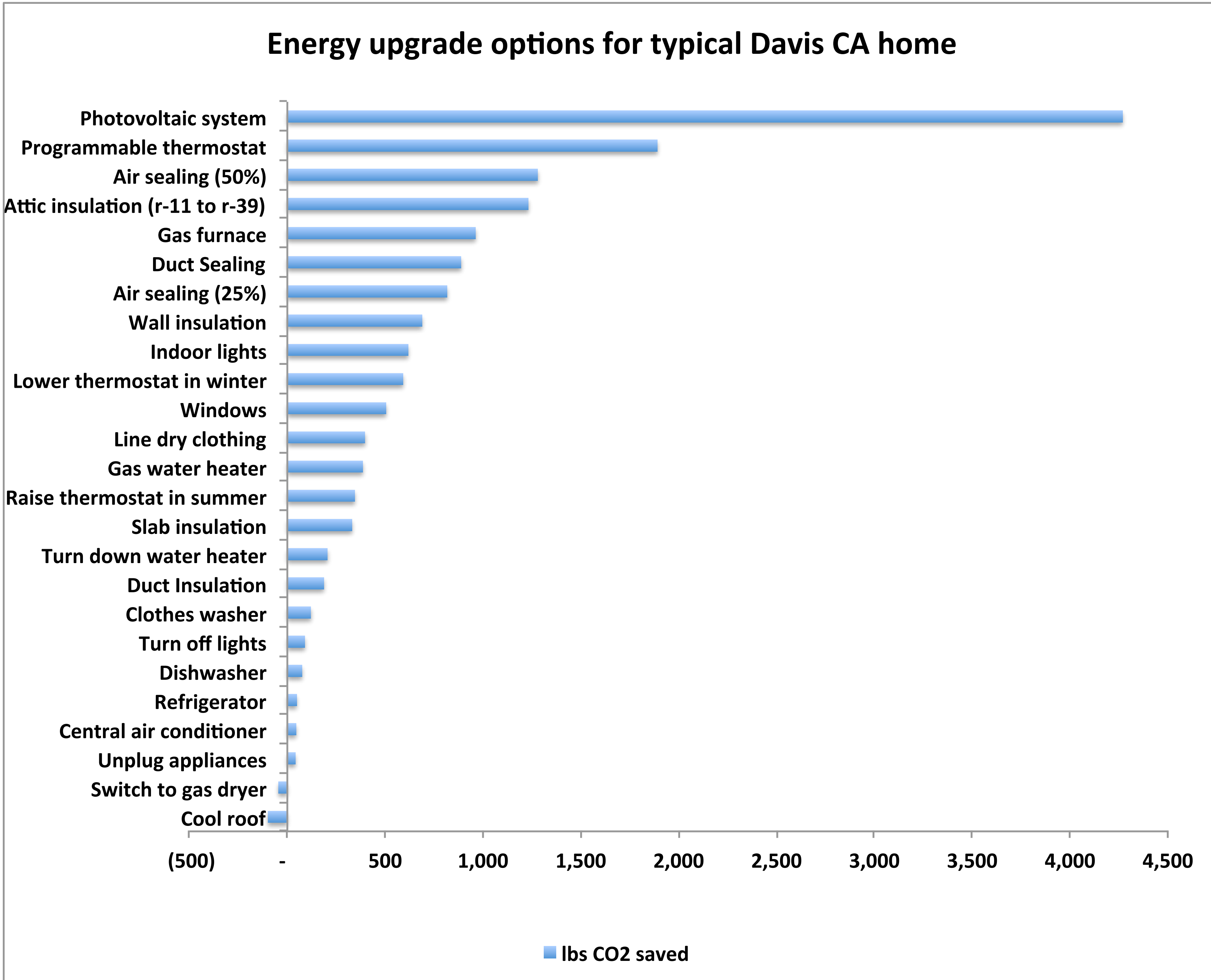
Water assumed to be 50% of waste

Introduction | Copyright | Buildings | Buildings Data | Power | Power Data | Solid Waste | Solid Waste Data | Streetlights | Streetlights Data | Transit | Transit Data

Normal View | Ready | Sum=10



Marginal abatement curve, transportation
Davis CA households
$100
$0
($100)
($200)
($300)
($400)
($500)
($600)
-
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
offset remaining carbon footrpint
Improve fuel economy by 20 mpg
reduce air travel by 1,000 miles
walk, bike 20 miles per week
walk, bike 20 miles per week
carpool
Telecommute 20 mi per week


Energy upgrade options for typical Davis CA home
Photovoltaic system
Programmable thermostat
Air sealing (50%)
Attic insulation (r-11 to r-39)
Gas furnace
Duct Sealing
Air sealing (25%)
Wall insulation
Indoor lights
Lower thermostat in winter
Windows
Line dry clothing
Gas water heater
Raise thermostat in summer
Slab insulation
Turn down water heater
Duct Insulation
Clothes washer
Turn off lights
Dishwasher
Refrigerator
Central air conditioner
Unplug appliances
Switch to gas dryer
Cool roof
(500)
-
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
lbs CO2 saved

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- Save Money & the Planet — LEARN MORE»
- Reduce Your Climate Impact — CALCULATE NOW»
- Climate Awards — LEARN MORE»
- Give us your Feedback — VIEW»

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TAKE ACTION TO KEEP THE PLANET COOL

WELCOME TO COOLCALIFORNIA.org, our goal is to provide resources to all Californians in order to reduce their environmental impact and take action to stop climate change. Realizing local governments, businesses, schools and individuals have different needs, we have customized pages for each audience. Click the tabs above to find:

- Money saving actions and best practices
- Financial incentives for actions and projects
- Carbon footprint and greenhouse gas emissions calculation tools
- Case studies and Success stories
- Educational resources

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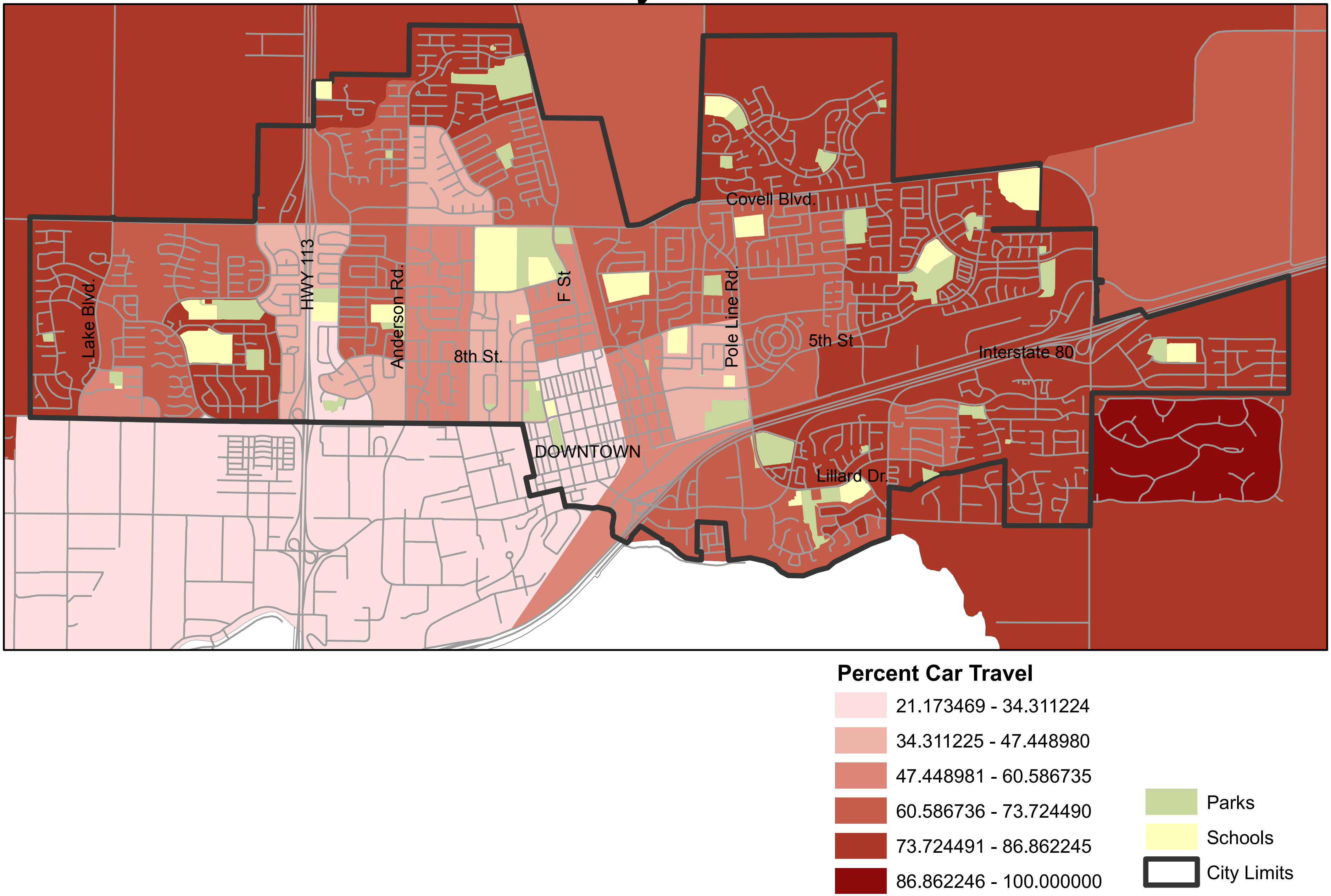
- Household Actions
- About Us
- Small Biz Actions
- Small Business Award Program

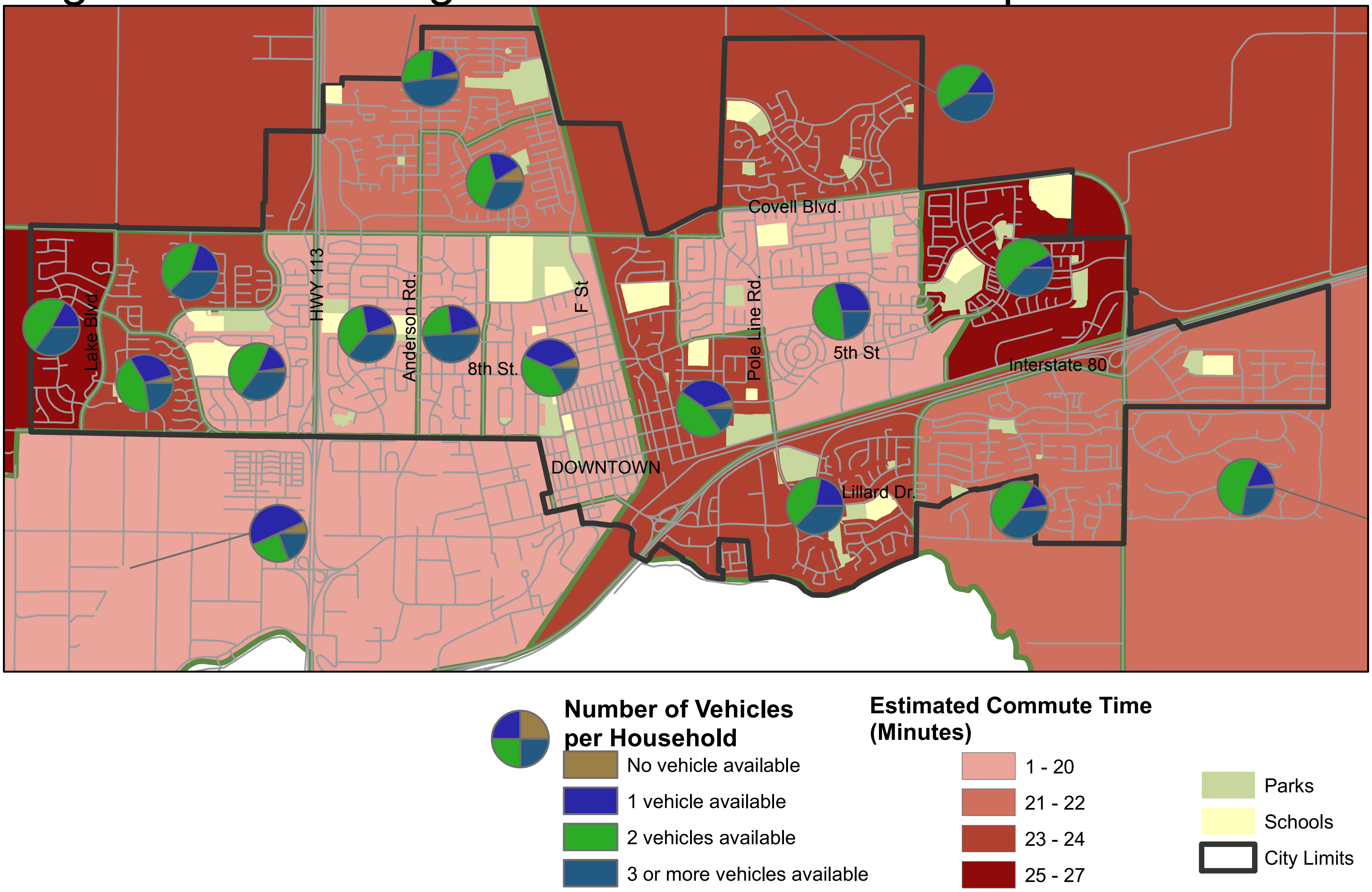
Recent Case Studies

- Diamond D General Engineering
  Heavy civil general engineering construction company...
- The Living Christmas Company

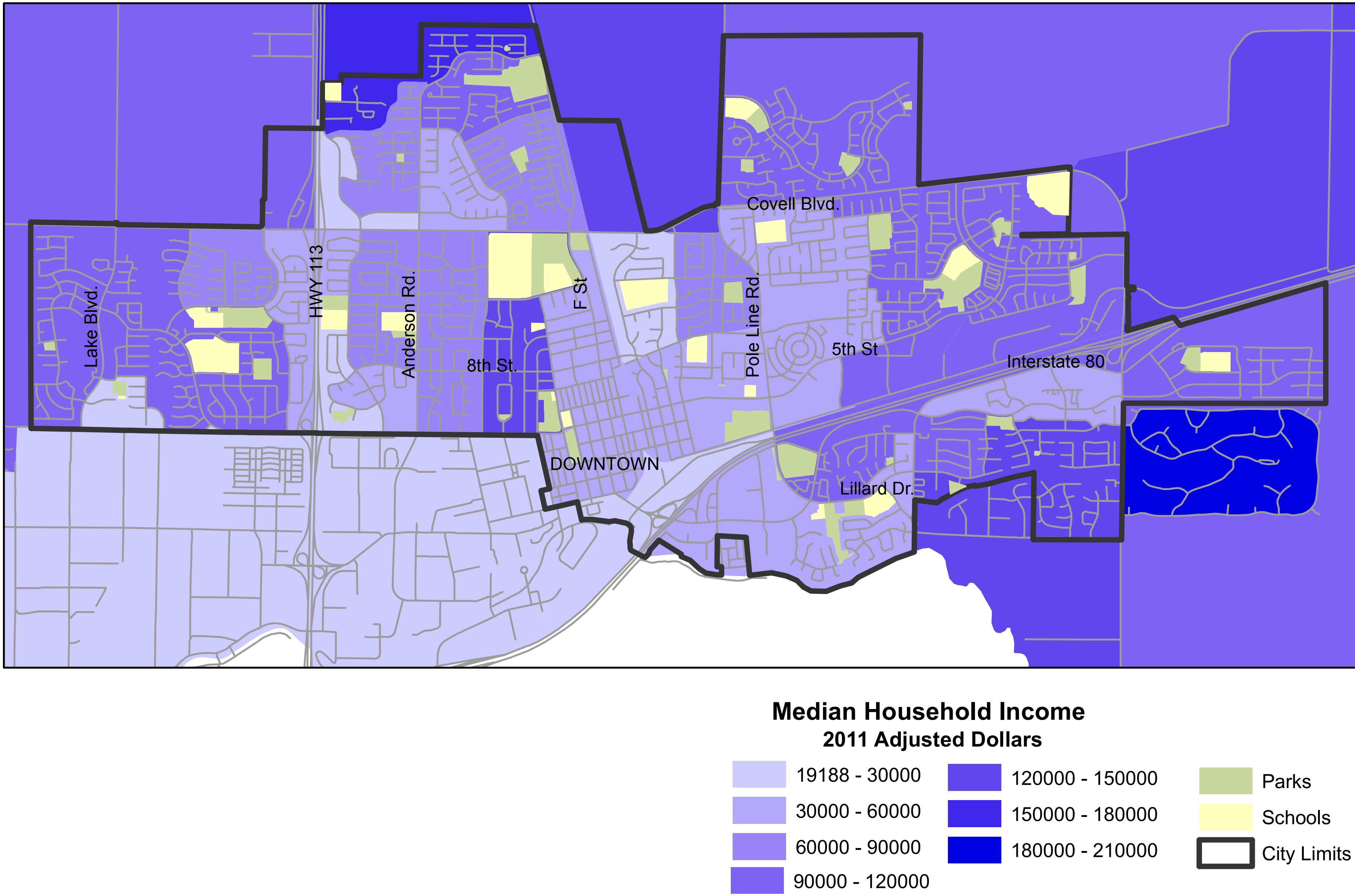
City of Davis
Percent of Work Commutes by Car

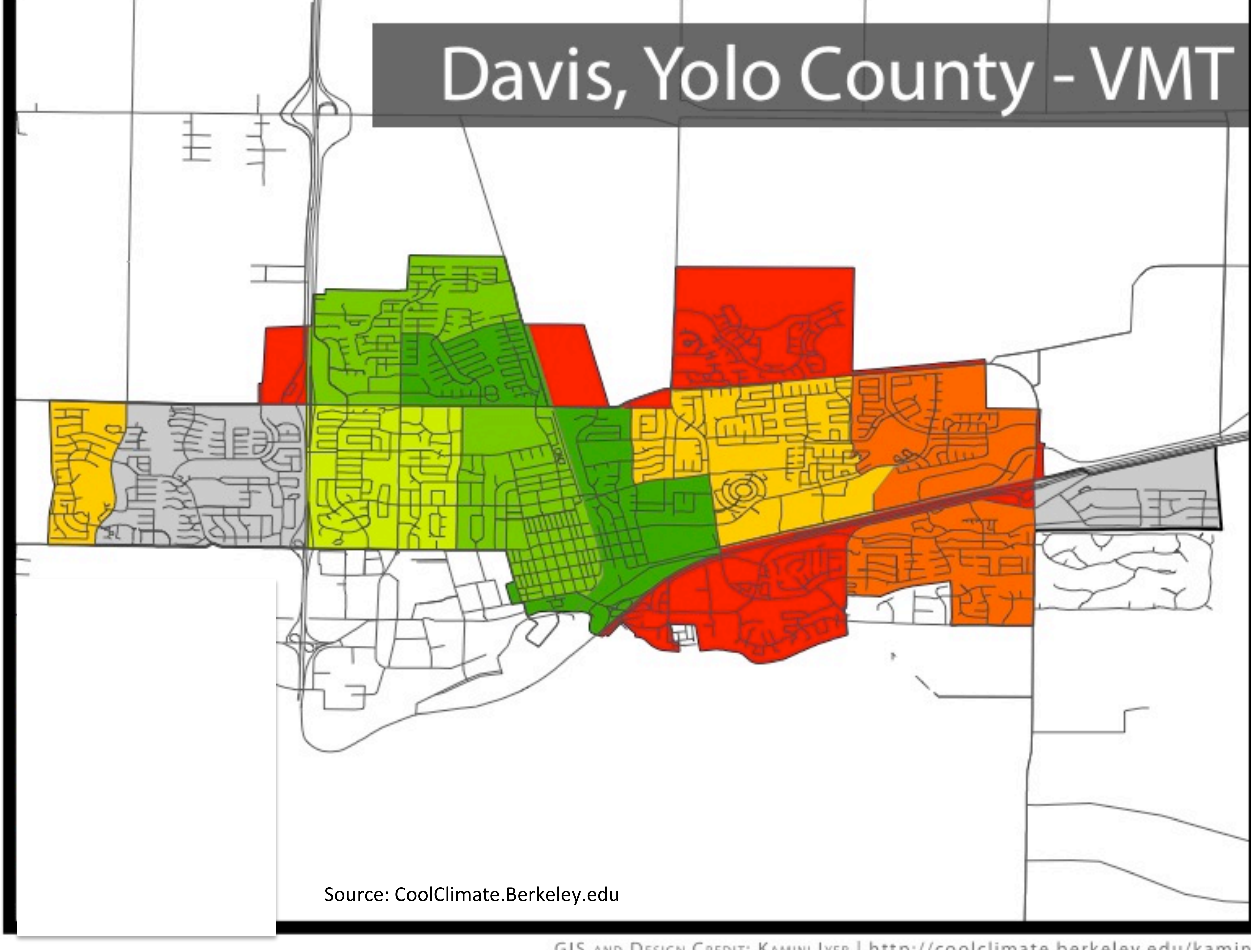


City of Davis
Avg. Commute Length & Number of Vehicles per Household

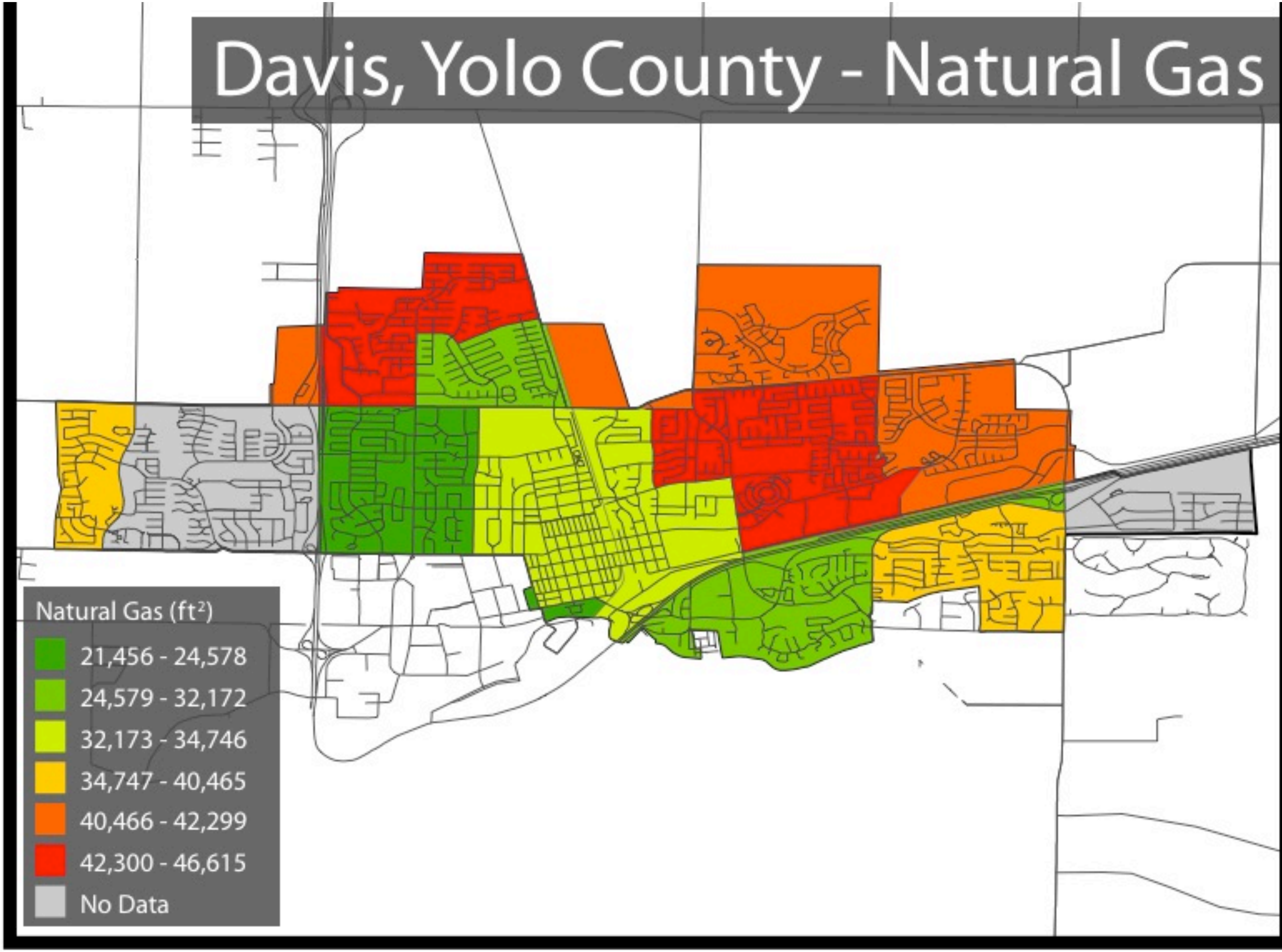


City of Davis
Median Household Income





Source: CoolClimate.Berkeley.edu



GIS and Design Credit: Kamini Iyer | http://coolclimate.berkeley.edu/kamini

Greenhouse gas and sustainability calculators:

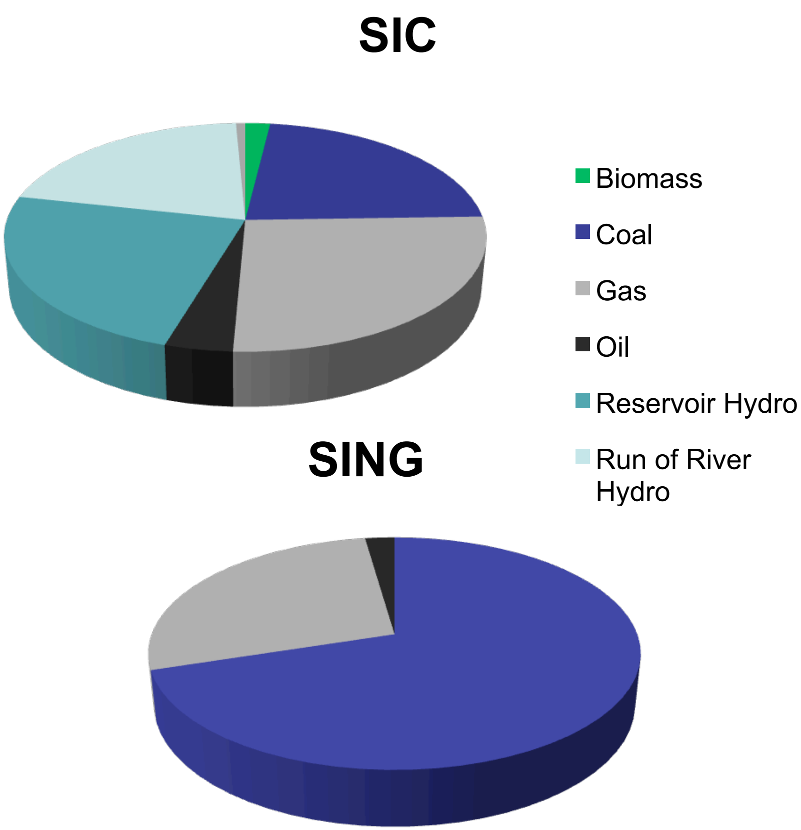
http://coolclimate.berkeley.edu

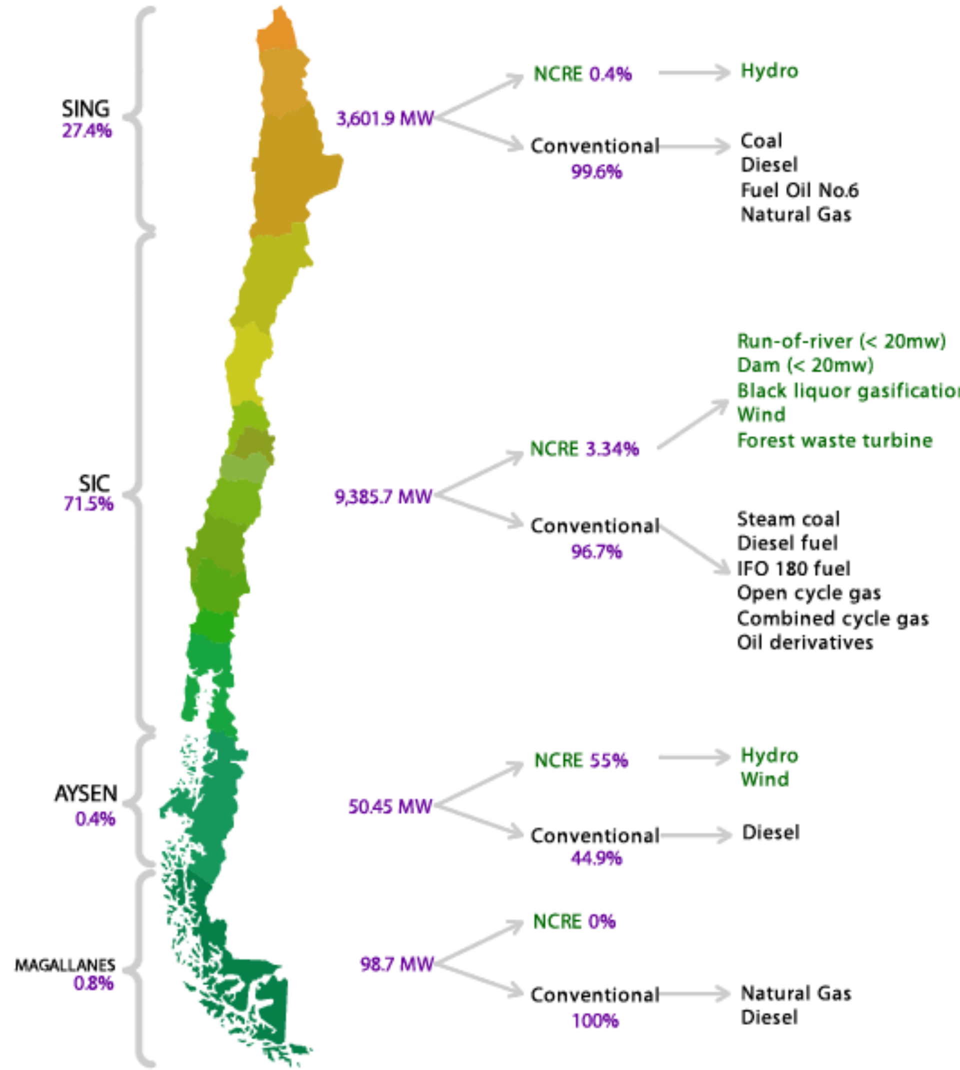
&

http://www.coolcalifornia.org

Four Grids in Chile

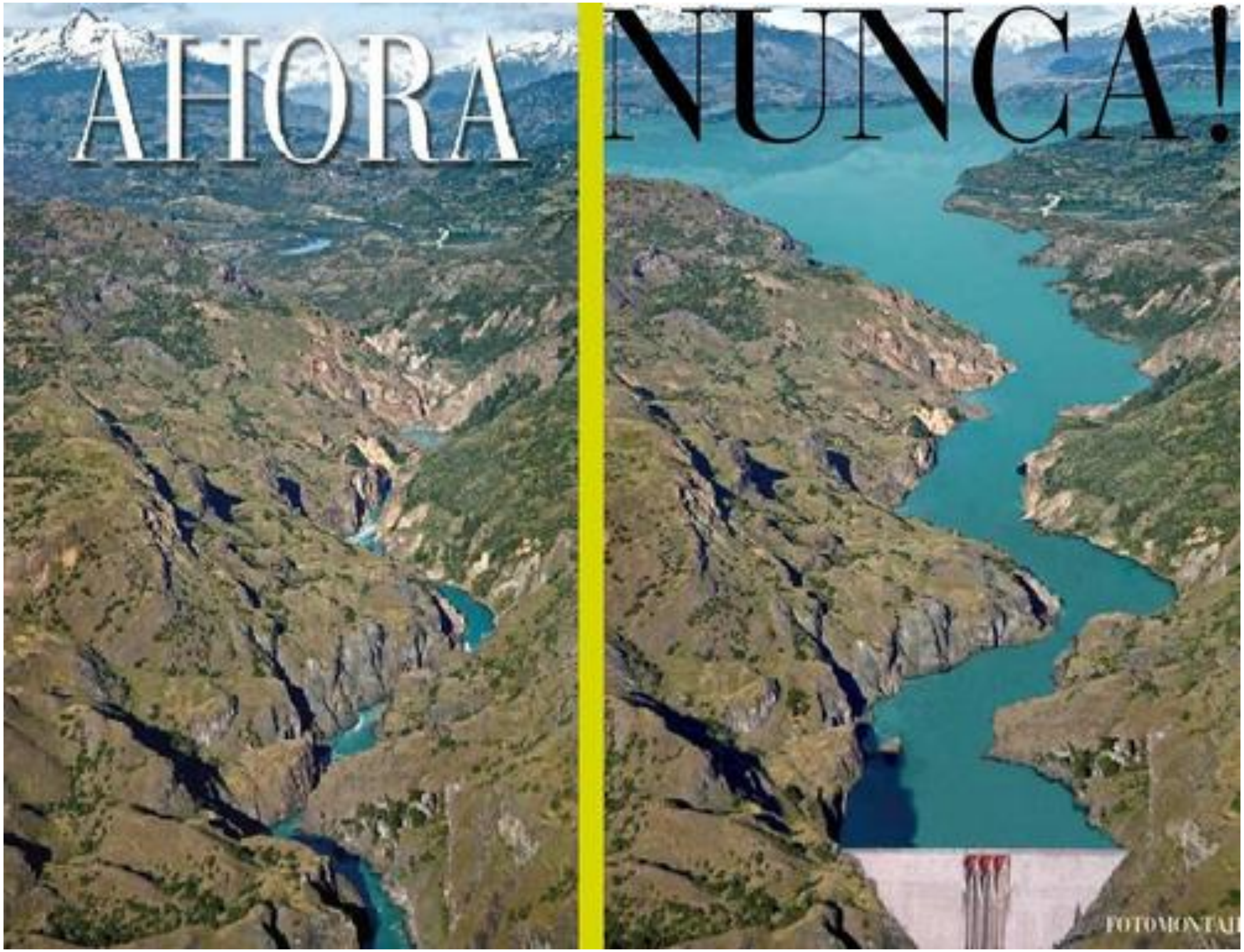
- Production Mix for 2011



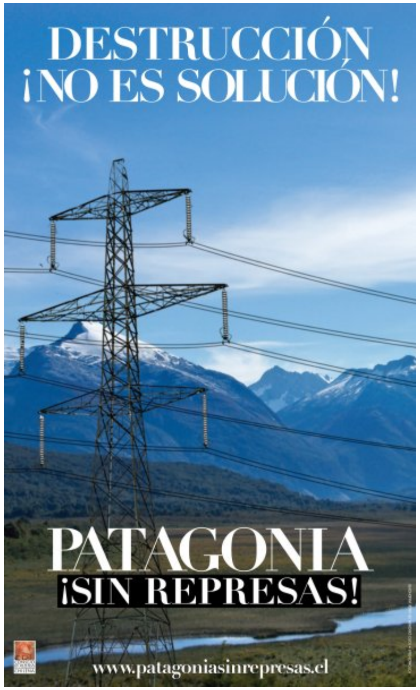


Source: http://www.investchile.cl/opportunities/renewable_energy/renewable_energy/regional_distribution_of_the_sector

SWITCH-Chile: hard policy decisions

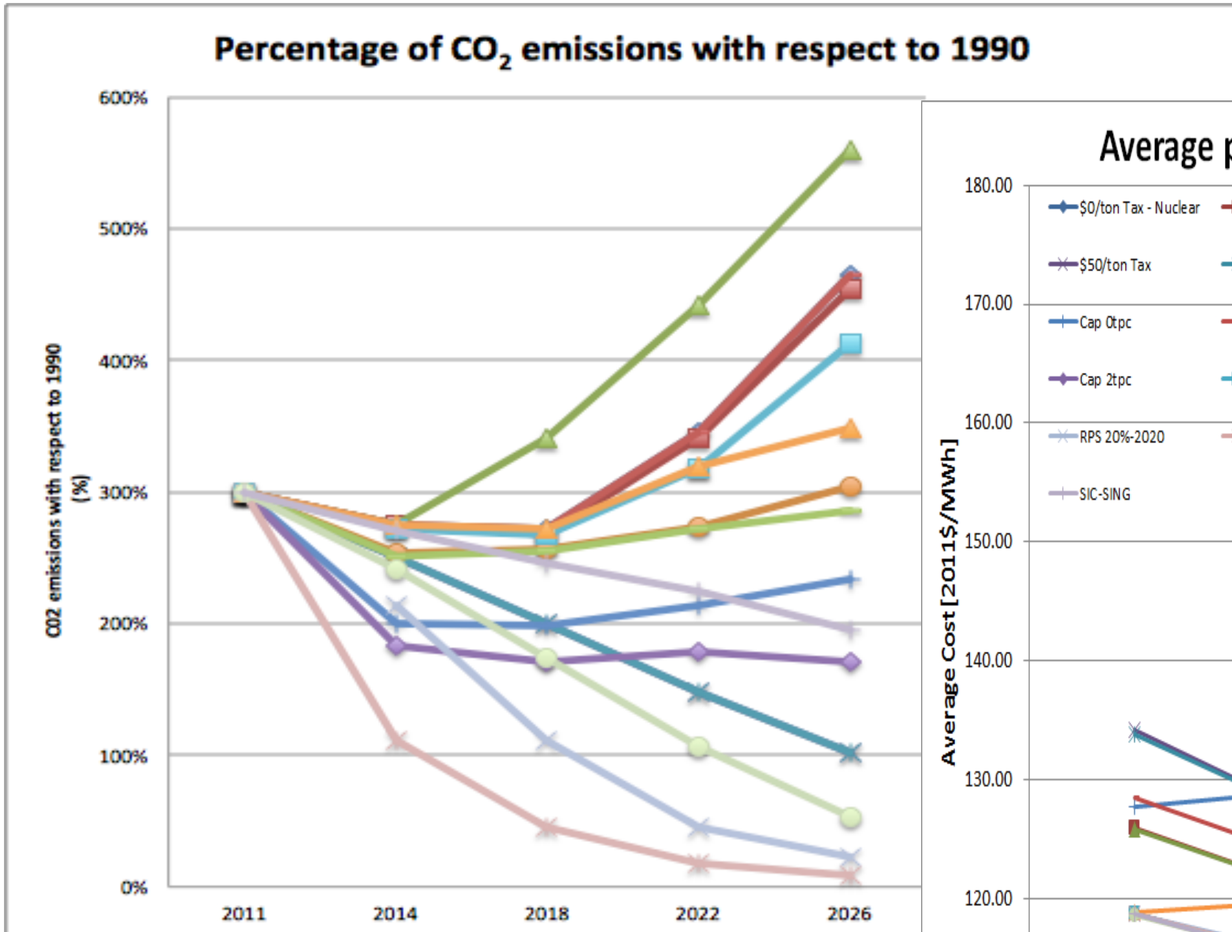


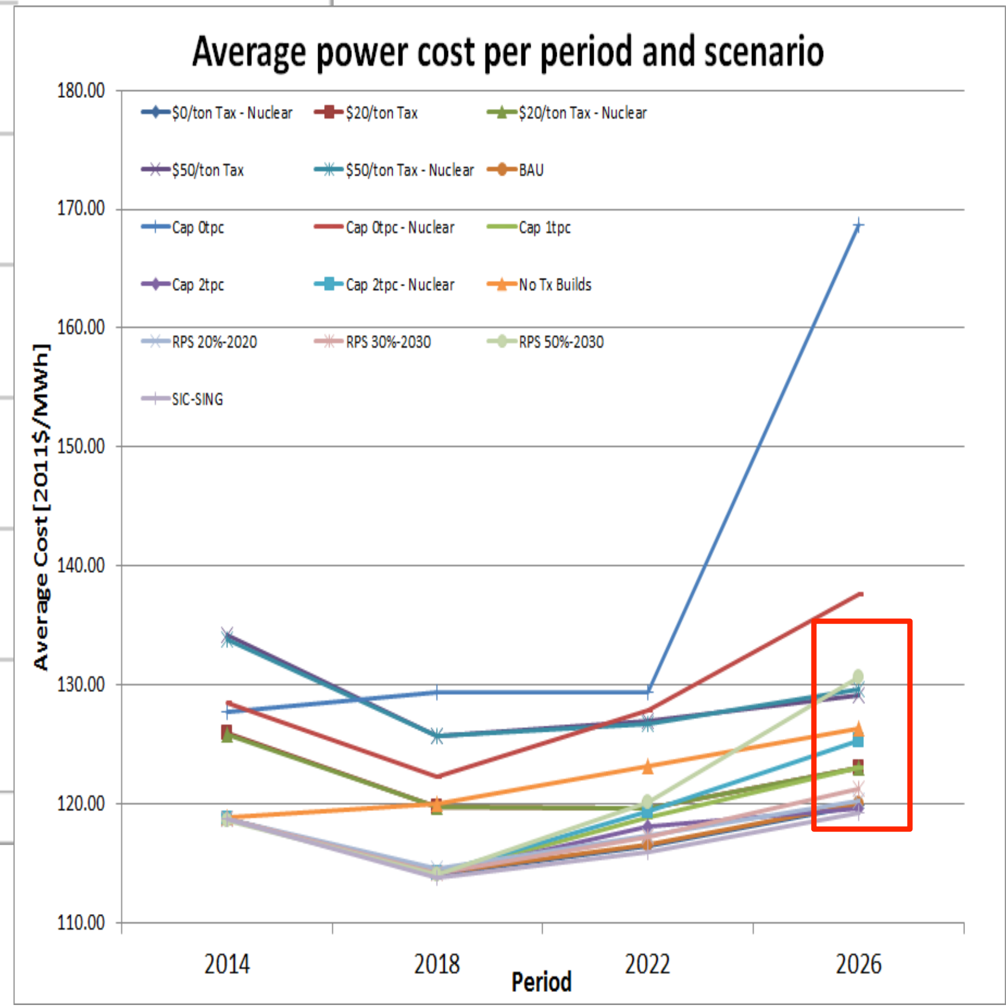
Source: http://www.democraticunderground.com/110819602



Source: http://
www.elciudadano.cl

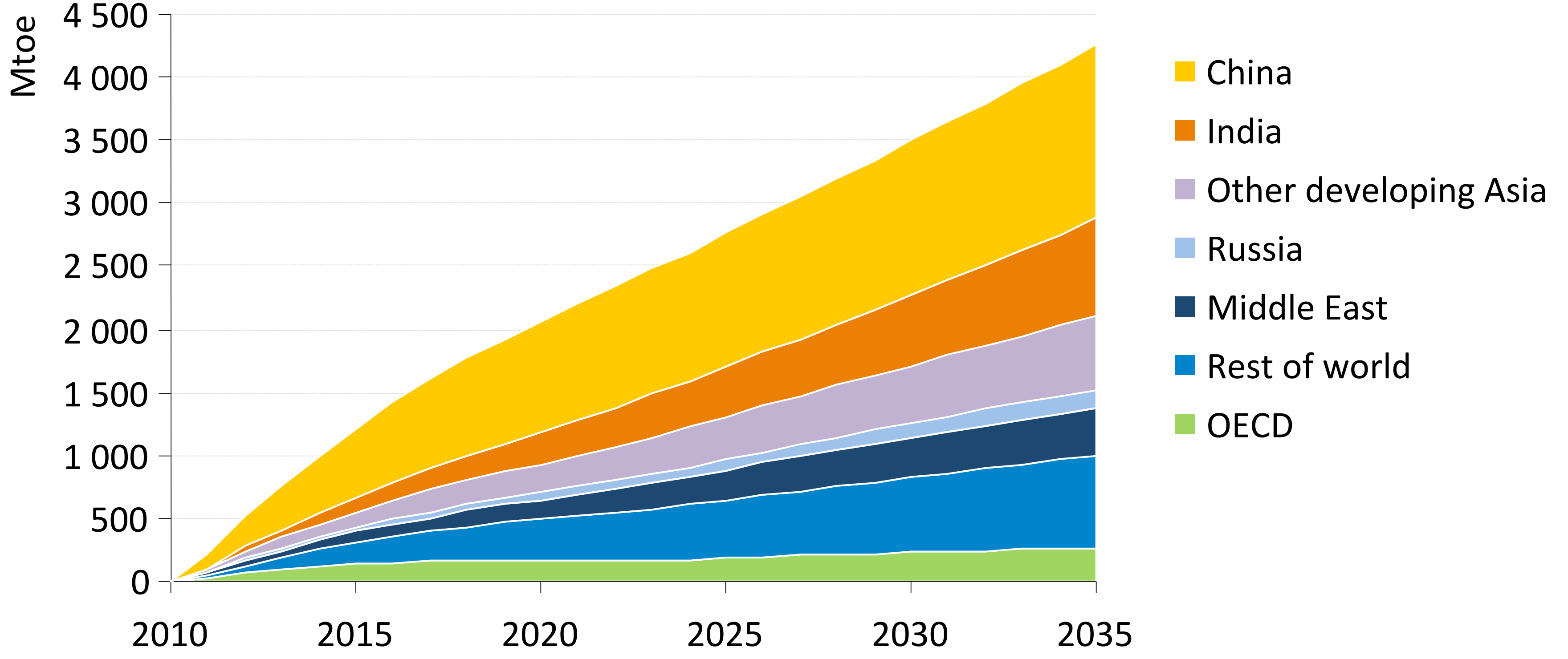
… supports existing policy choices …





Emerging economies drive global energy demand

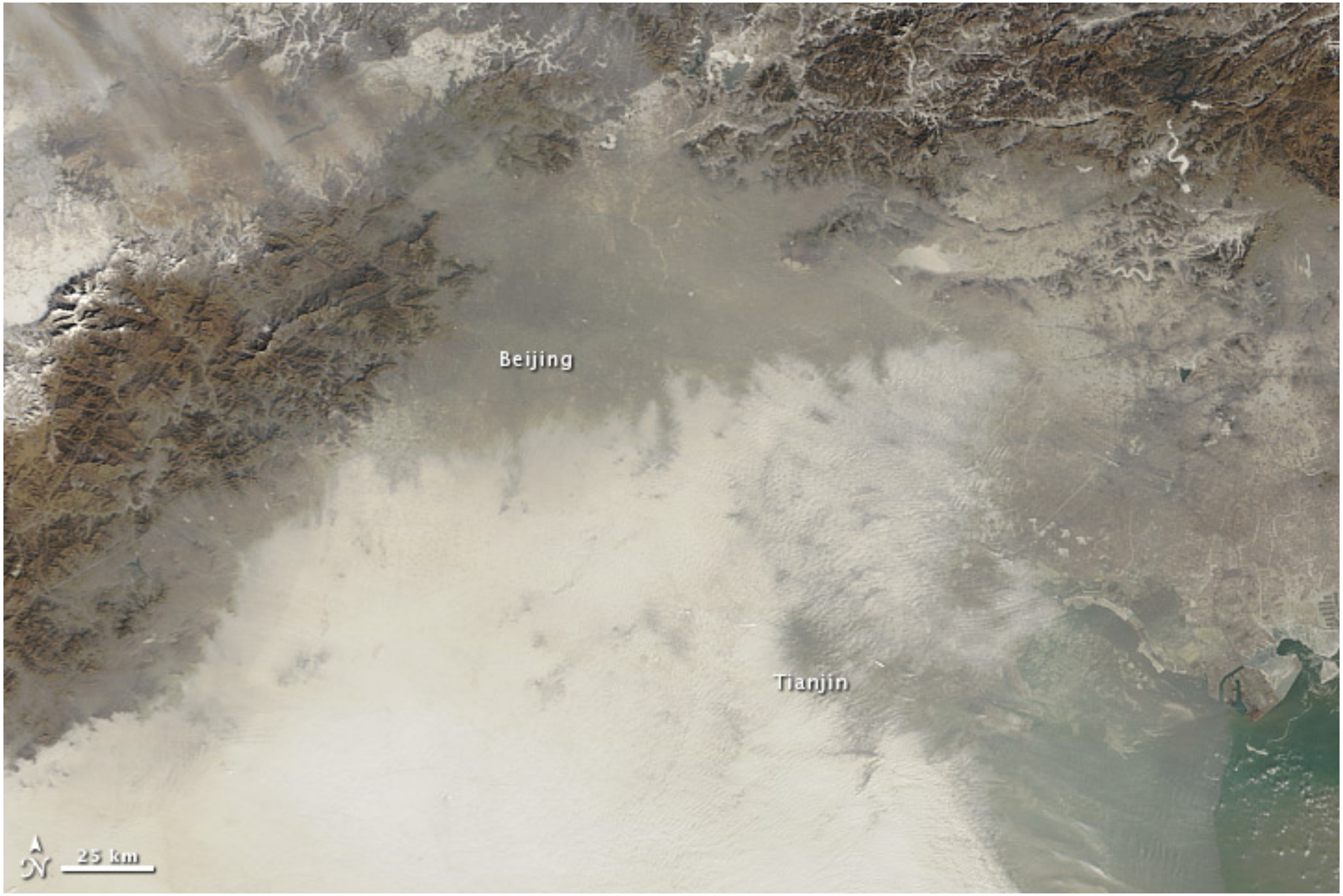
- Growth in primary energy demand



- Global energy demand increases by one-third from 2010 to 2035, with China & India accounting for 50% of the growth

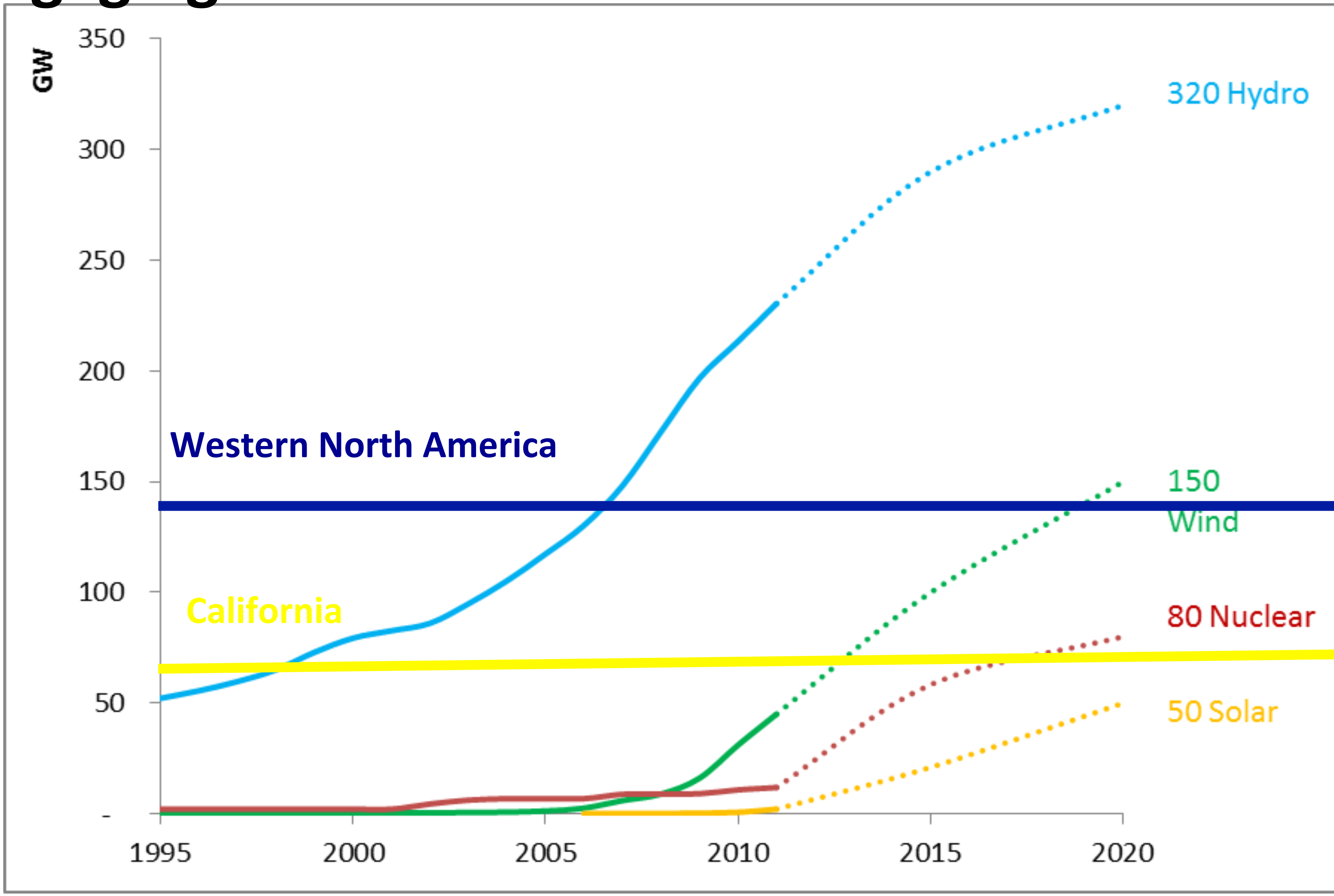
Source: IEA WEO 2011

Beijing and northern China hit hazardous air pollution in mid Jan 2013



Source: http://earthobservatory.nasa.gov/IOTD/view.php?id=80152

Engaging China on Clean Economic Growth



Data Source: Gang He and Daniel M. Kammen,
China Statistic Yearbook; CEC; Chinese Renewable Energy Industry Association. 2020 targets proposed by Chinese planners

A energy and development strategy for the next decade

OFFICIAL USE ONLY
CODE2011-0021

March 16, 2011

For meeting of
Committee: Monday, April 11, 2011

COMMITTEE ON DEVELOPMENT EFFECTIVENESS

FROM: The Secretary, Committee on Development Effectiveness

Energizing Sustainable Development:
Energy Sector Strategy of the World Bank Group

66 **The WBG will finance greenfield coal power generation projects in IDA countries only, and in accordance with the WBG operational guidance on screening coal projects.** The WBG fully recognizes that coal will continue to be used across developed and developing countries in the coming decades. However, given its limited resources, the WBG will restrict its financing in power generation to IDA countries for the purpose of increasing access and improving the reliability of energy services. No new coal-based power generation project will be financed in IDA-blend or IBRD countries.[5] The WBG would, however, consider assistance for emerging technologies, such as coal-combustion plants with carbon capture and storage, in all countries. The World Bank is supporting institutional capacity building through the Carbon Capture and Sequestration Capacity Building Trust Fund, launched in December 2009 (Annex 1).

A energy and development strategy for the next decade

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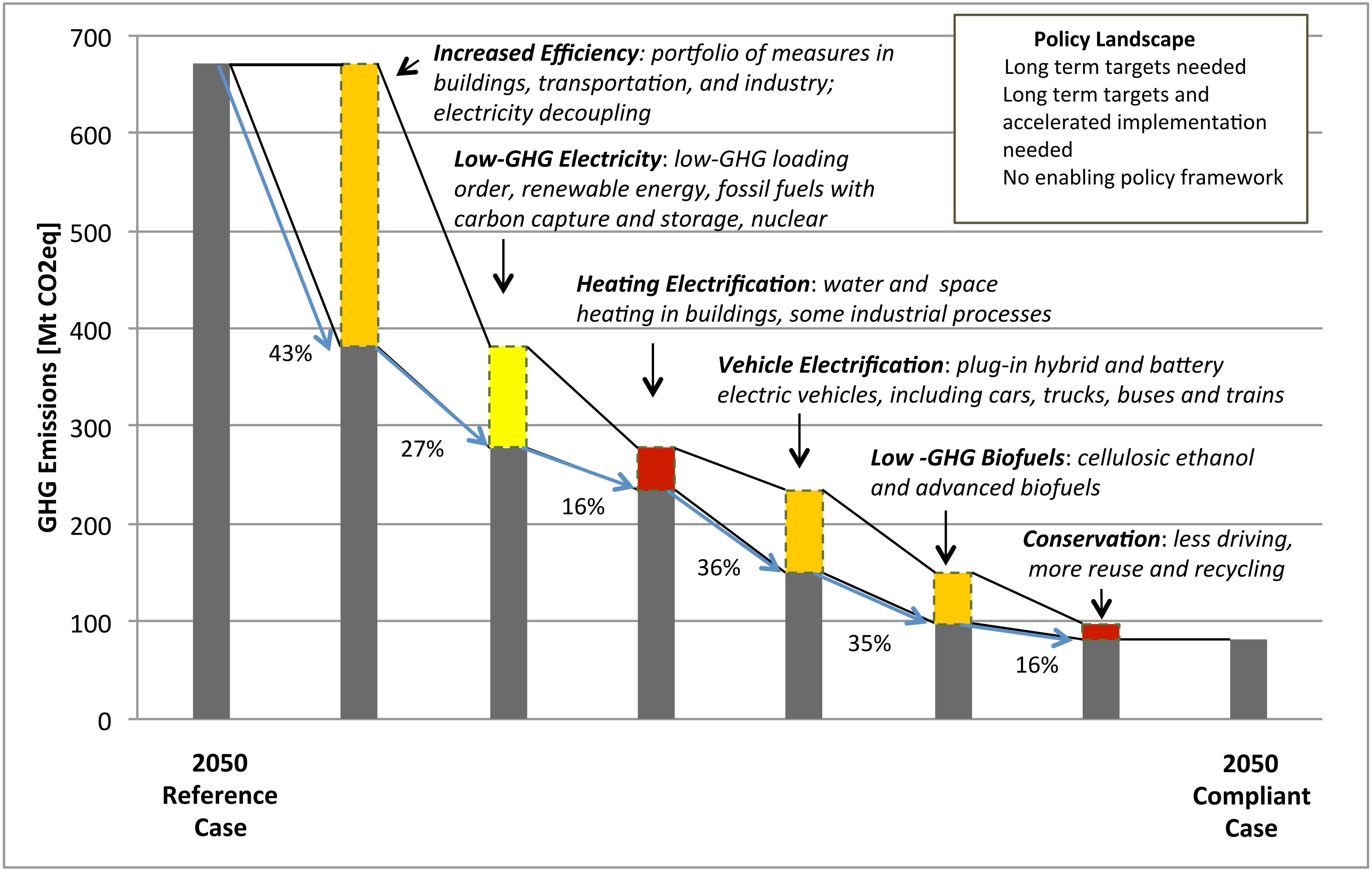
FROM: The Secretary, Committee on Development Effectiveness

Energizing Sustainable Development:
Energy Sector Strategy of the World Bank Group

85 **The WBG will undertake GHG emissions analysis in energy investment projects as a business requirement to help countries identify lower-emissions alternatives and seek additional financing**. The practice of undertaking GHG emissions analysis will be extended beyond coal projects

Dense Networsk: Systems Science and California's Greenhouse Gas *and* Local Environmental Goals

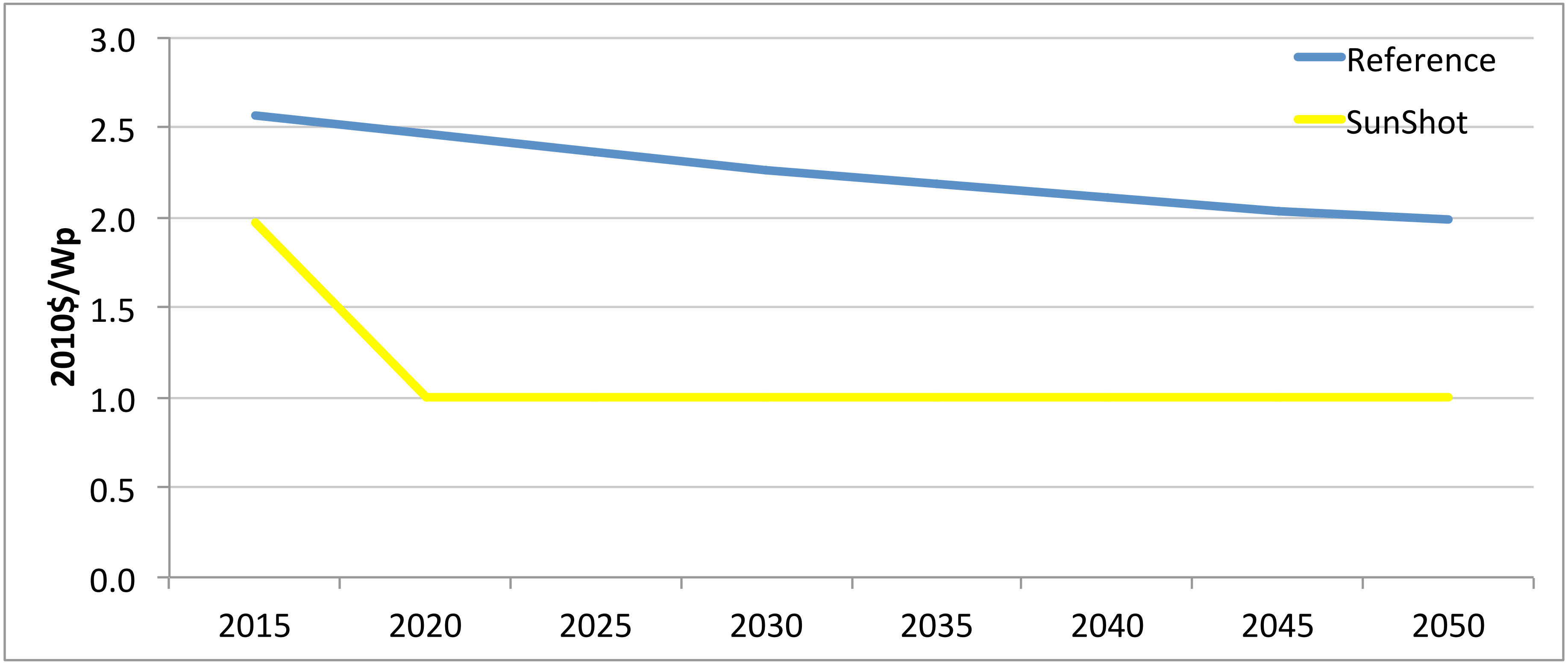
1979 Decades of sustained energy efficiency investments
1980 Decoupling electricity revenues and sales
1996 Electricity de-regulation (a mess) & re-regulation
2000 Electricity loading order (EE / RE / fossil)
2006 2050 target of 80% less greenhouse gas emissions
2006 Global warming solutions act (25% reduction by 2020
2007 Low-Carbon fuel standard (1% less CO_2/mile/year)
2010 Increase RPS to 33% of electricity from RE by 2020
2012 Electric vehicle mandate (1 million EVs in 2020 years)
2012 12 GW DG Mandate



Wei M, Nelson, J.H, Greenblatt, J.B., Mileva, A., Johnston, J.,Ting, M., Jones, C.M., Yang, C., McMahon, J.E., Kammen, D.M., *Deep carbon reductions in California require electrification and integration across economic sectors*. Environmental Research Letters (8) 014038

- *Reference Scenario*:
  - Carbon cap across the WECC: 1990 emissions levels by 2020, 86% below 1990 levels by 2050
  - No technological cost-reductions assumed with the exception of solar and battery technologies
  - Natural gas price from EIA AEO 2012 Reference Case
  - No new nuclear and CCS plants allowed
  - Renewable Portfolio Standards and distributed generation targets enforced

- Parameters varied:
  - Cost of solar technologies
  - Cost of batteries
  - Price of natural gas
  - Availability of nuclear and CCS
  - Cost of transmission
  - Combinations thereof



3.0
2.5
2.0
1.5
1.0
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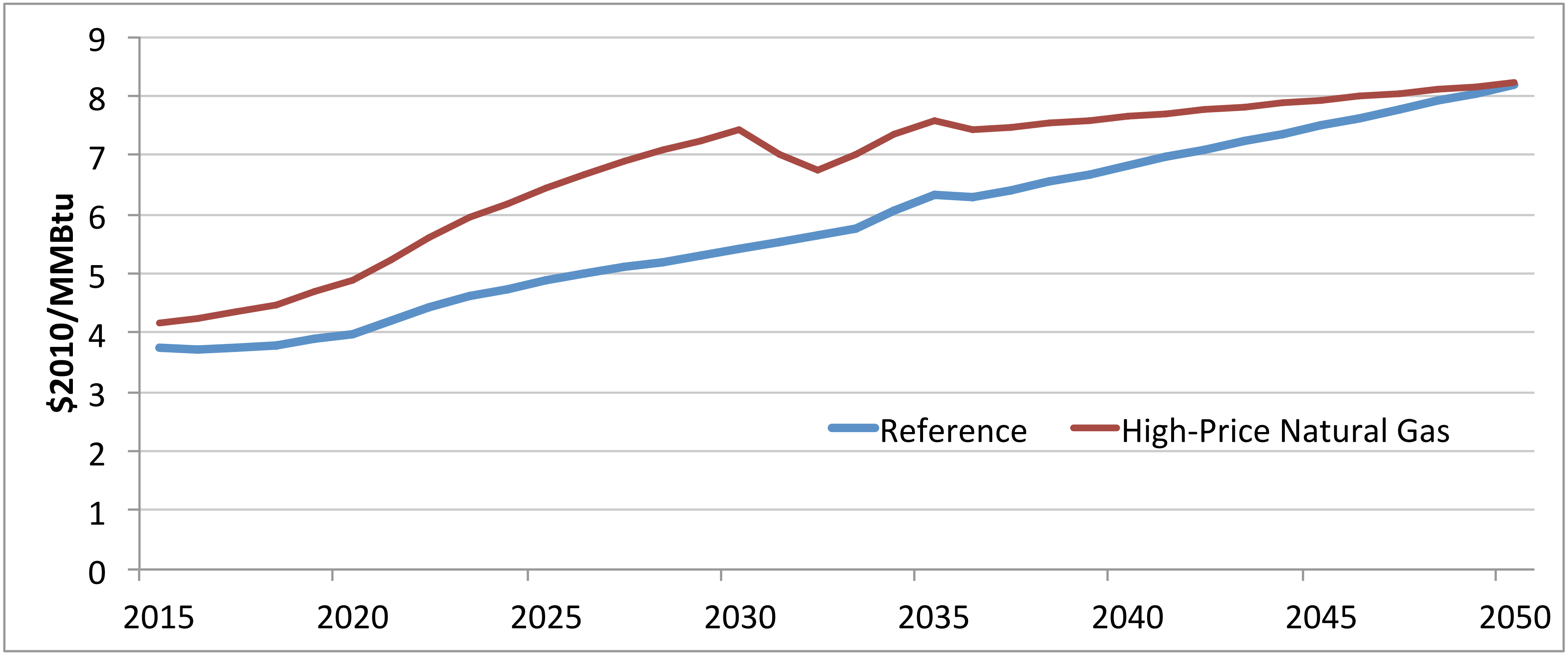
0.0
2010$/Wp
2015
2020
2025
2030
2035
2040
2045
2050
Reference
SunShot



9
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$2010/MMBtu
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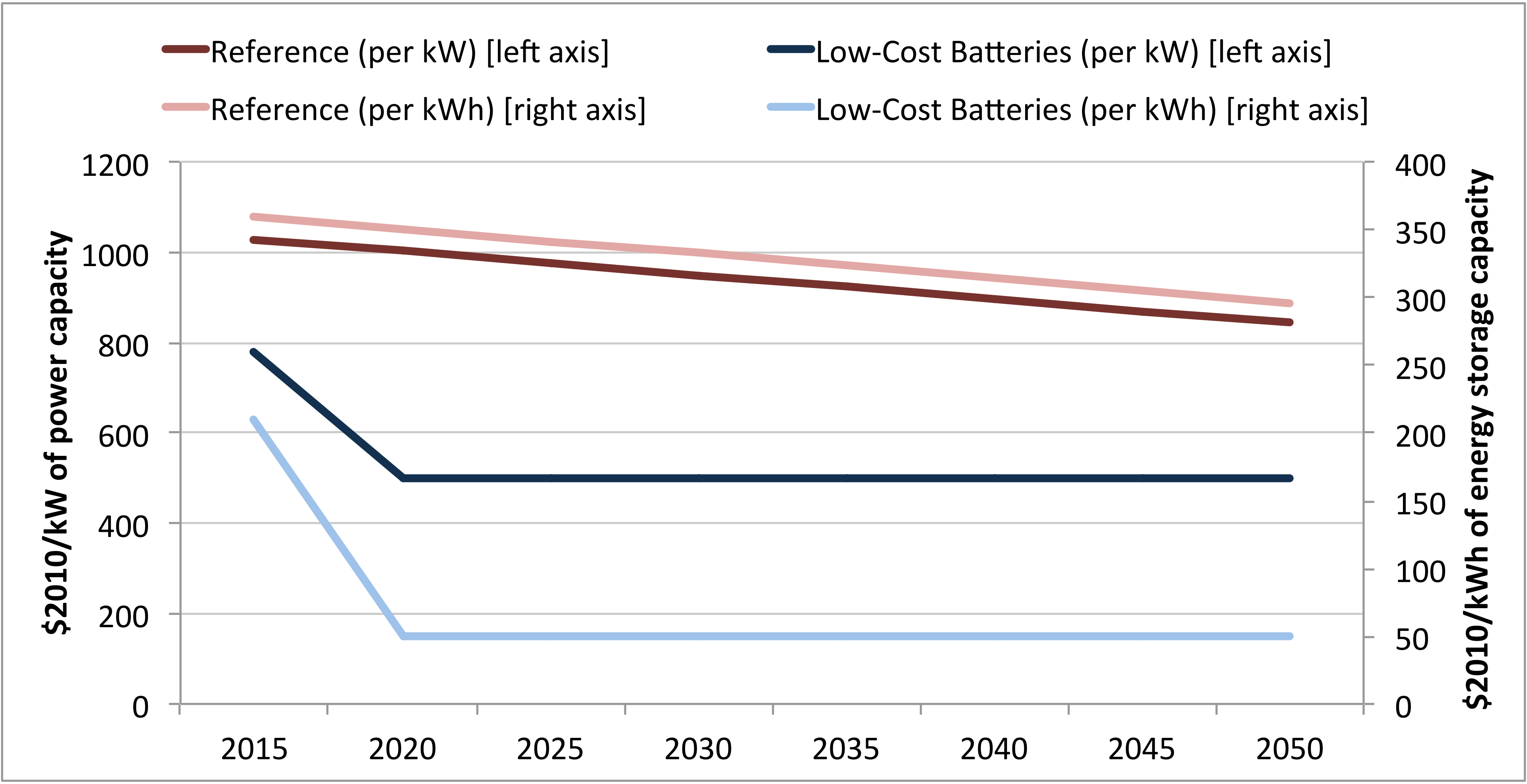
Reference
High-Price Natural Gas



Reference (per kW) [left axis]
Low-Cost Batteries (per kW) [left axis]
Reference (per kWh) [right axis]
Low-Cost Batteries (per kWh) [right axis]
$2010/kW of power capacity
$2010/kWh of energy storage capacity
1200
1000
800
600
400
200
0
400
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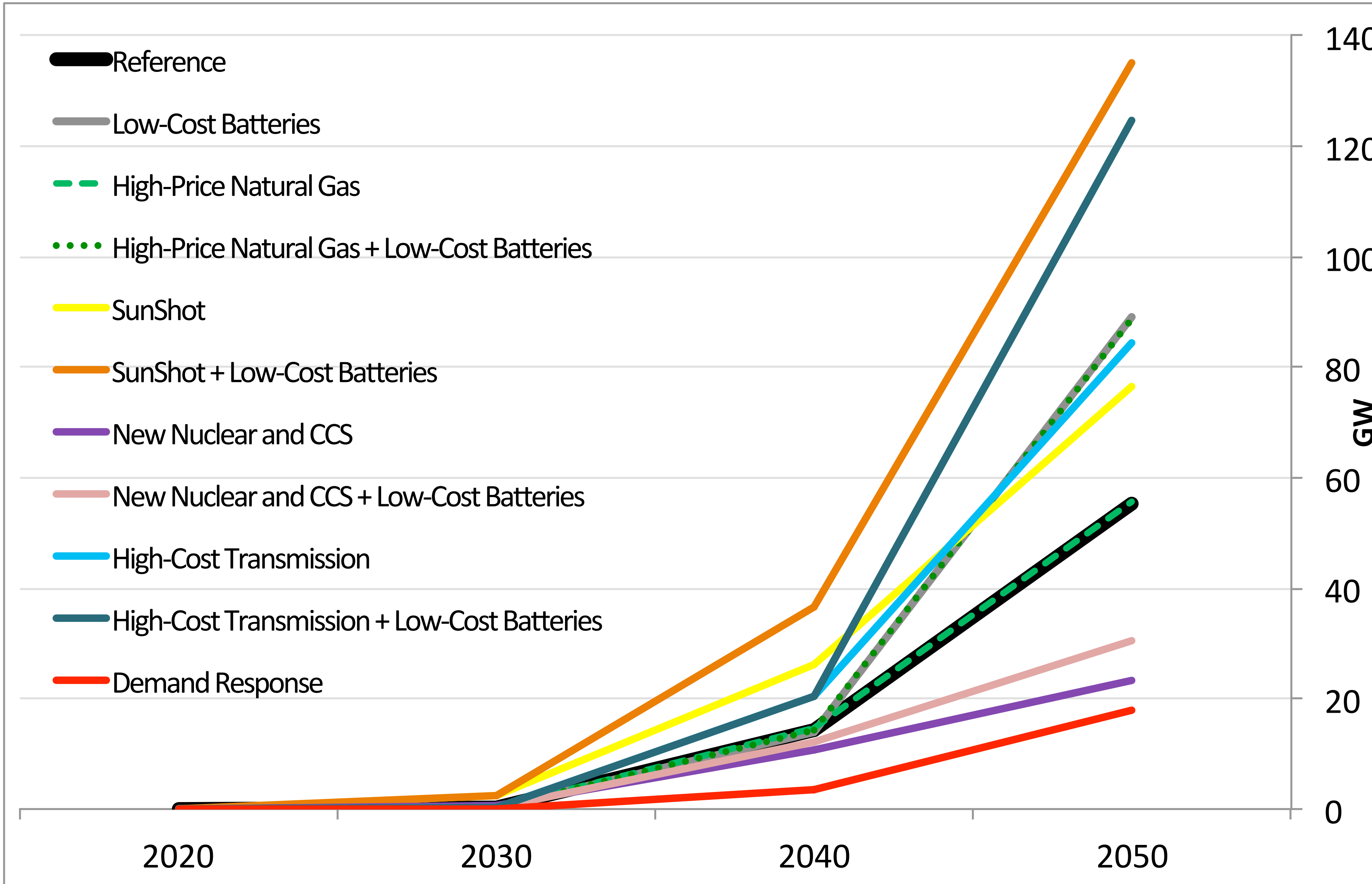
300
250
200
150
100
50
0
2015
2020
2025
2030
2035
2040
2045
2050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Low-Cost Batteries
High-Price Natural Gas
High-Price Natural Gas + Low-Cost Batteries
SunShot
SunShot + Low-Cost Batteries
New Nuclear and CCS
New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
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120
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80
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40
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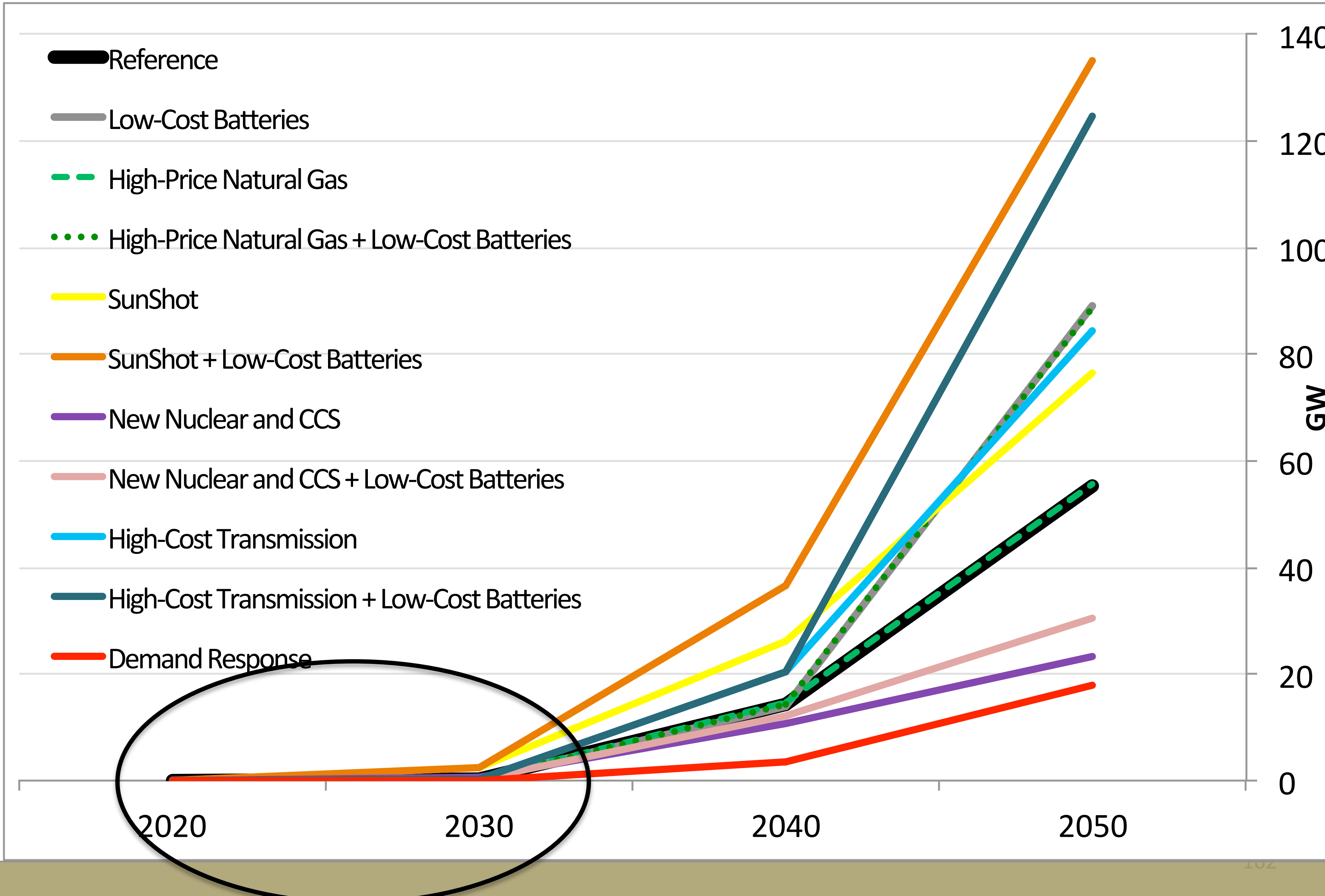
GW
2020
2030
2040
2050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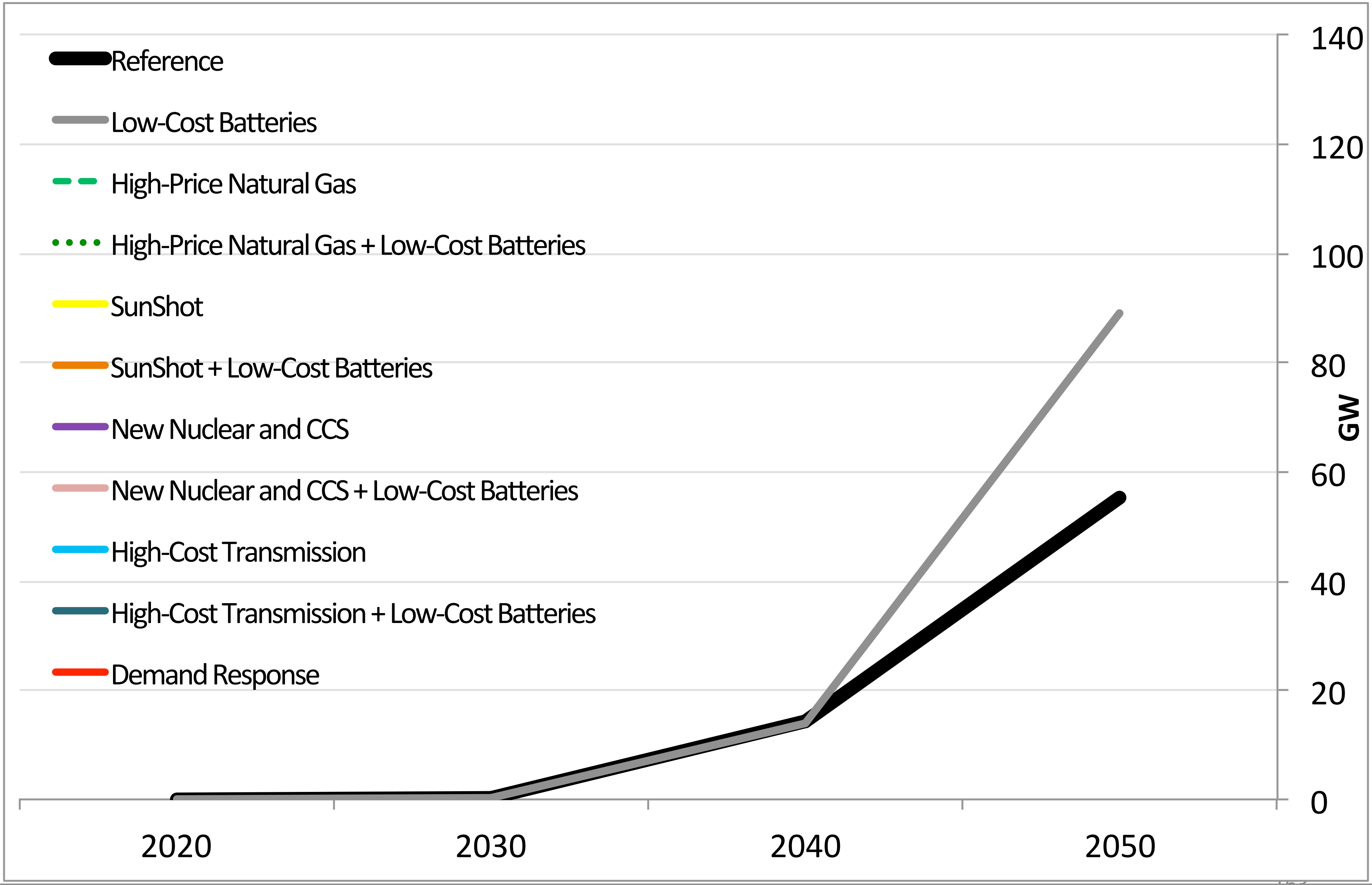

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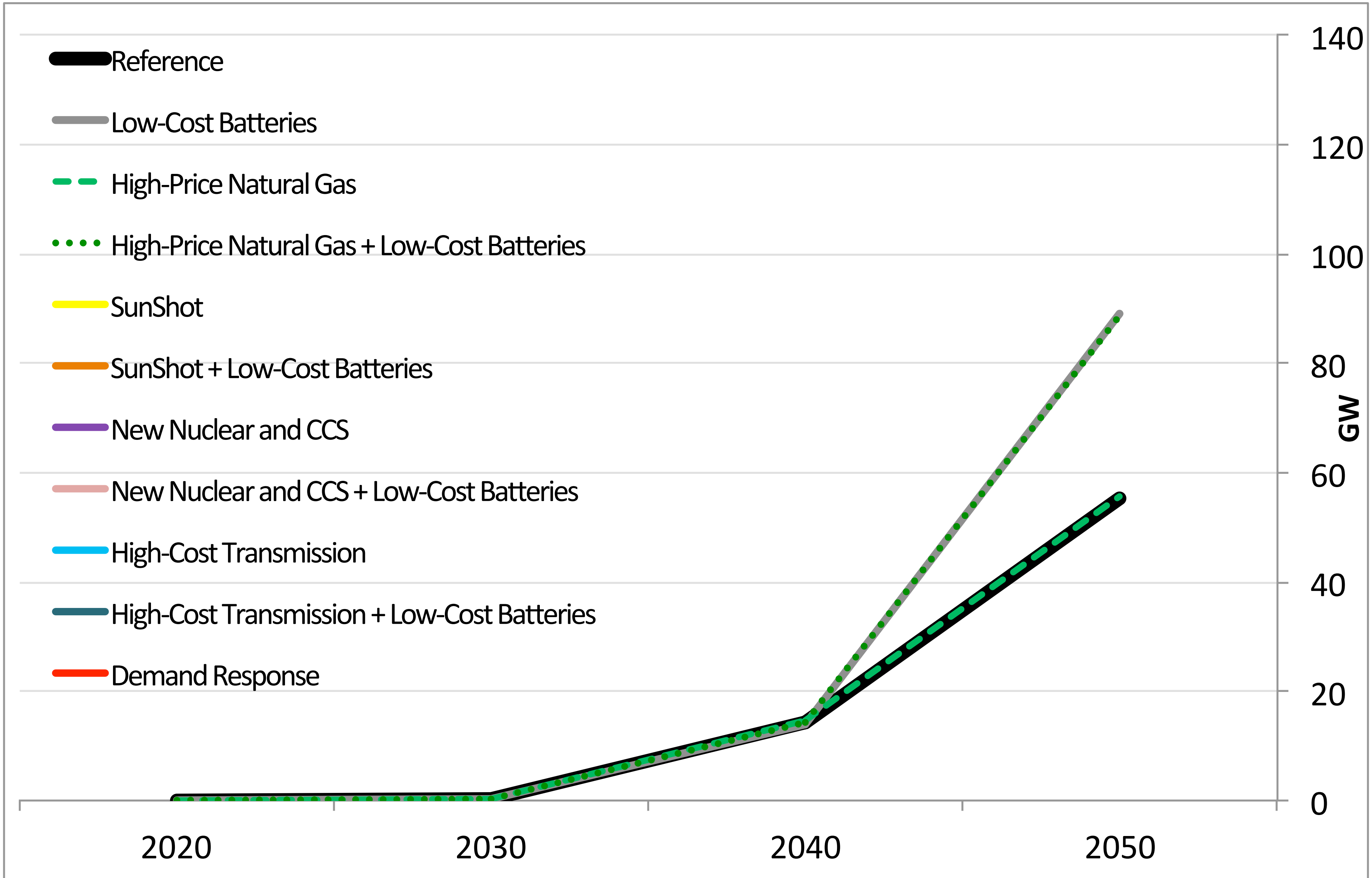

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Demand Response
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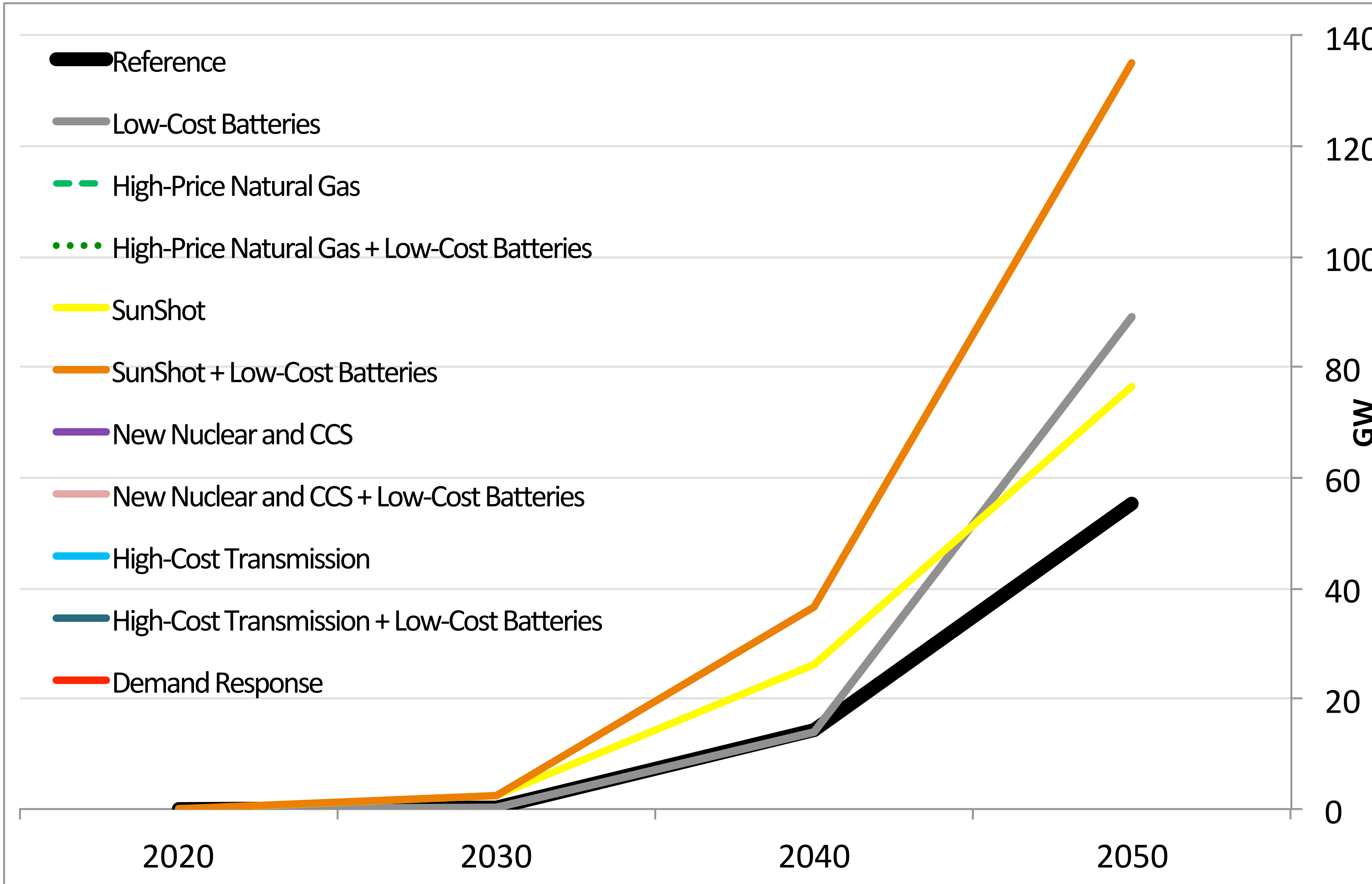
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High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
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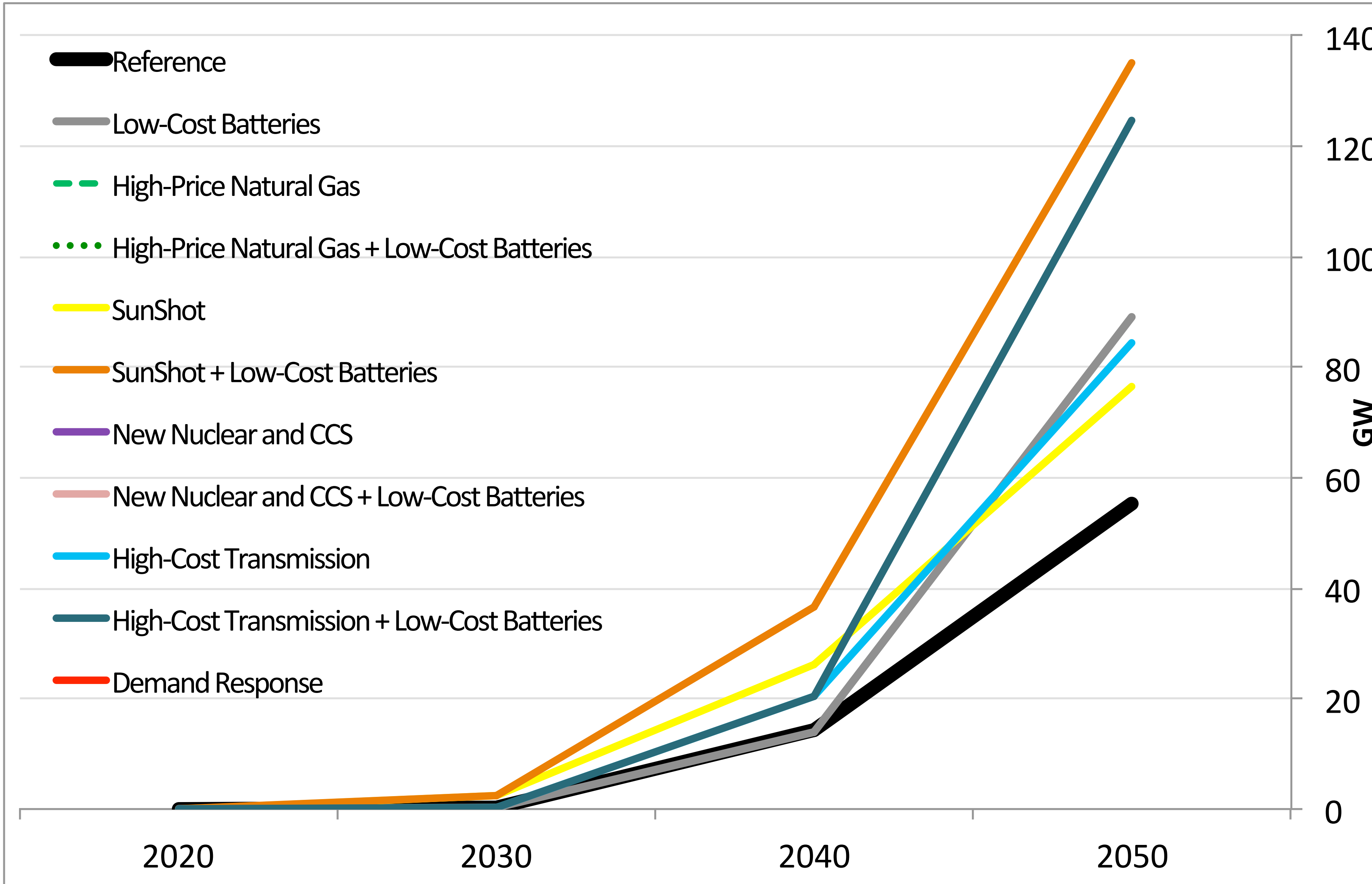
2050



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High-Cost Transmission + Low-Cost Batteries
Demand Response
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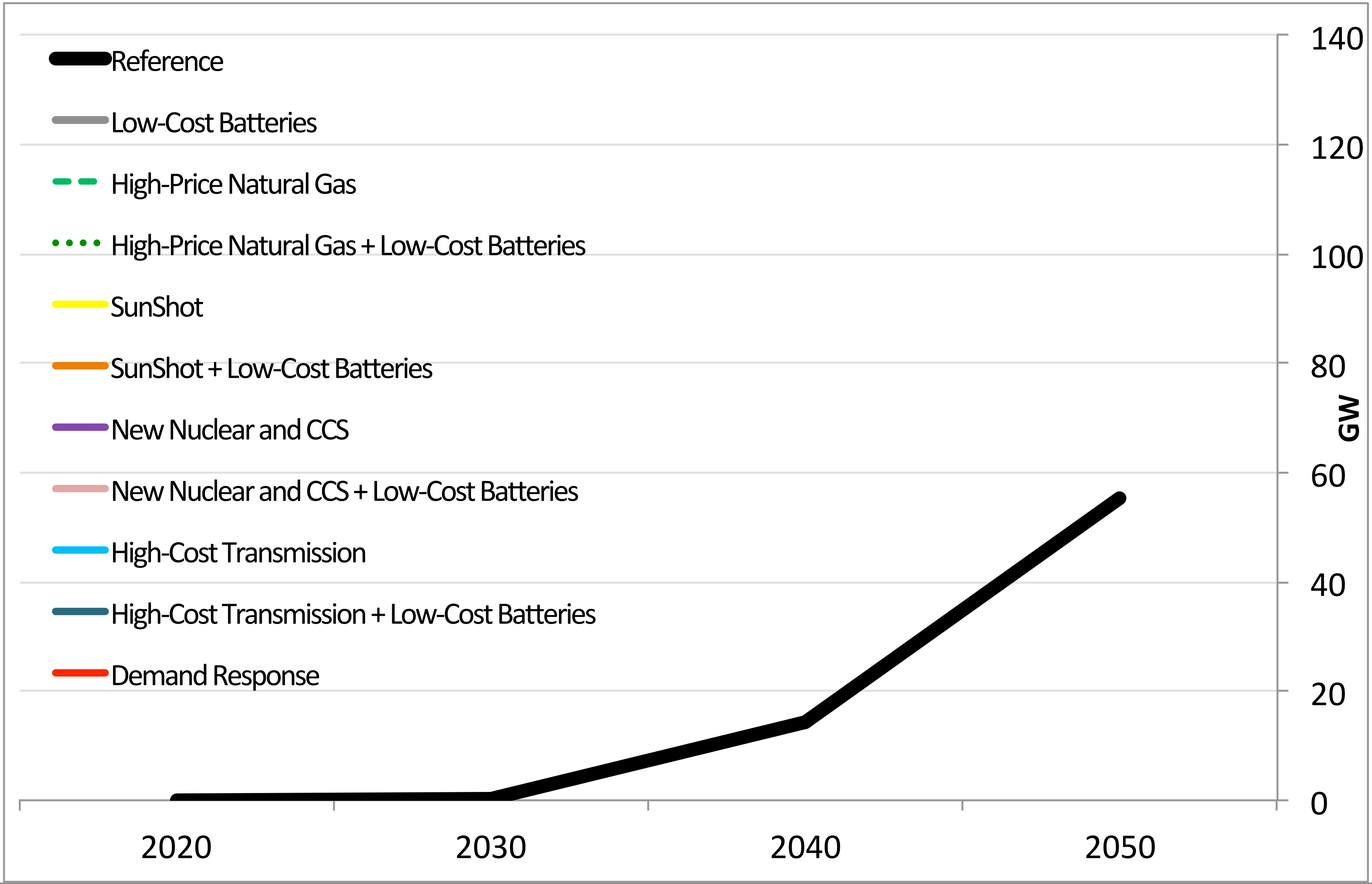
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New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
GW
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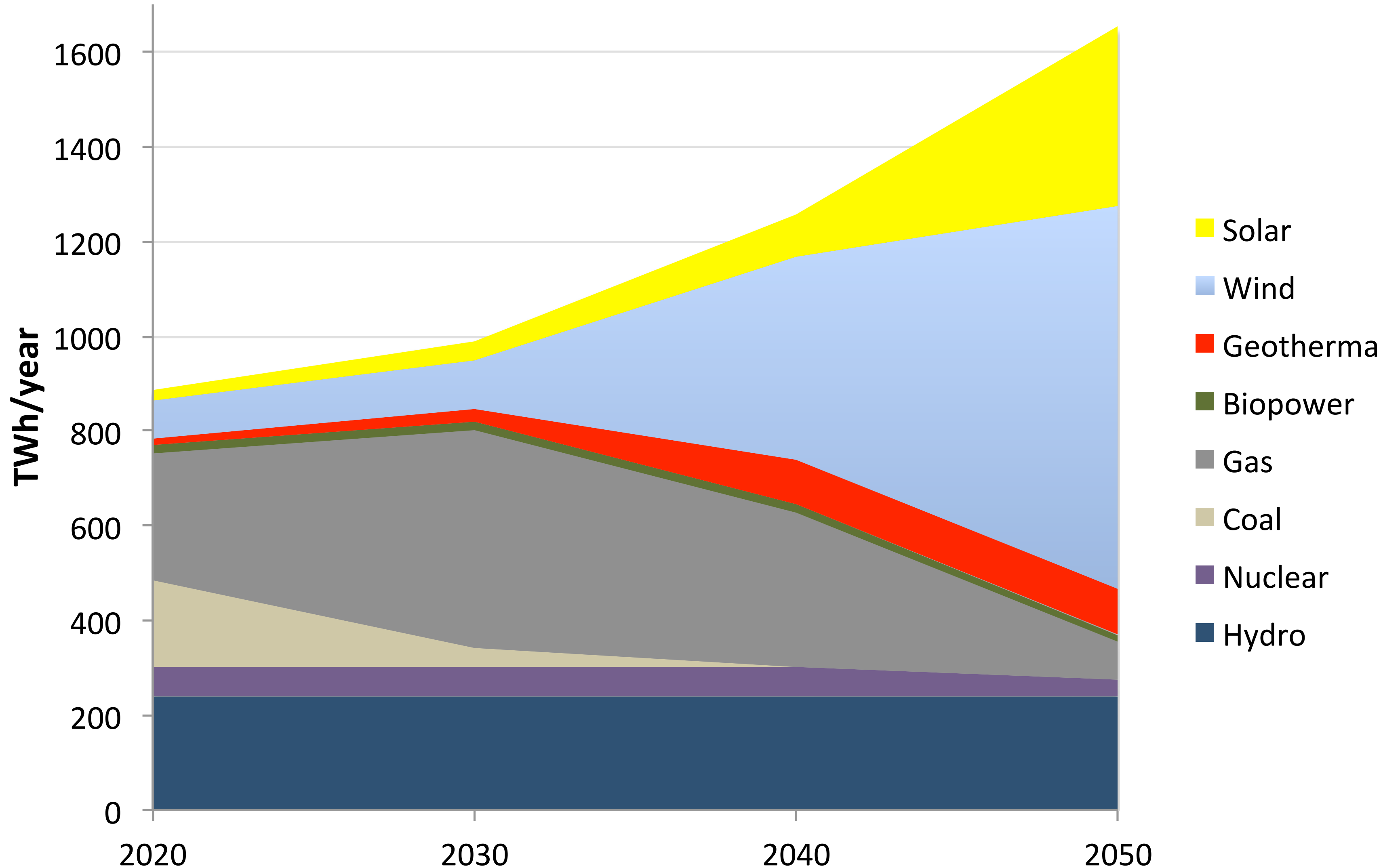
TWh/year
1600
1400
1200
1000
800
600
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200
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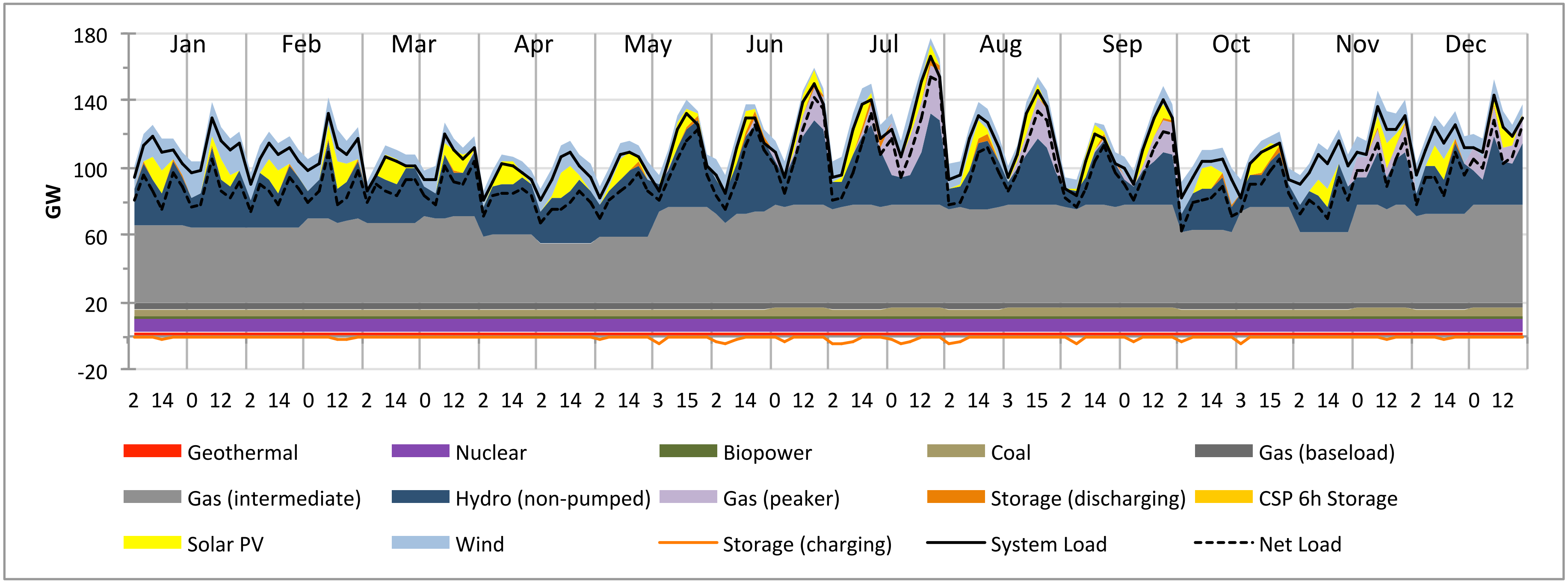
2020
2030
2040
2050
Solar
Wind
Geothermal
Biopower
Gas
Coal
Nuclear
Hydro



180
140
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-20
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Jan
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Mar
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May
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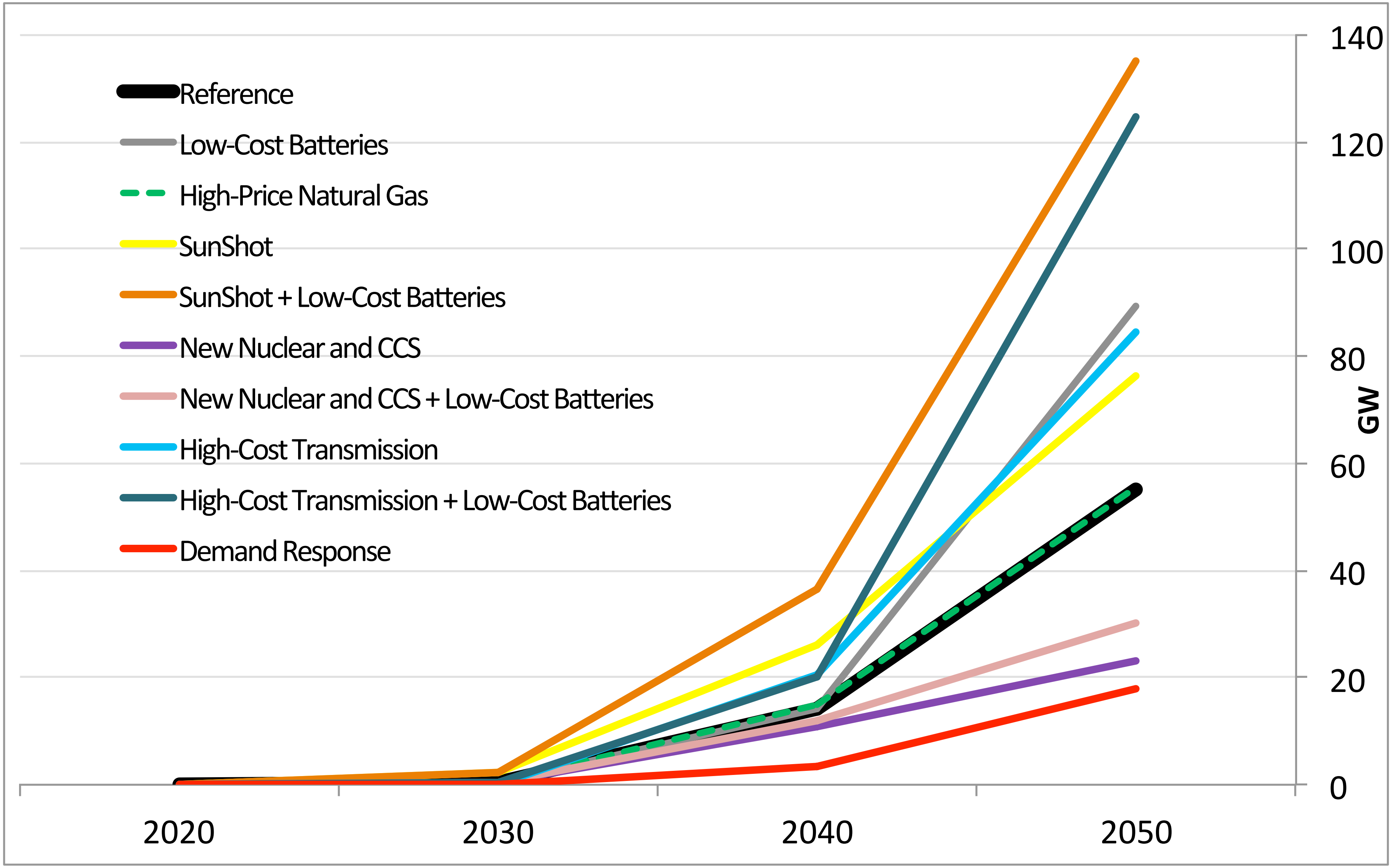
2 14 0 12 2 14 0 12 2 14 0 12 2 14 2 14 2 14 3 15 2 14 0 12 2 14 0 12 2 14 3 15 2 14 0 12 2 14 3 15 2 14 0 12 2 14 0 12
Geothermal
Nuclear
Biopower
Coal
Gas (baseload)
Gas (intermediate)
Hydro (non-pumped)
Gas (peaker)
Storage (discharging)
CSP 6h Storage
Solar PV
Wind
Storage (charging)
System Load
Net Load



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New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
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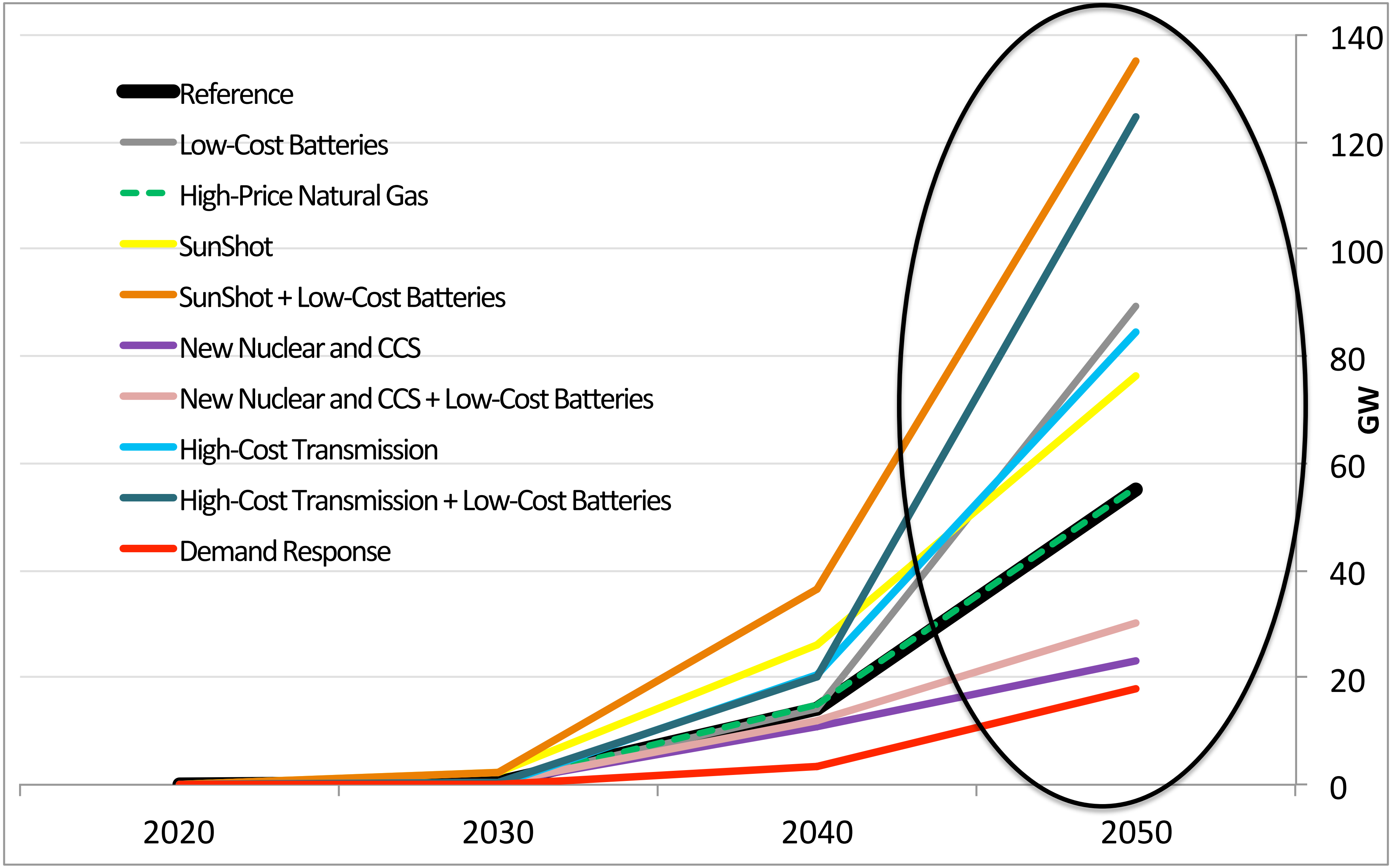

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High-Price Natural Gas
SunShot
SunShot + Low-Cost Batteries
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New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
GW
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140
2020
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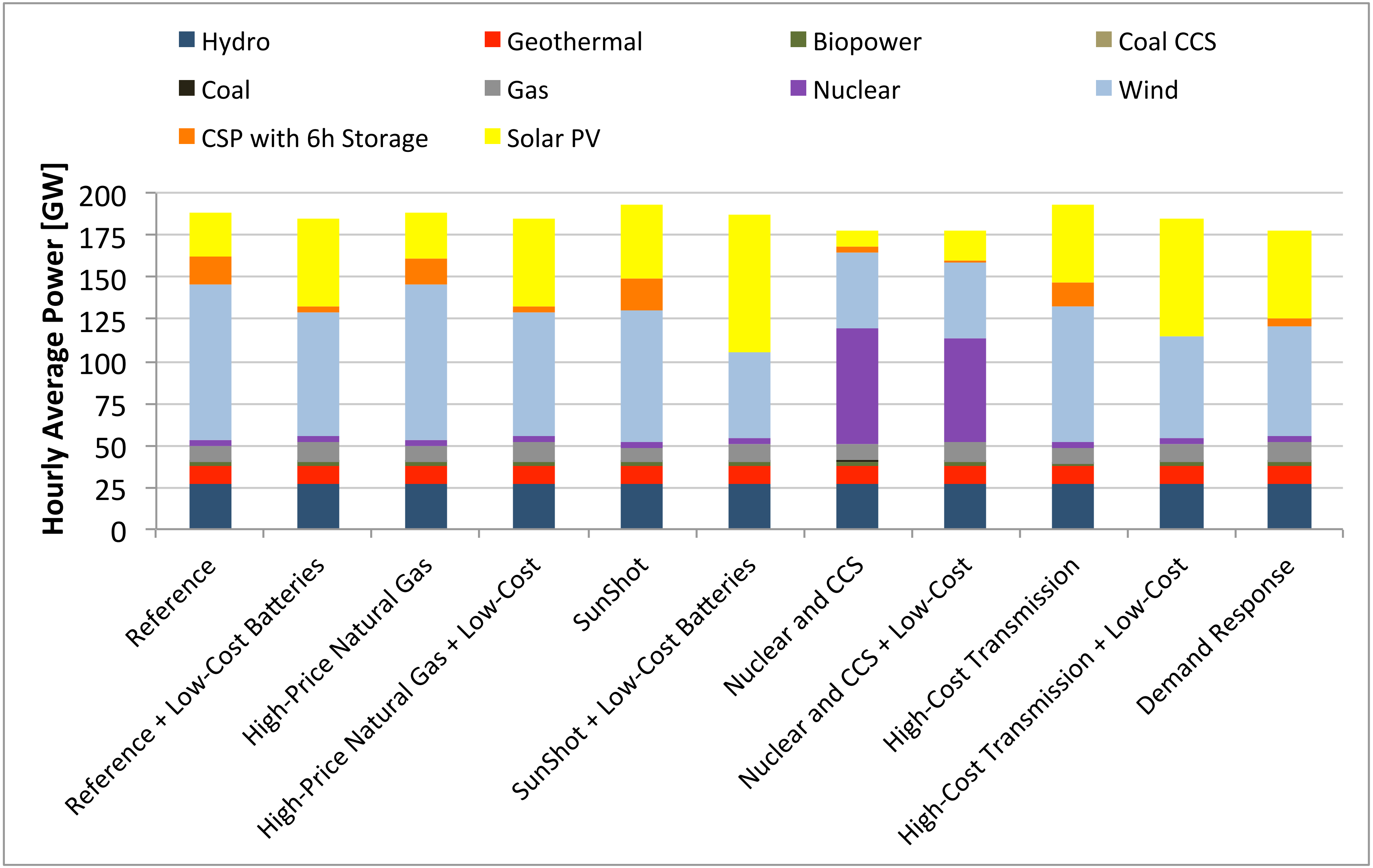
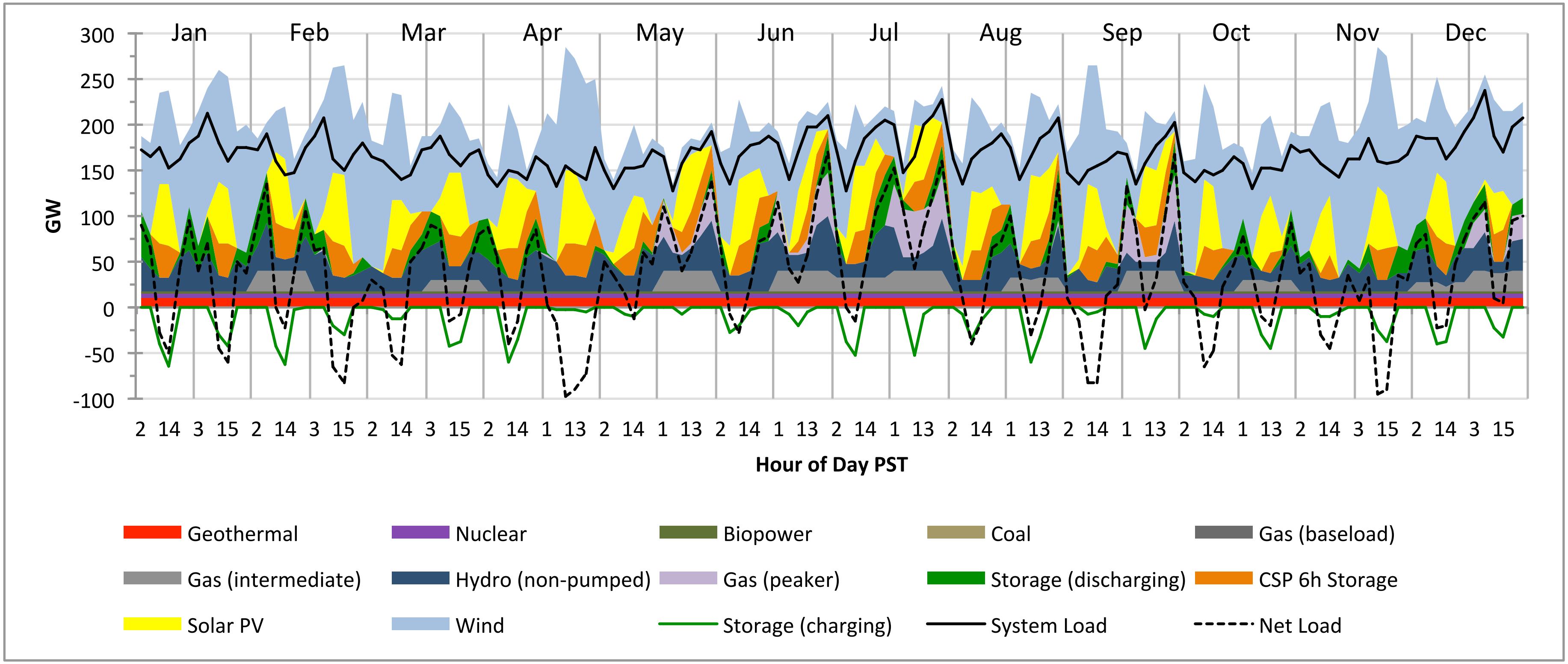
2050


Hydro
Geothermal
Biopower
Coal CCS
Coal
Gas
Nuclear
Wind
CSP with 6h Storage
Solar PV
Hourly Average Power [GW]
200
175
150
125
100
75
50
25
0
Reference
Reference + Low-Cost Batteries
High-Price Natural Gas
High-Price Natural Gas + Low-Cost
SunShot
SunShot + Low-Cost Batteries
Nuclear and CCS
Nuclear and CCS + Low-Cost
High-Cost Transmission
High-Cost Transmission + Low-Cost
Demand Response



Jan
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Jul
Aug
Sep
Oct
Nov
Dec
GW
Hour of Day PST
Geothermal
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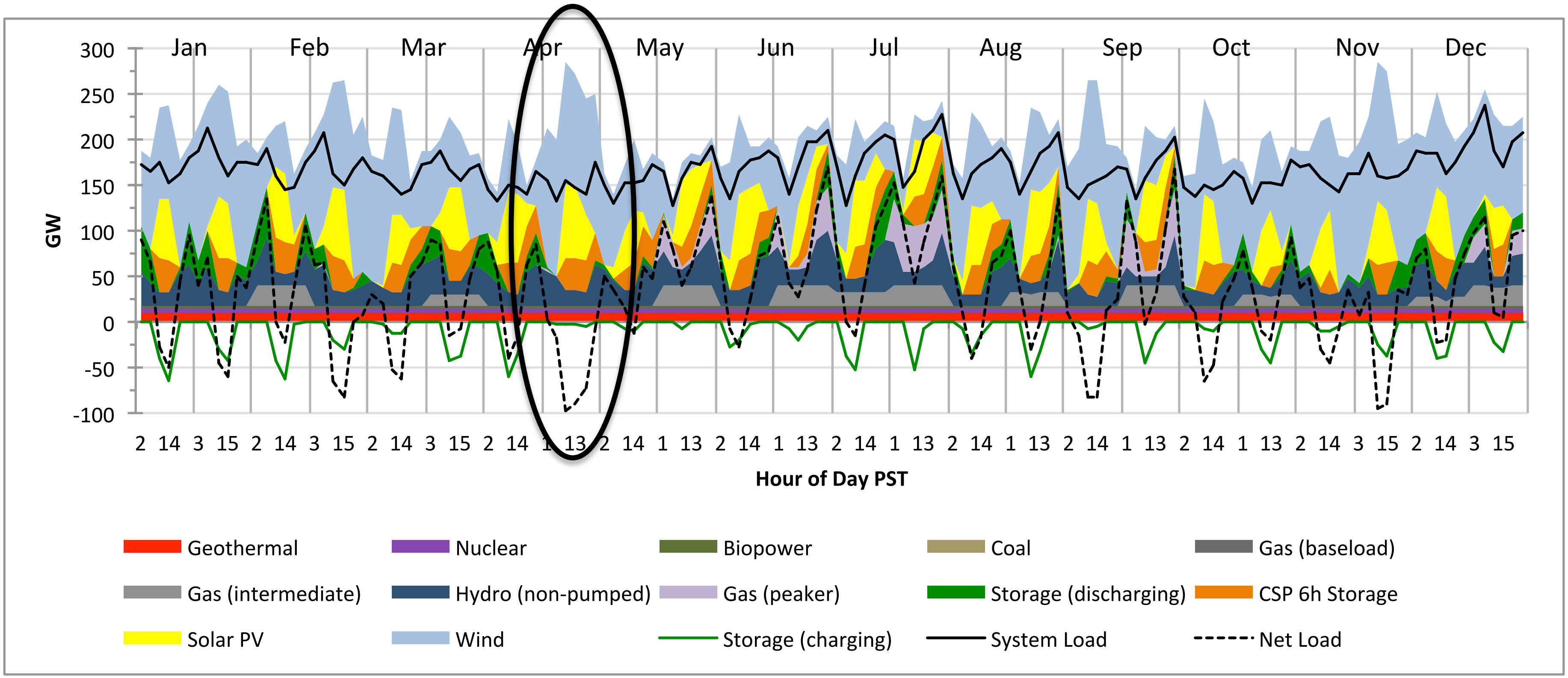
Biopower
Coal
Gas (baseload)
Gas (intermediate)
Hydro (non-pumped)
Gas (peaker)
Storage (discharging)
CSP 6h Storage
Solar PV
Wind
Storage (charging)
System Load
Net Load



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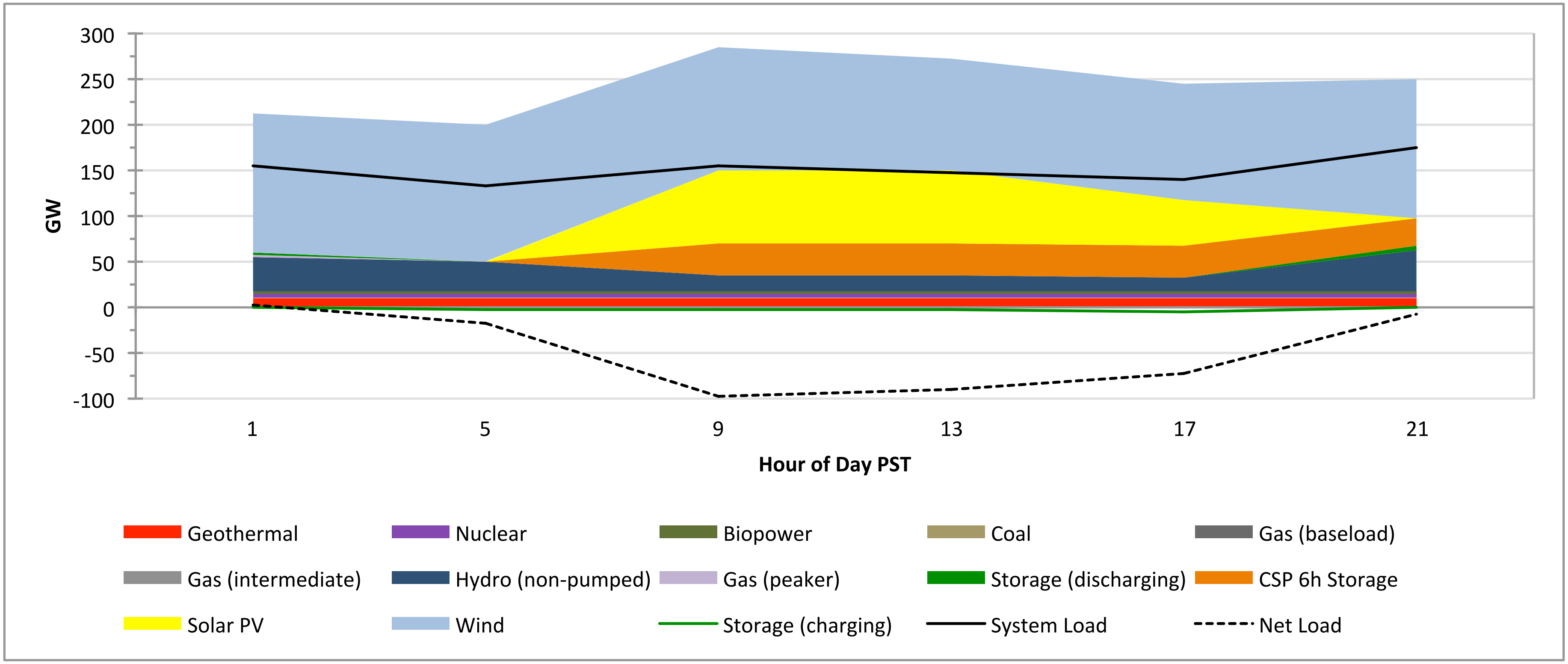
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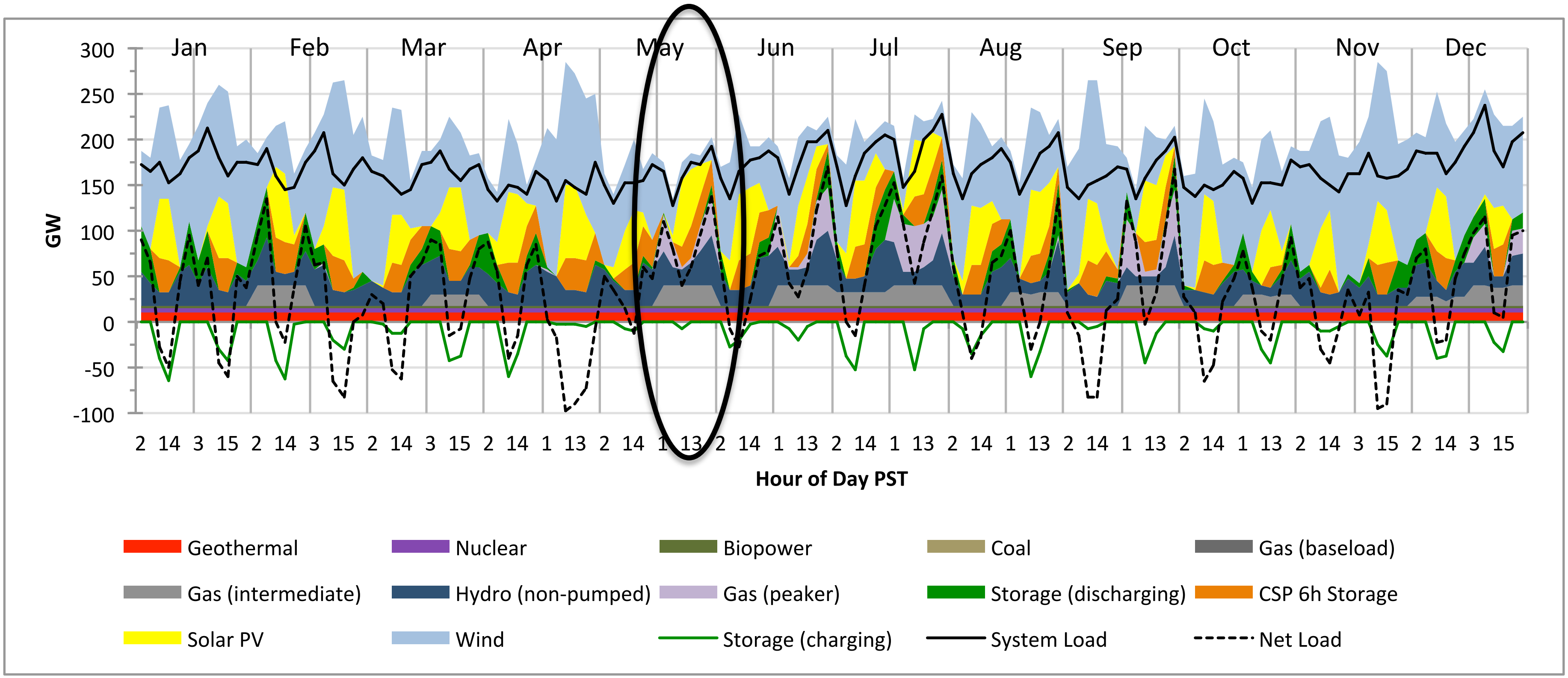
Net Load

DR Potential Assumptions

Sector	End Use	% Shiftable 2020	% Shiftable 2030	% Shiftable 2040	% Shiftable 2050
Residential	Space heating	2%	20%	40%	60%
	Water heating	20%	40%	60%	80%
	Cooling	2%	20%	40%	60%
	Dryer	2%	20%	60%	80%
Commercial	Space heating	2%	20%	40%	60%
	Water heating	20%	40%	60%	80%
	Cooling	2%	20%	40%	60%

- Potentials estimated based on above DR penetration levels applied to Itron hourly load projections by end-use for California
  - Rest of WECC assumed to be at same levels a decade after California



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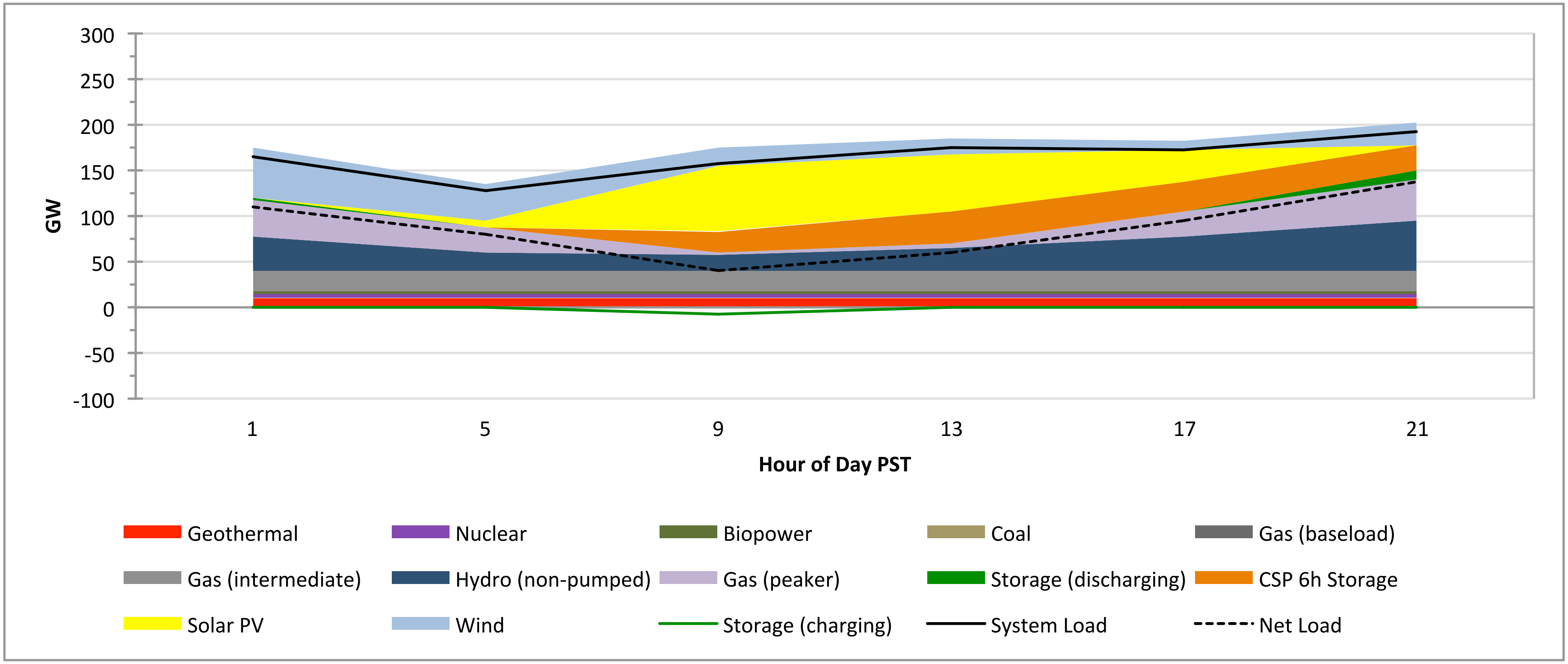
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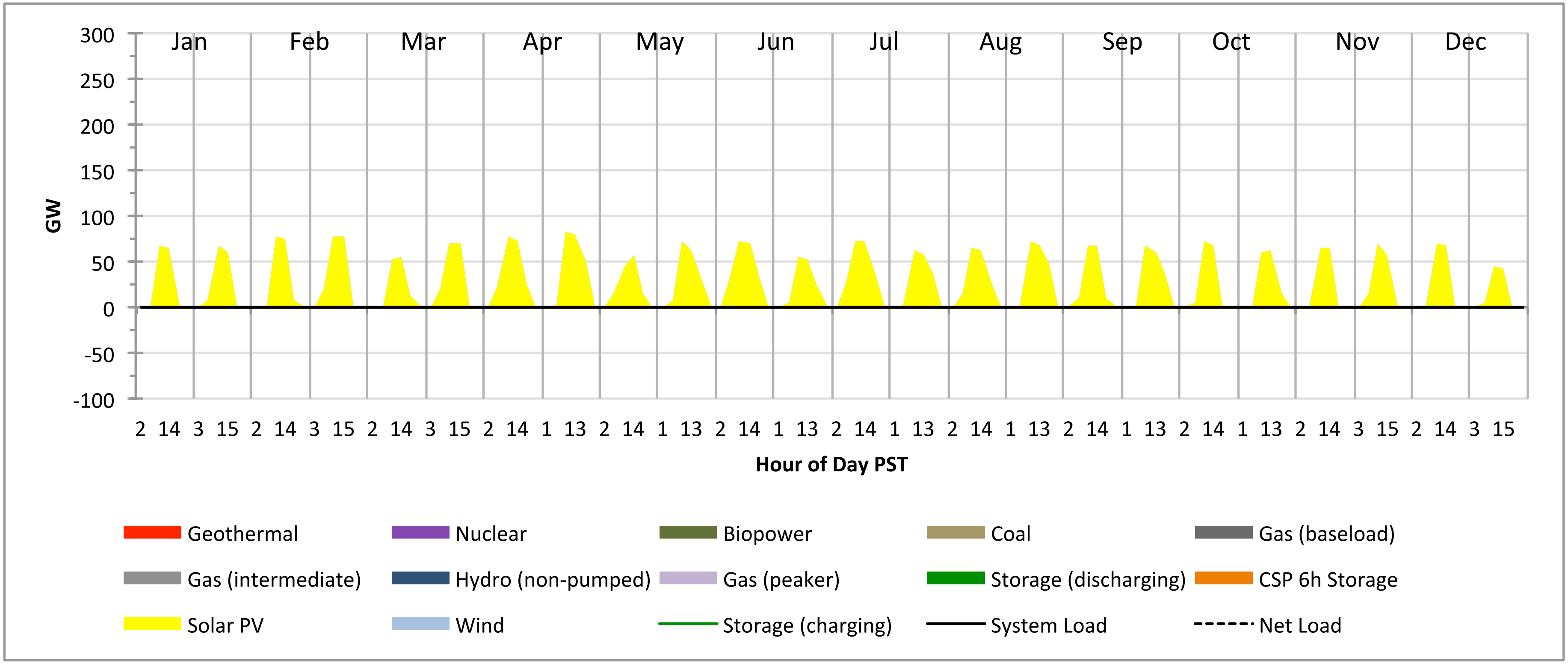

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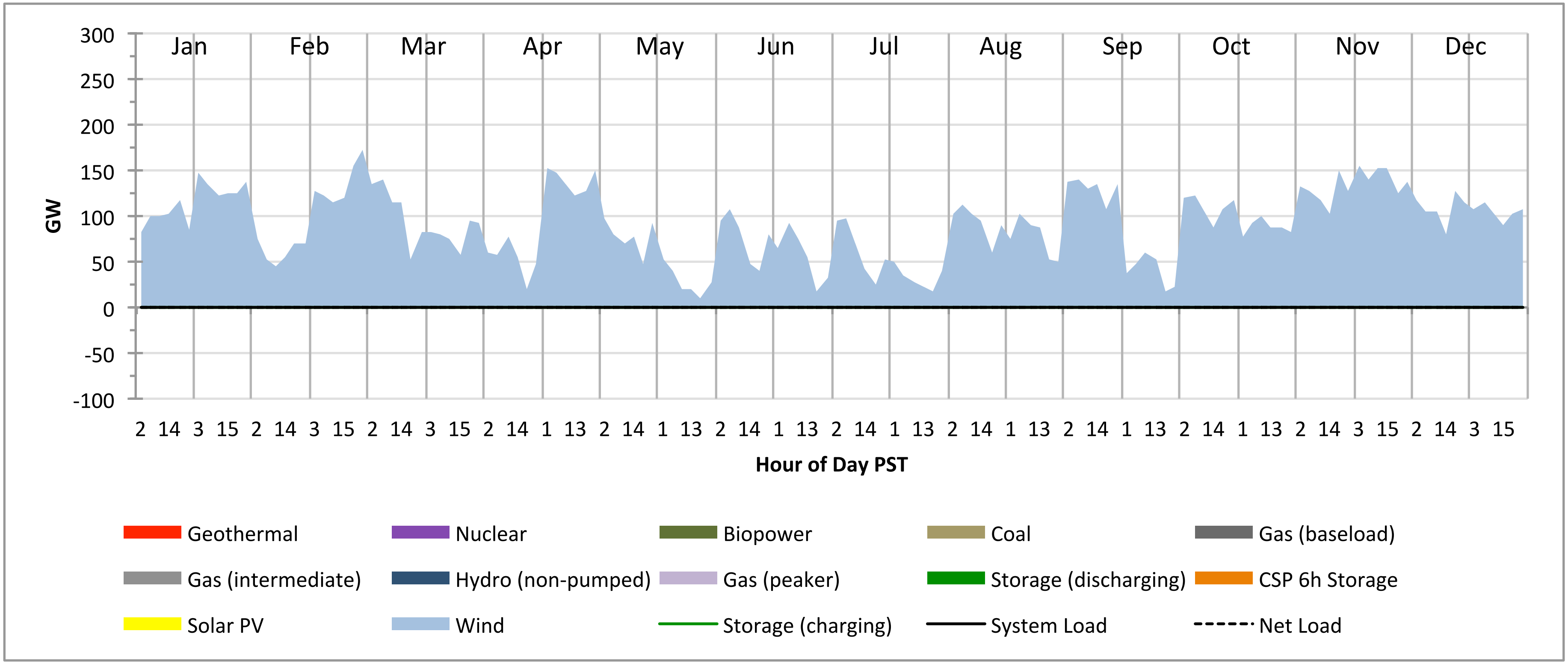

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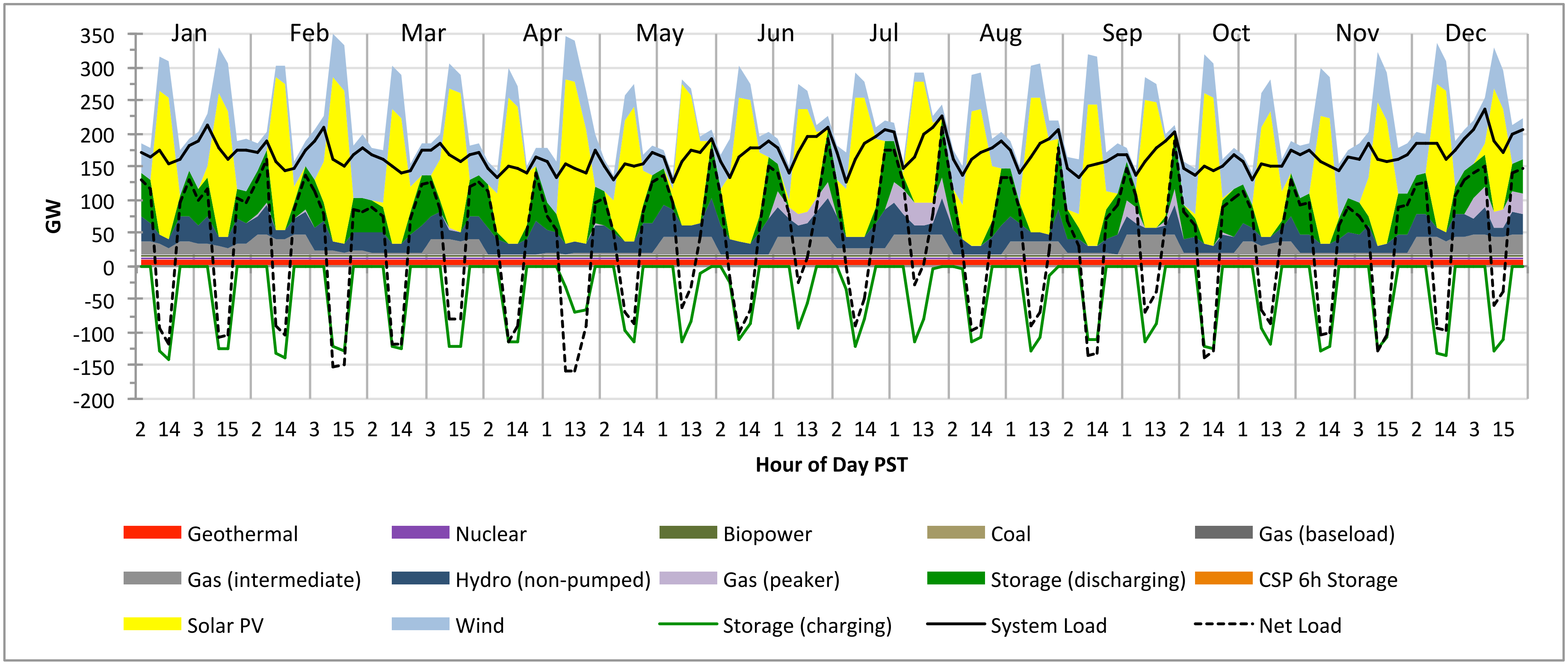

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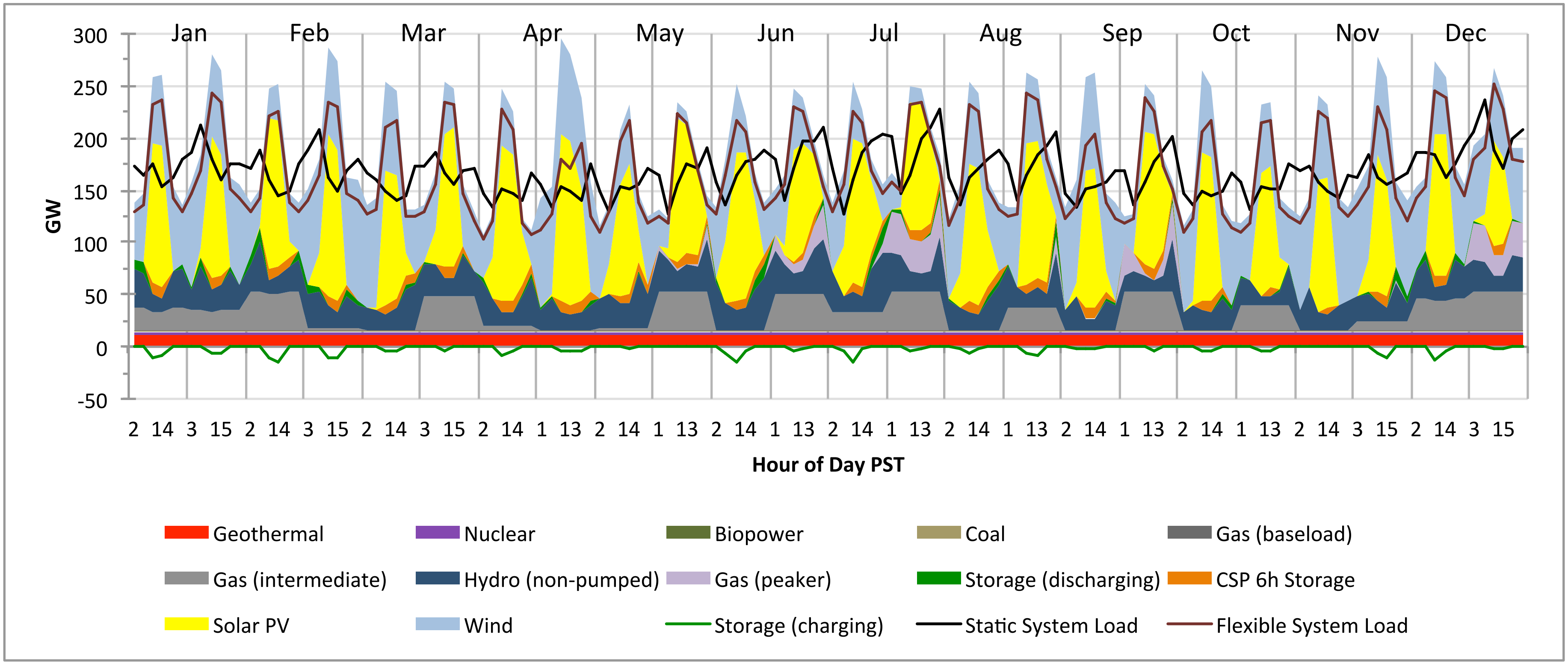

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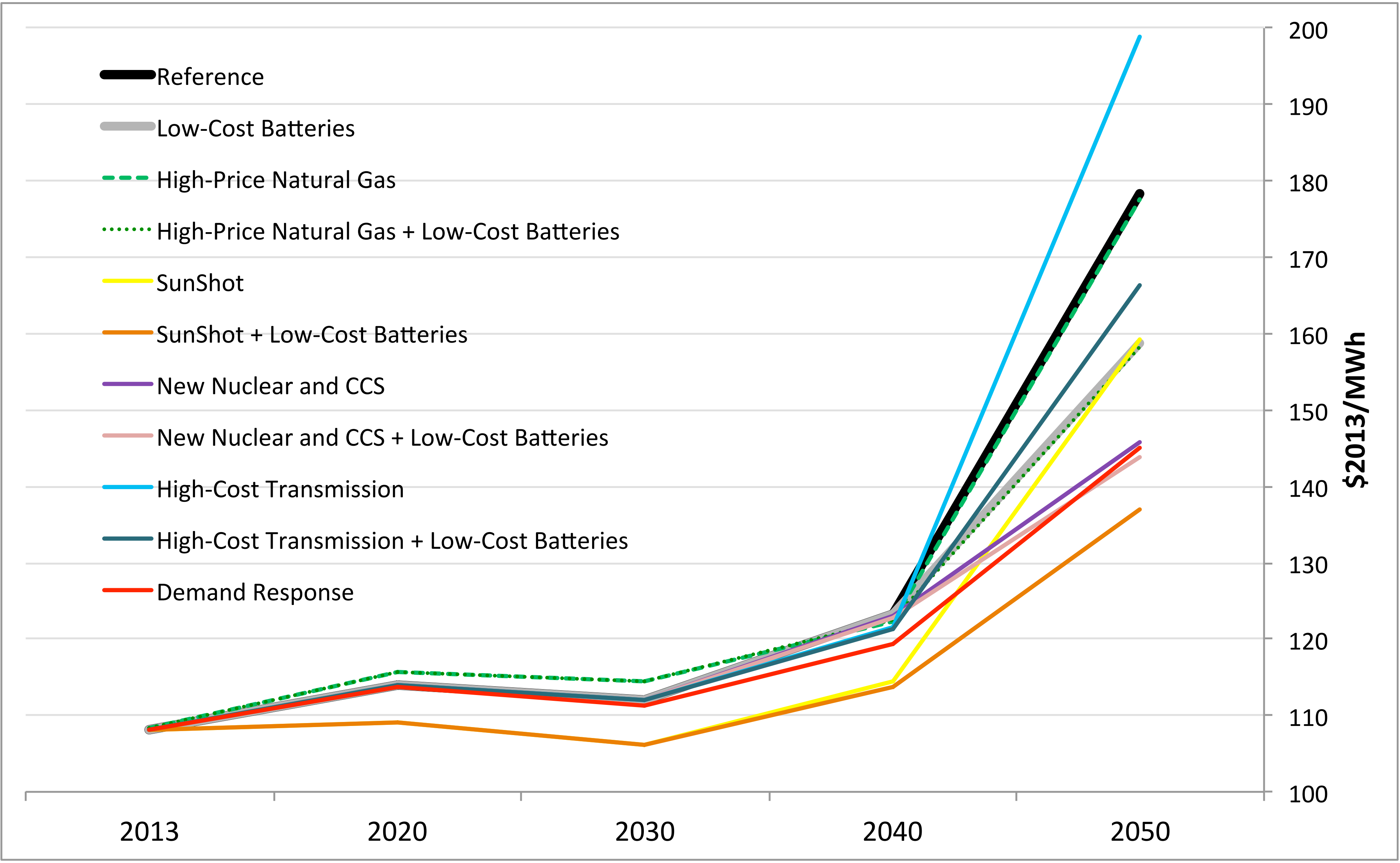
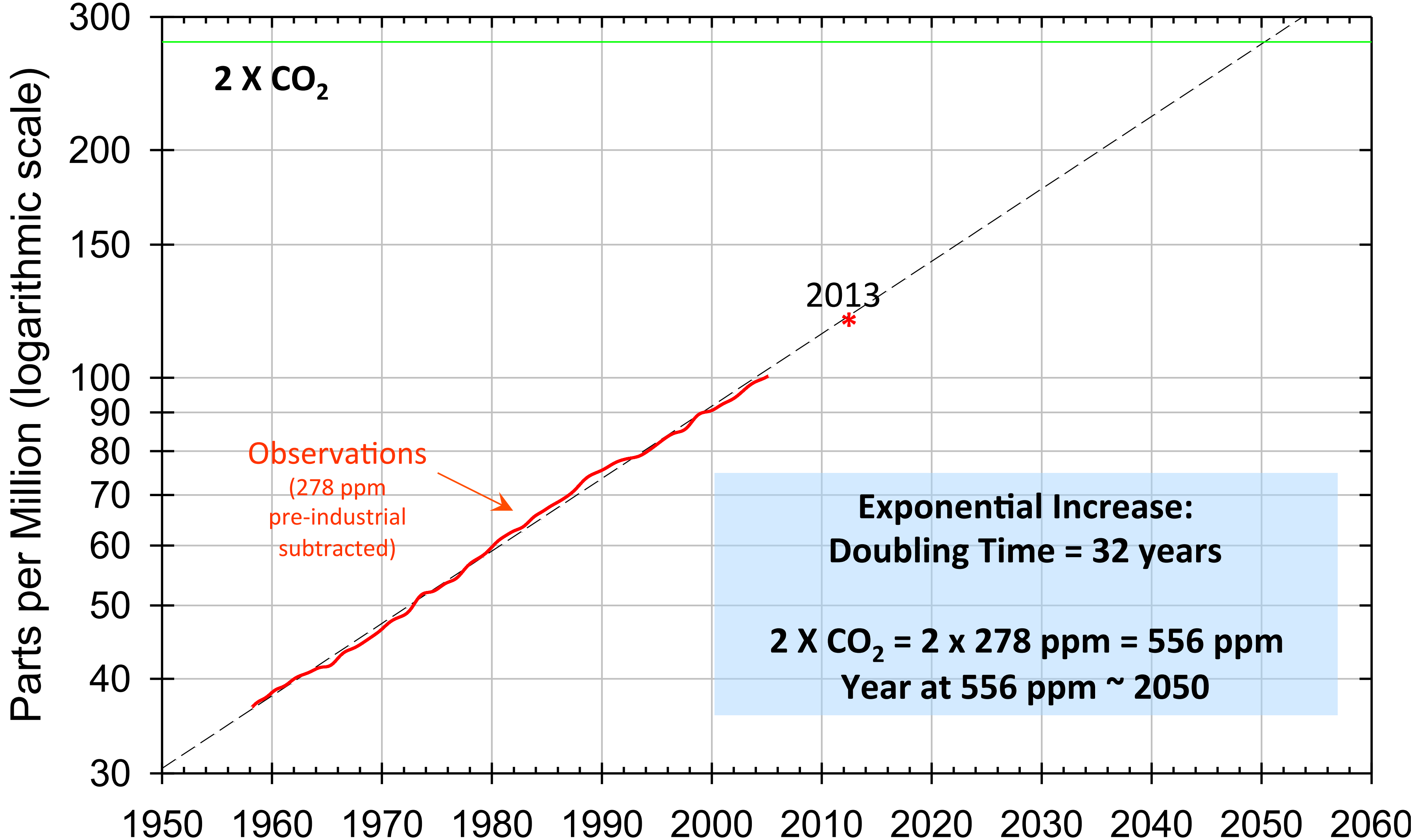
Static System Load
Flexible System Load



Reference
Low-Cost Batteries
High-Price Natural Gas
High-Price Natural Gas + Low-Cost Batteries
SunShot
SunShot + Low-Cost Batteries
New Nuclear and CCS
New Nuclear and CCS + Low-Cost Batteries
High-Cost Transmission
High-Cost Transmission + Low-Cost Batteries
Demand Response
$2013/MWh
200
190
180
170
160
150
140
130
120
110
100
2013
2020
2030
2040
2050

Post Industrial Carbon Dioxide Rise

When (years ago):	**30**	**3M**	**20 M**	**40 M**
Equilibrium climate:	**Pleistocene**	**Pliocene**	**Miocene**	**Eocene (2080)**



Slide from PNAS paper, Hofmann, et al; Solomon et al, Irreversible Climate Change, 10Feb2009;
Beerling & Royer, Convergent Cenezoic CO2, Nature Geoscience, July 2011