Renewable & Appropriate Energy Laboratory
RAEL

kammen@berkeley.edu

http://rael.berkeley.edu

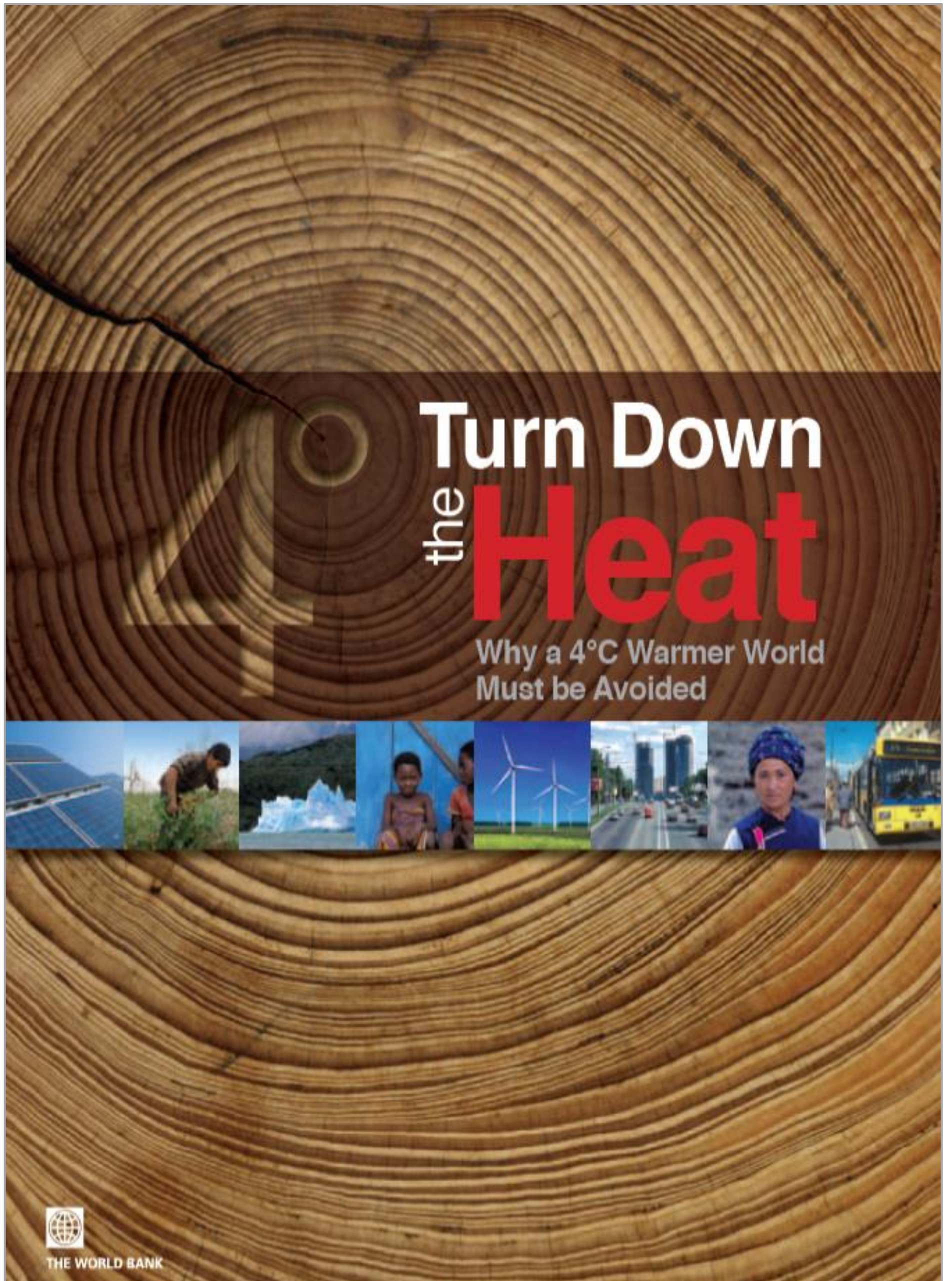
Energy and Climate Opportunities for the Bay Area

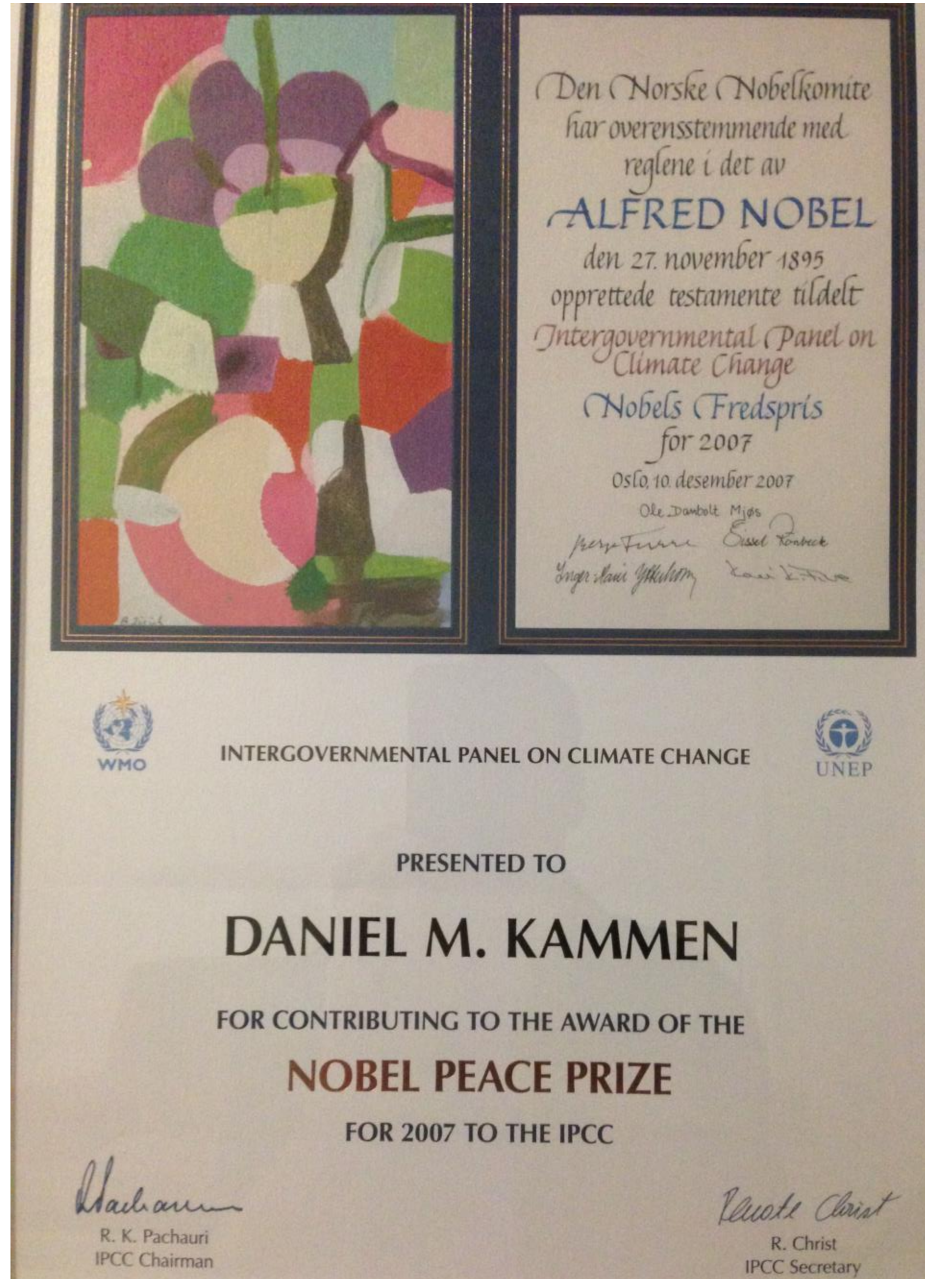
Daniel Kammen

Class of 1935 Distinguished Professor of Energy
Energy and Resources Group | Goldman School of Public Policy
Director, Renewable and Appropriate Energy Laboratory
University of California, Berkeley

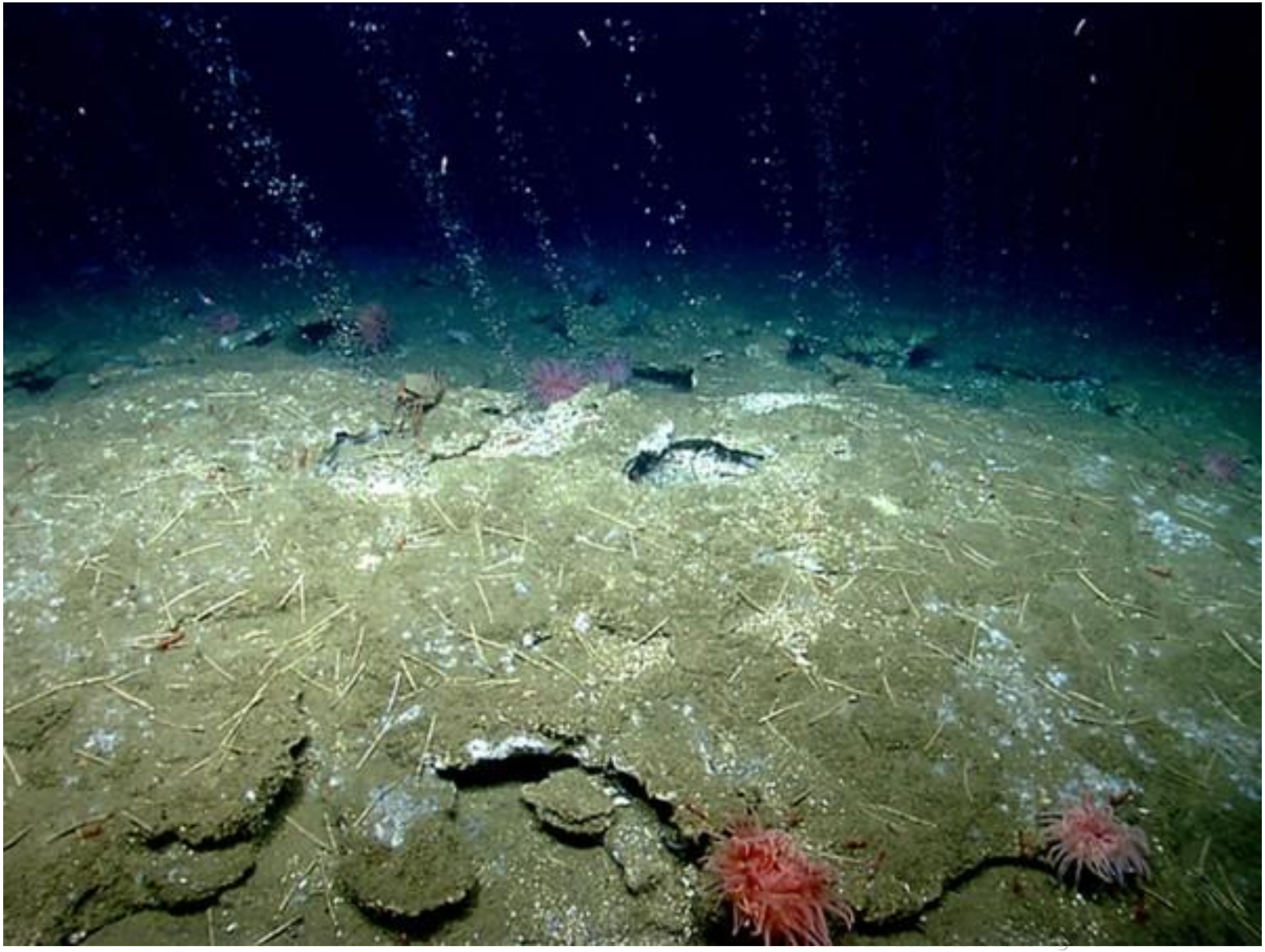
September 10, 2014

The Meaning of 4° C Warming





Science 2014: 570 plumes of Methane observed percolating up from the sea floor off the eastern coast of the United States



Vast costs of Arctic change

Methane released by melting permafrost will have global impacts that must be better modelled, say **Gail Whiteman, Chris Hope** and **Peter Wadhams.**

Unlike the loss of sea ice, the vulnerability of pol
human popu
impacts of a warm
ignored.
Most economic dis
that opening up the re
The Arctic is though
the world's undiscove
undiscovered oil, an
routes would increas
insurance market Ll
mates that investme

reach US$100 billion within ten years[3].

pivotal to the functioning of Earth systems

Nature
2013

ARTICLES
PUBLISHED ONLINE: 24 NOVEMBER 2013 | DOI: 10.1038/NGEO2007
nature geoscience

Ebullition and storm-induced methane release from the East Siberian Arctic Shelf

Natalia Shakhova[1,2*†], Igor Semiletov[1,2†], Ira Leifer[3,4†], Valentin Sergienko[5], Anatoly Salyuk[2], Denis Kosmach[2], Denis Chernykh[2], Chris Stubbs[3], Dmitry Nicolsky[6], Vladimir Tumskoy[7] and Örjan Gustafsson[8]

Nature Geoscience
2013

PNAS
2014

PNAS

Methanogenic burst in the end-Permian carbon cycle

Daniel H. Rothman[a,b,1], Gregory P. Fournier[c], Katherine L. French[b], Eric J. Alm[c], Edward A. Boyle[b], Changqun Cao[d], and Roger E. Summons[b]

[a]Lorenz Center, [b]Department of Earth, Atmospheric, and Planetary Sciences, and [c]Department of Biological Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139; and [d]State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

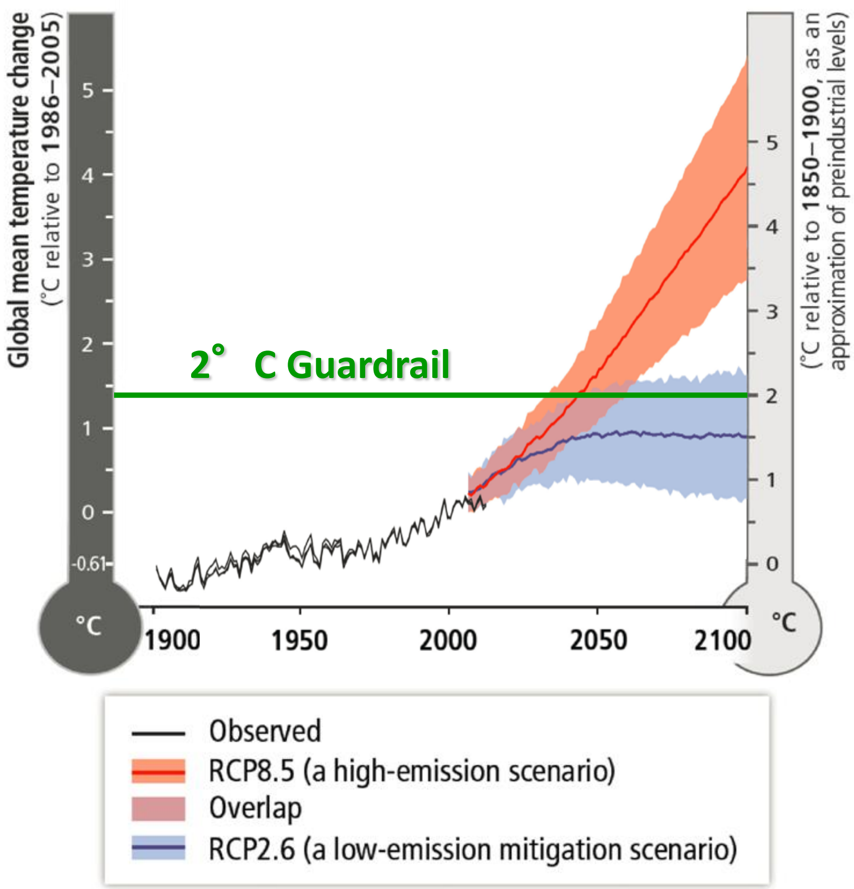
Edited by John M. Hayes, Woods Hole Oceanographic Institution, Woods Hole, MA, and approved February 4, 2014 (received for review September 27, 2013)

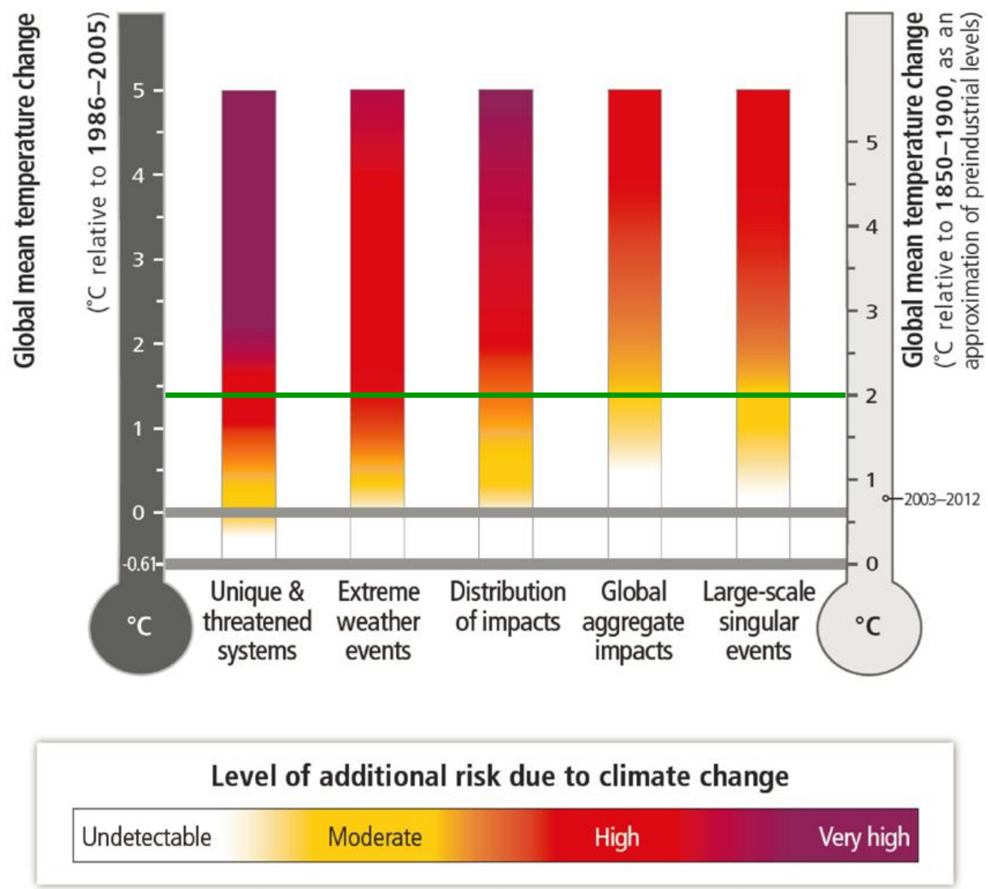
The end-Permian extinction is associated with a mysterious disrup-
...
the extinction, probably as a consequence of massive Siberian volcanism, enabling a methanogenic expansion by removal of nickel limitation. Collectively, these results are consistent with the instigation of Earth's greatest mass extinction by a specific microbial innovation.

and its perturbation to the carbon cycle but also to amplify the
...
a period of about 100 thousand years (Kyr), first slowly, and subsequently rapidly. At the same time, the isotopic composition δ_2 of organic carbon also changes. We seek the physical fluxes in the carbon cycle that predict the chemical signals $\delta_1(t)$ and $\delta_2(t)$. Of

Collectively, these results are consistent with the instigation of Earth's greatest mass extinction by a specific microbial innovation.

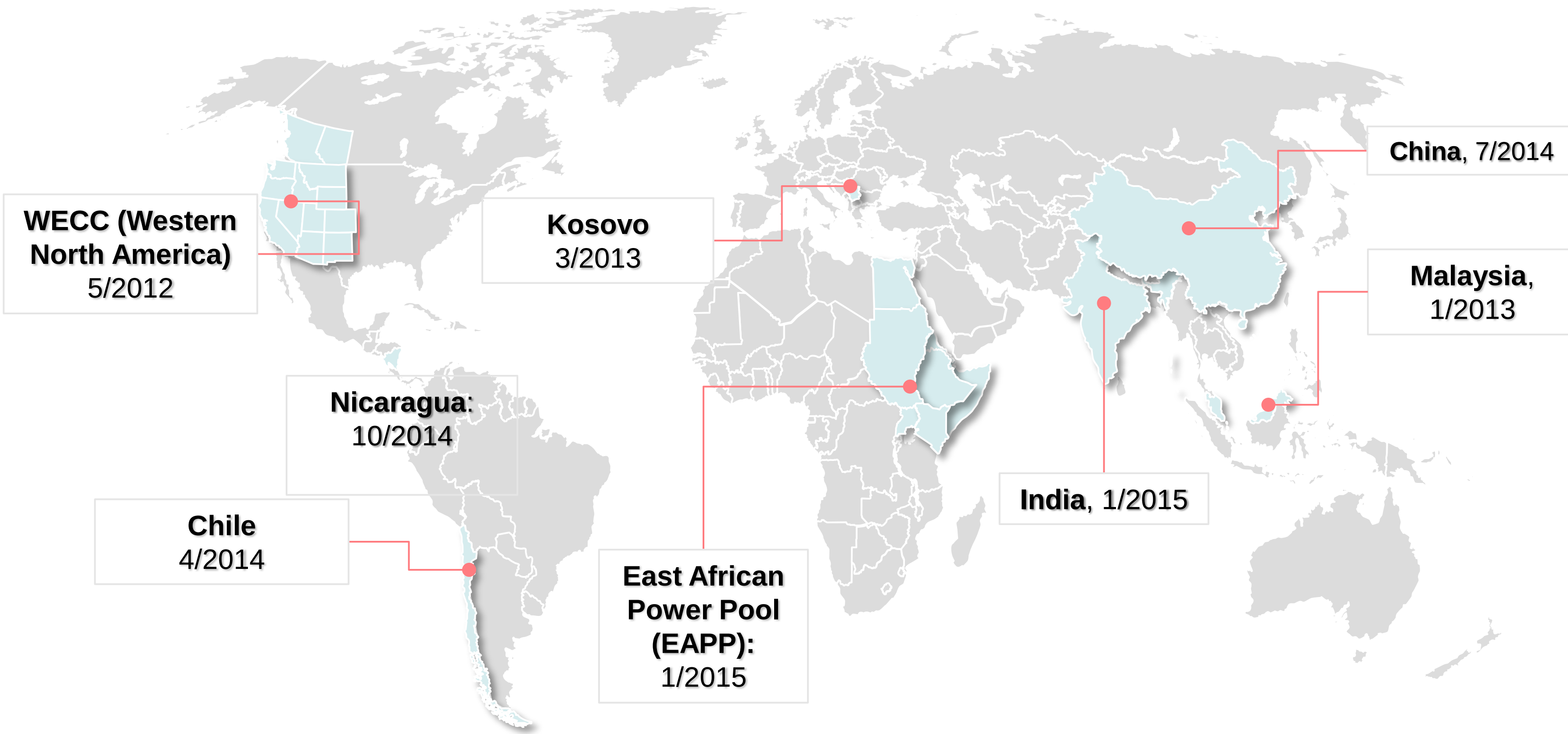
IPCC AR5 (2014):
Climate Projections and Associated Risks





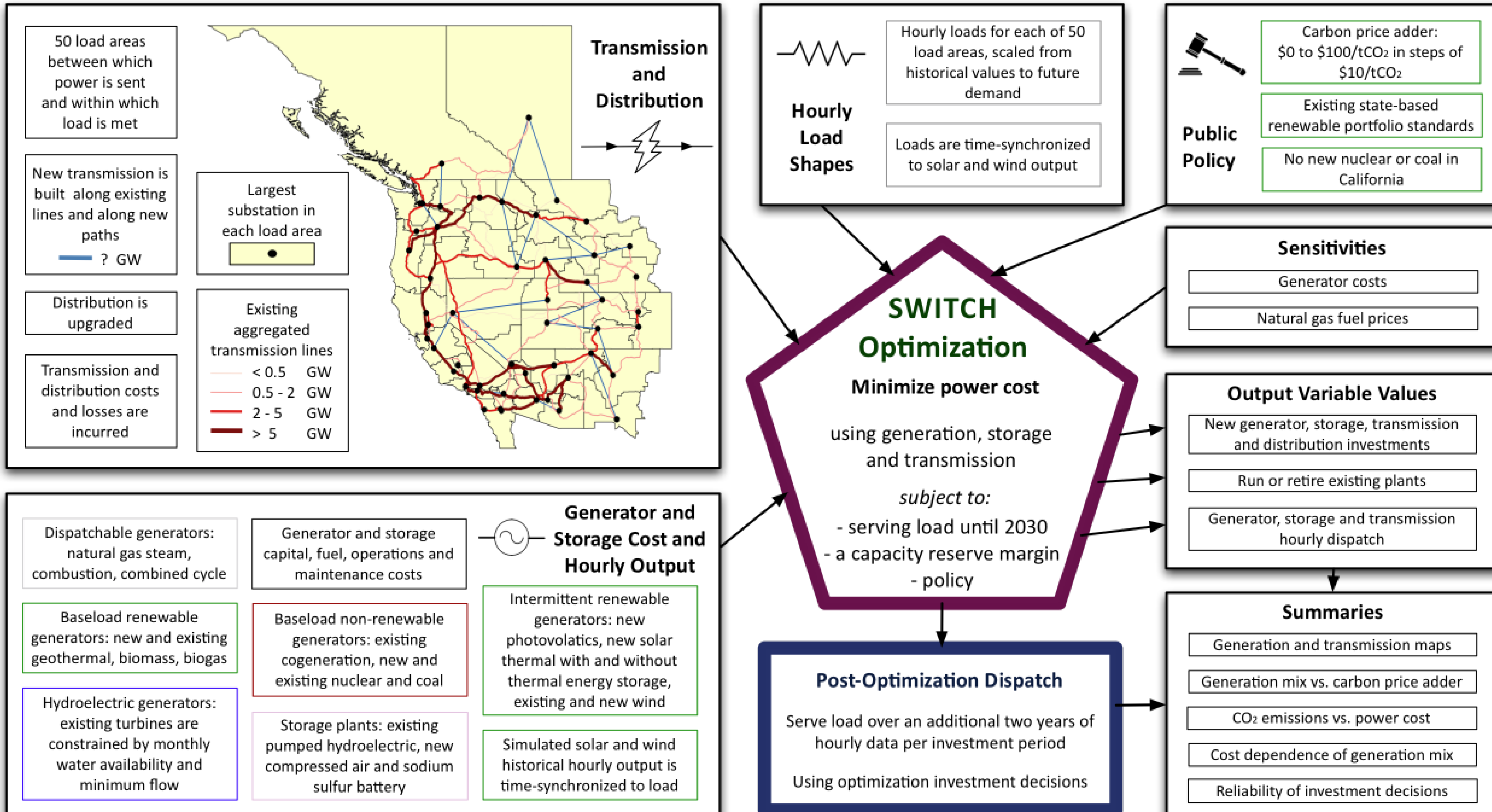
Energy System Modeling Efforts in the Renewable and Appropriate Energy Laboratory, UC Berkeley

(Kammen, et al.,http://rael.berkeley.edu/switch)



A consistent story emerges: Policy clarity and about $40 per ton of Carbon emissions by 2030 decarbonizes western North America, China, Chile. The technology and market forces vary by region.

The SWITCH-WECC Model



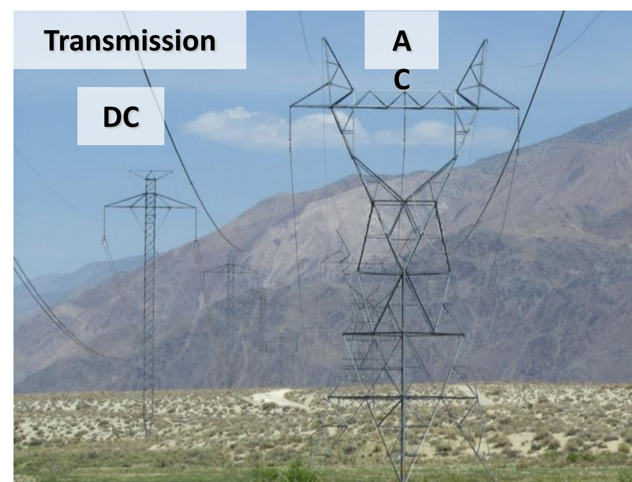
Optimization and data framework of the western North American SWITCH model.

http://rael.berkeley.edu/switch

Renewable Generation

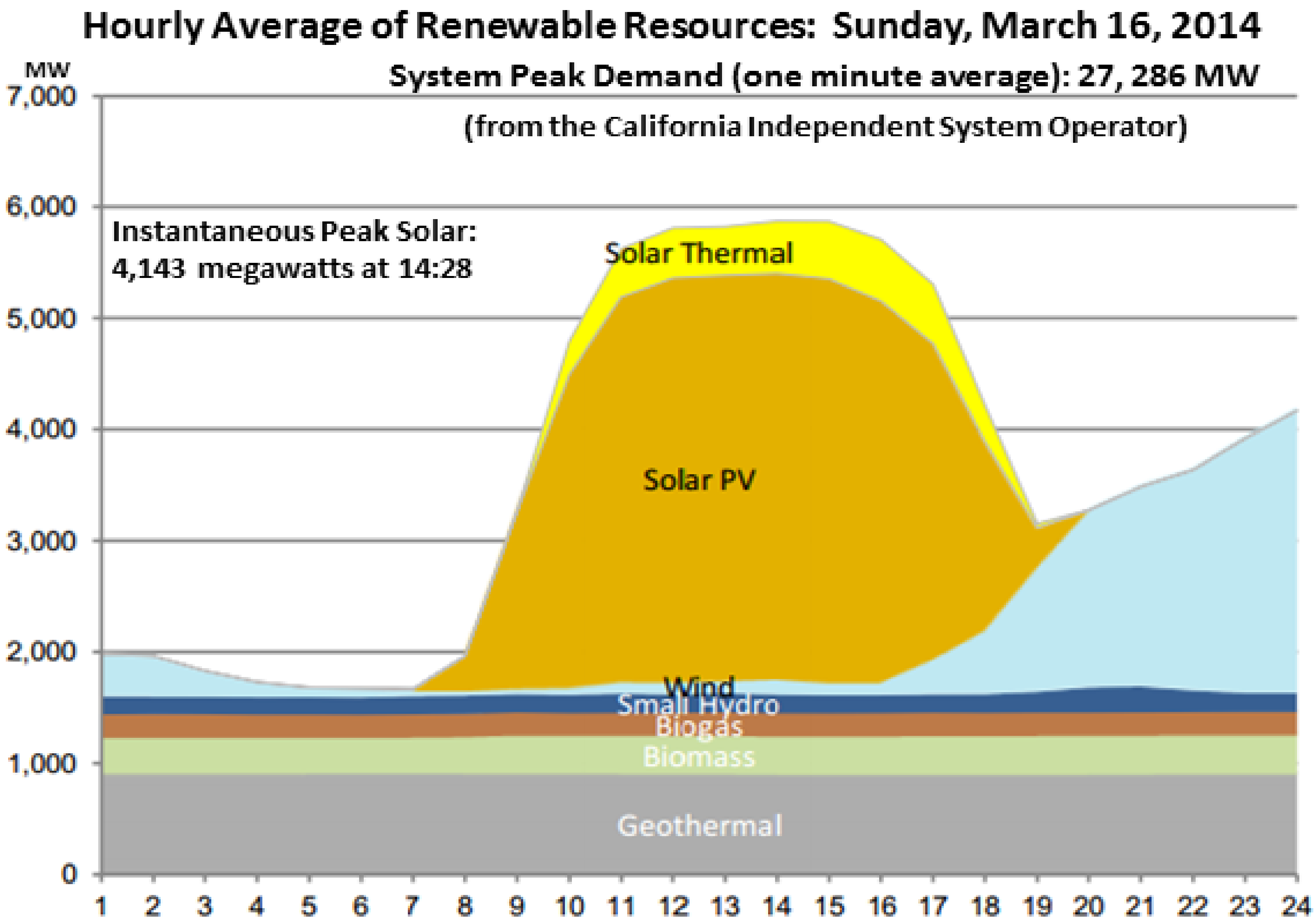
Conventional Generation

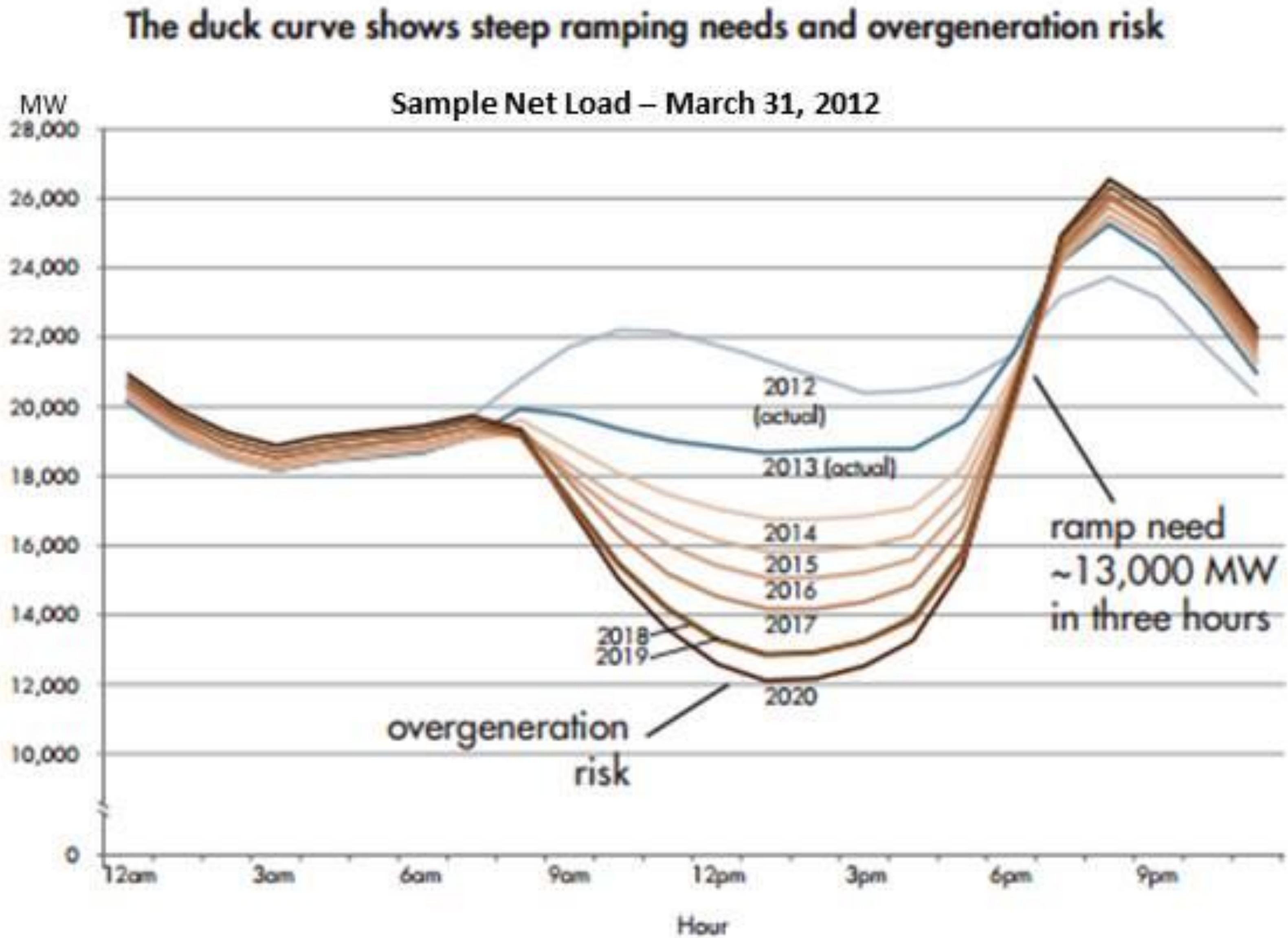
Carbon Capture and Sequestration



Storage

Example utility 'fear'

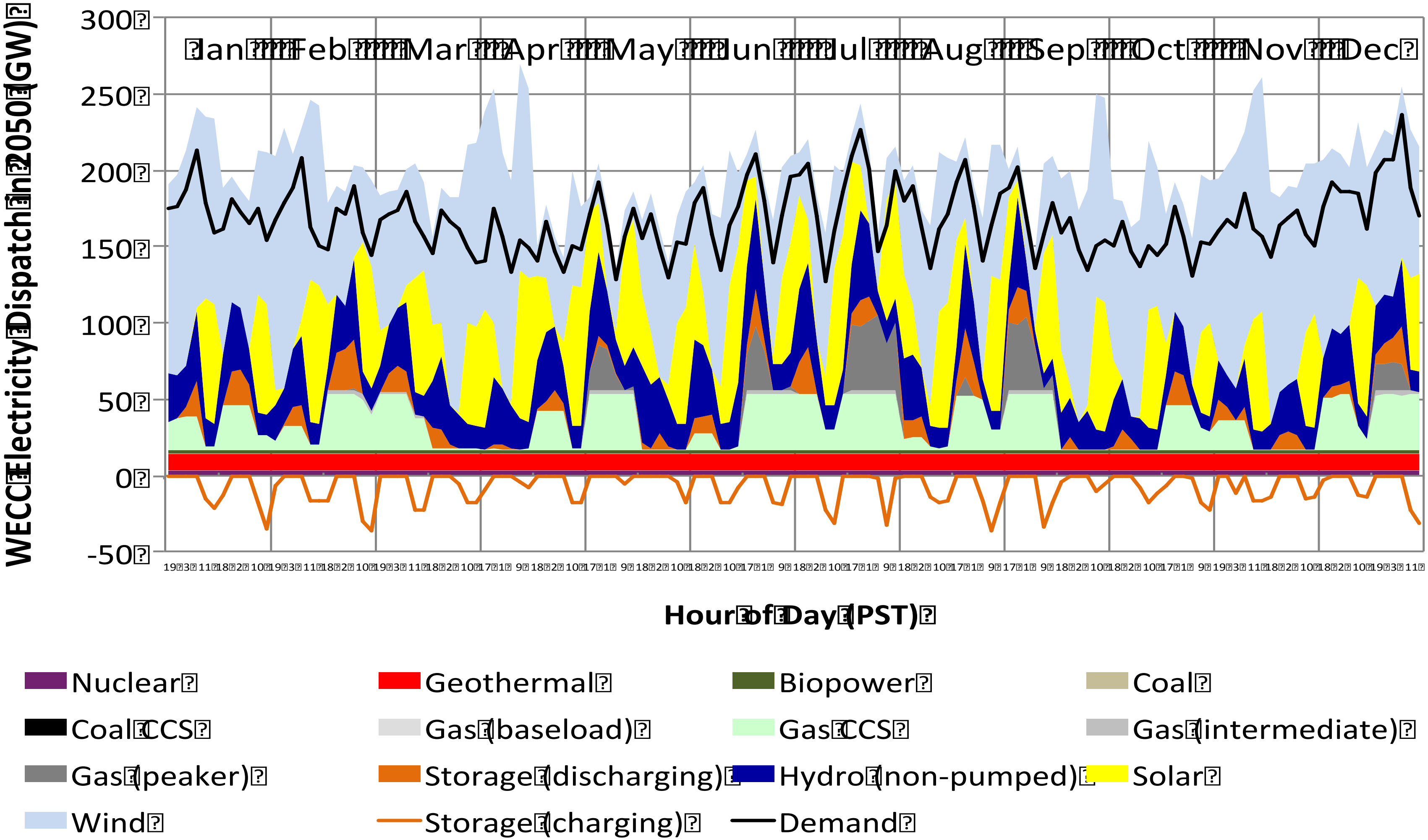




(from the California Independent System Operator)

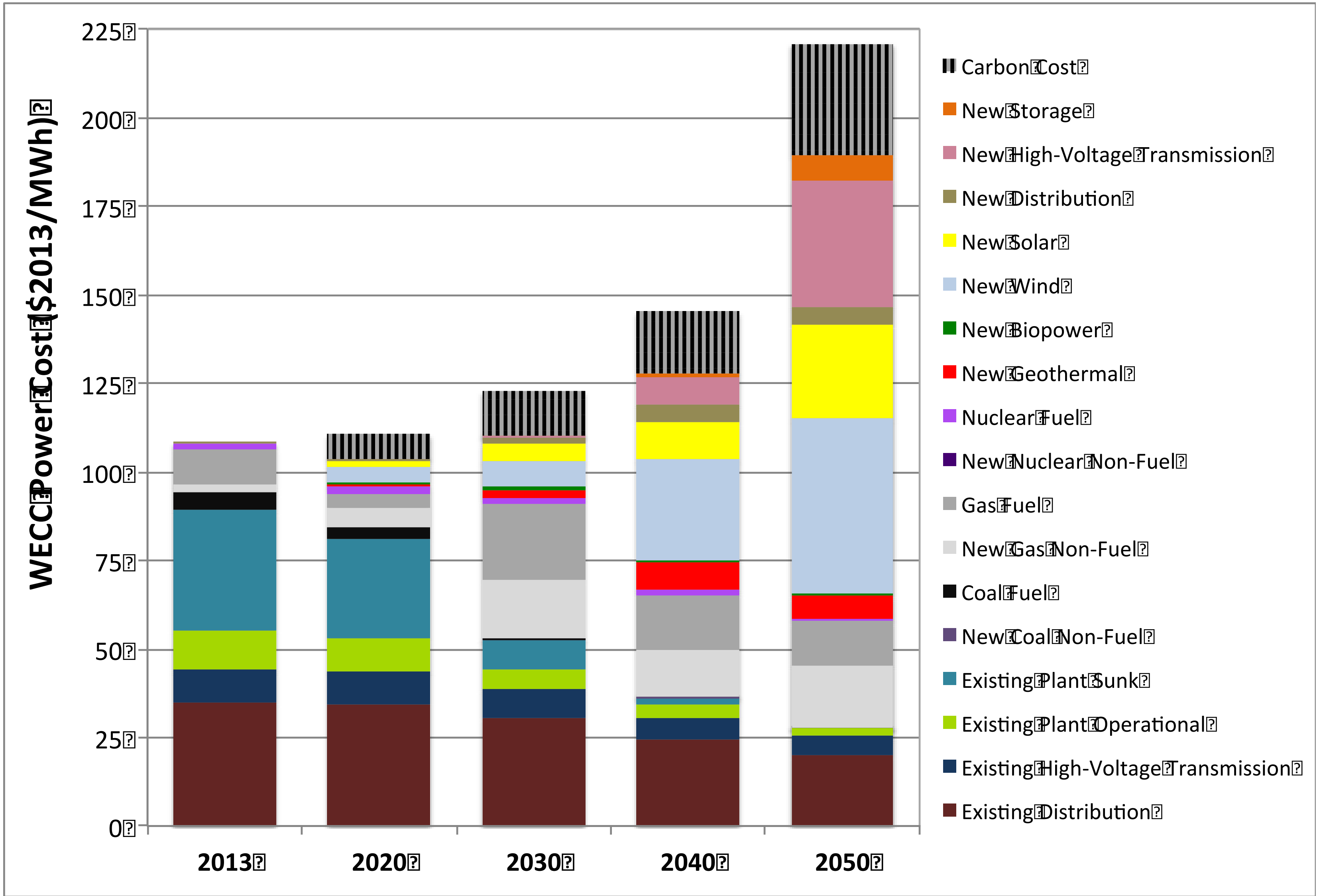
Dispatch in 2050:
Flexibility and variable renewables dominate

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



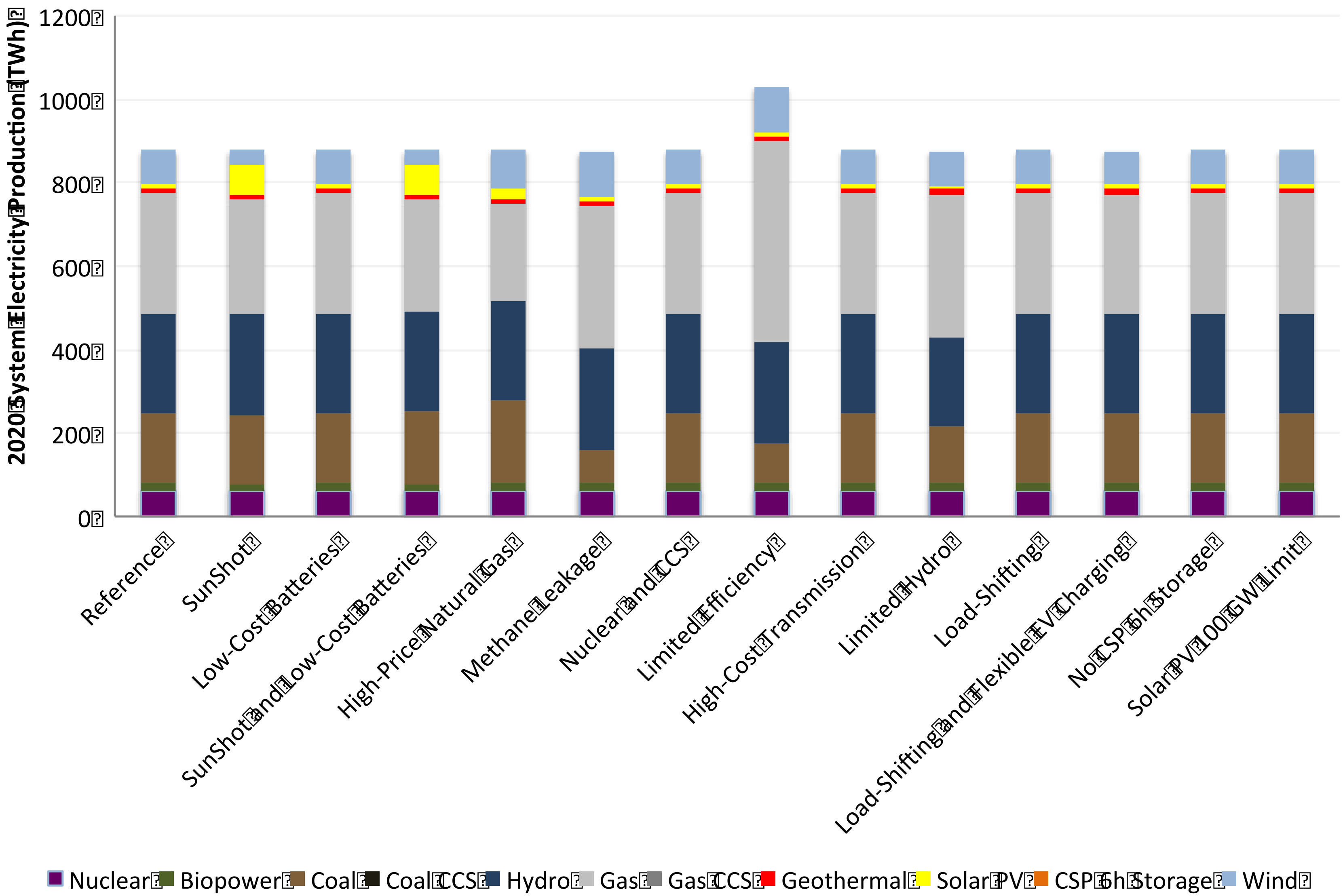
Power system cost increasingly dominated by flexibility rather than energy

- Allocation of carbon revenues important



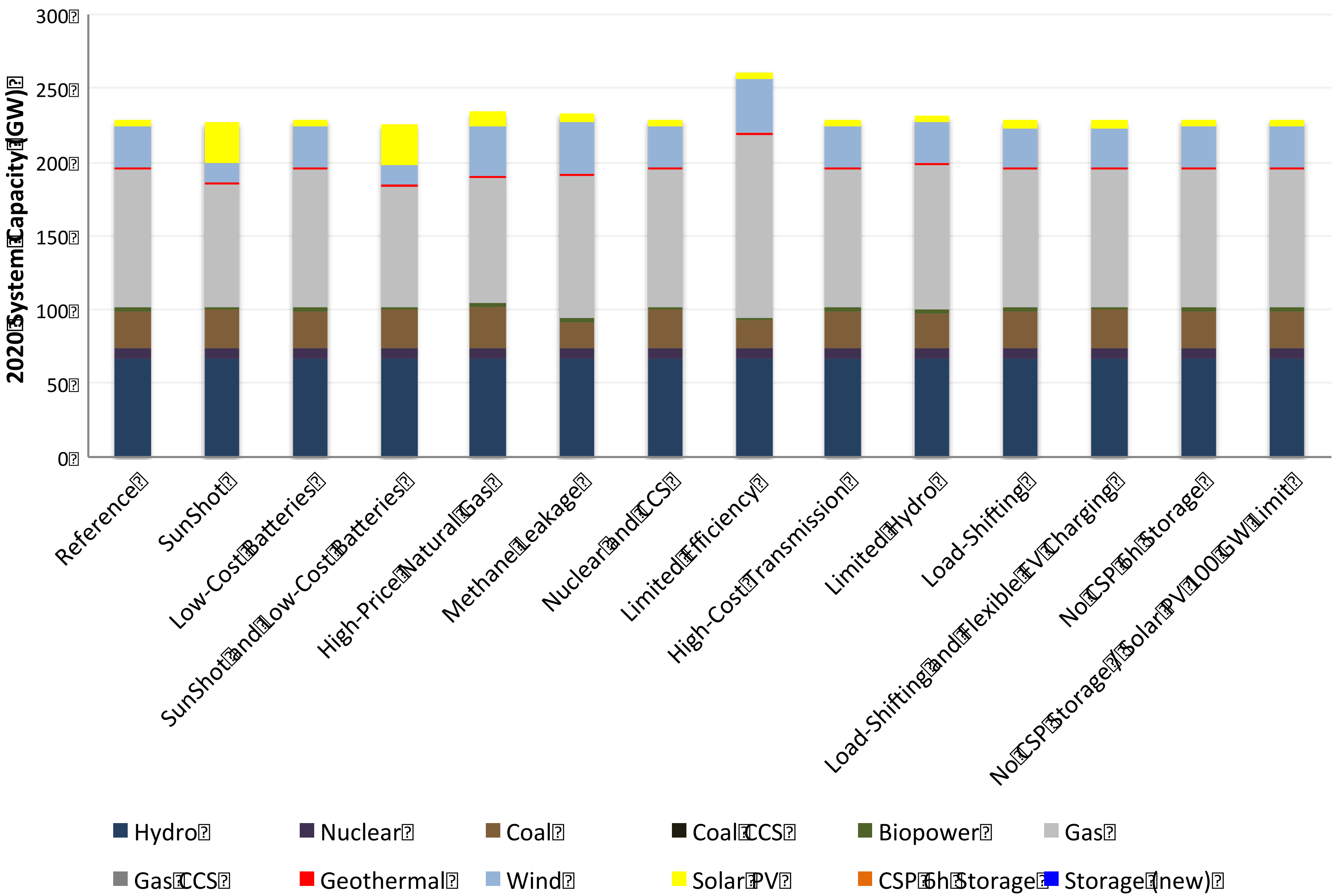
Electricity Mix, 2020

- Coal, hydropower, and gas generation dominate the system



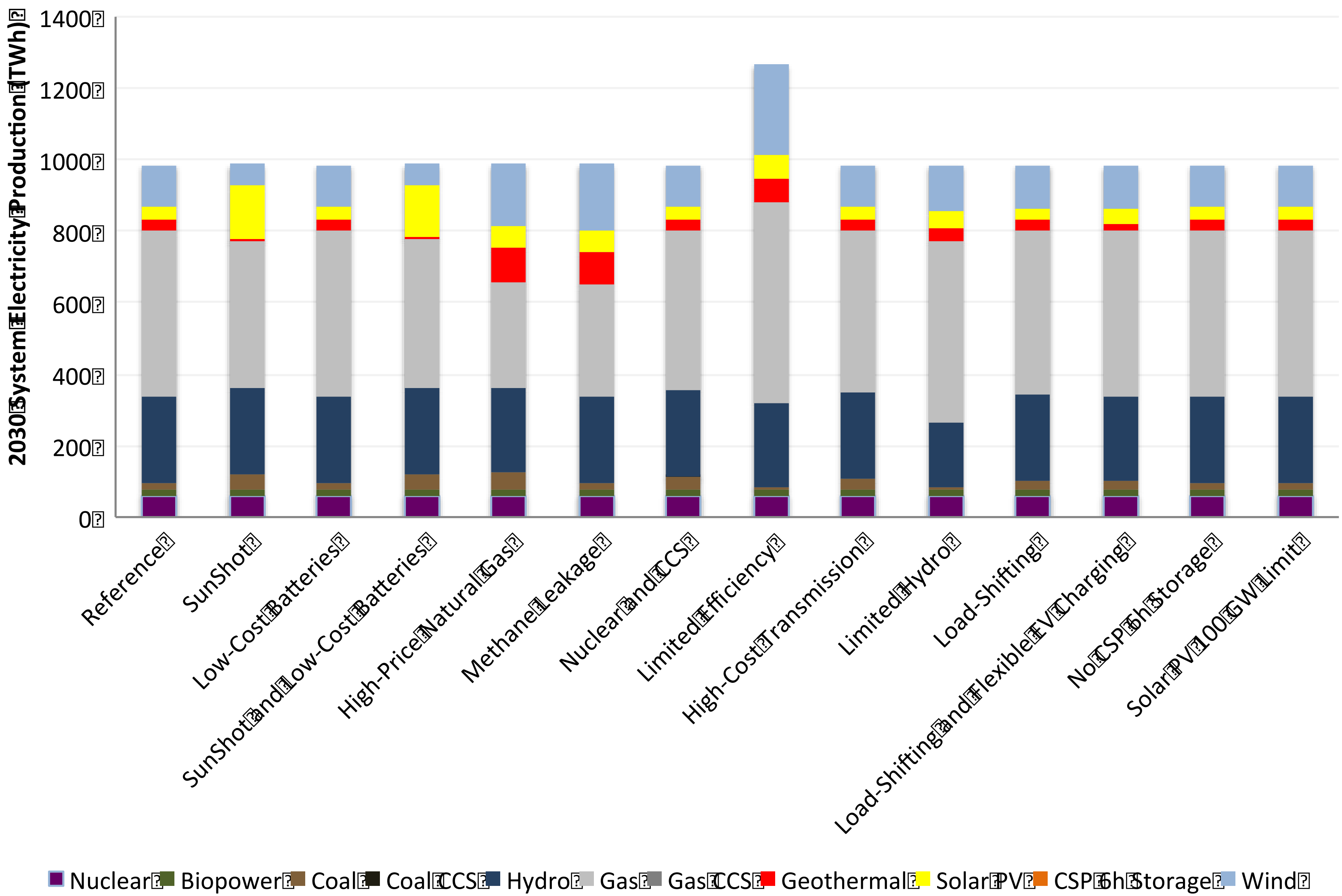
System Capacity, 2020

- No new storage deployed in a system dominated by flexible natural gas and hydro generation across scenarios



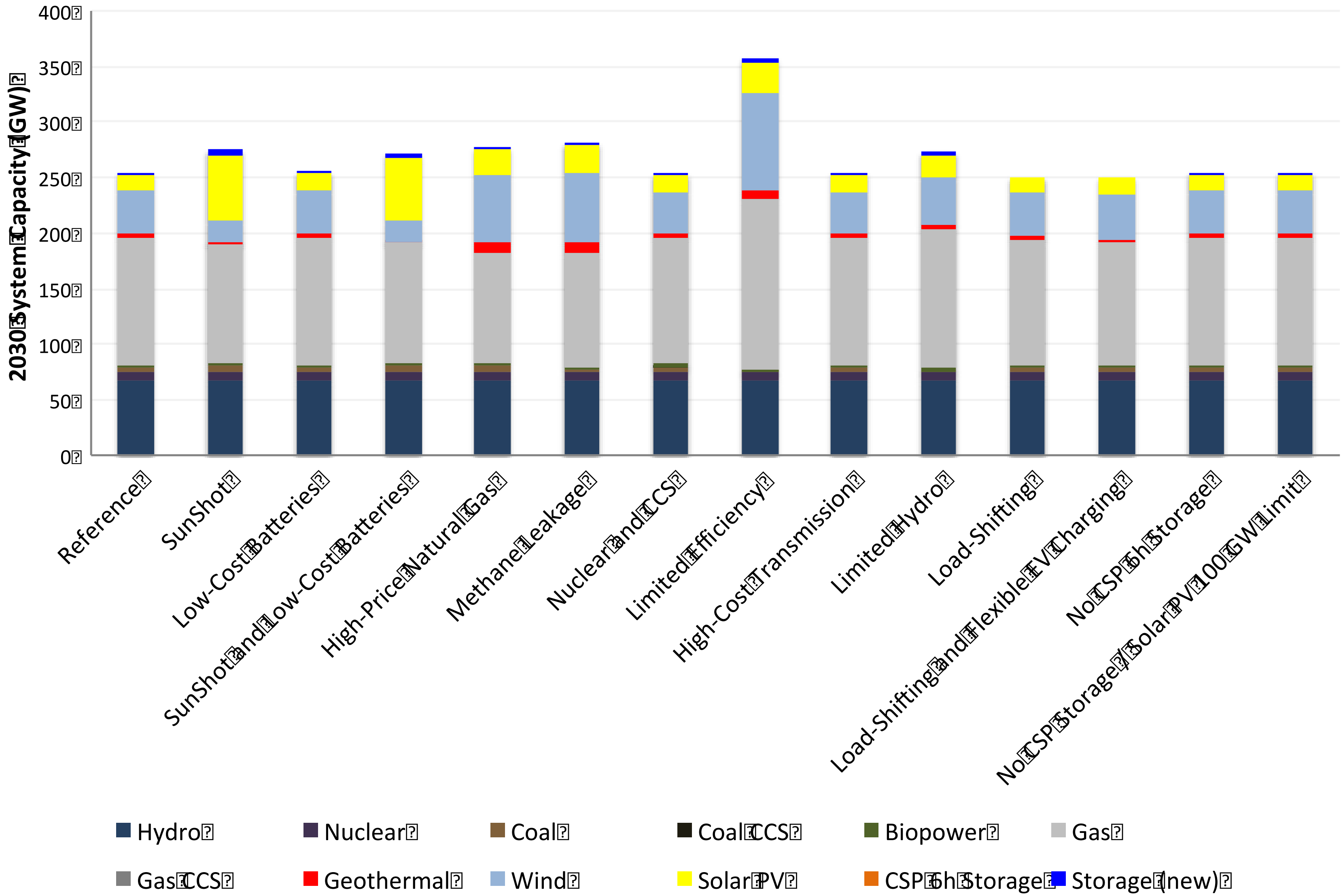
Electricity Mix, 2030

- Electricity production heavily dominated by natural gas



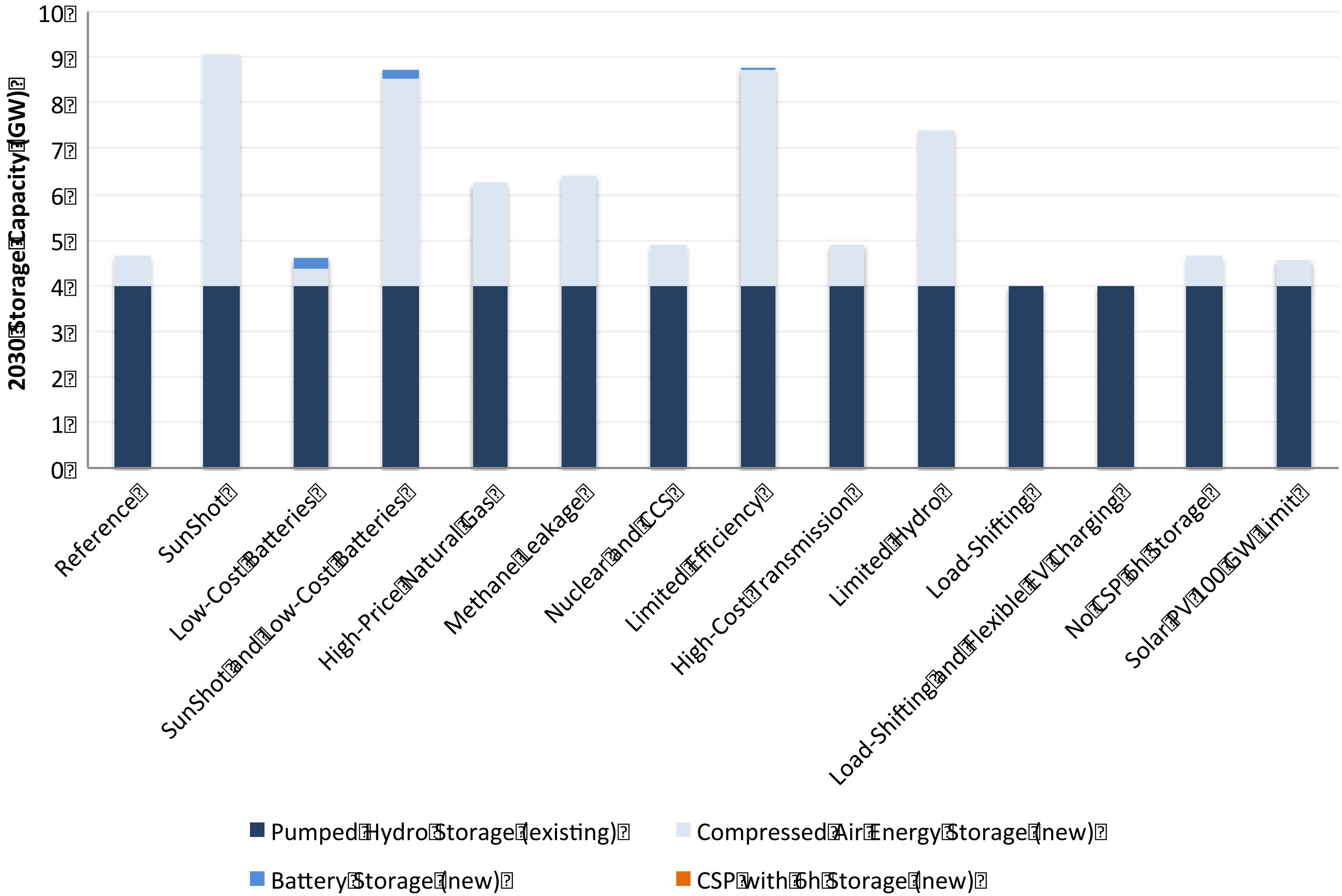
System Capacity, 2030

- New storage is installed in several scenarios in 2030



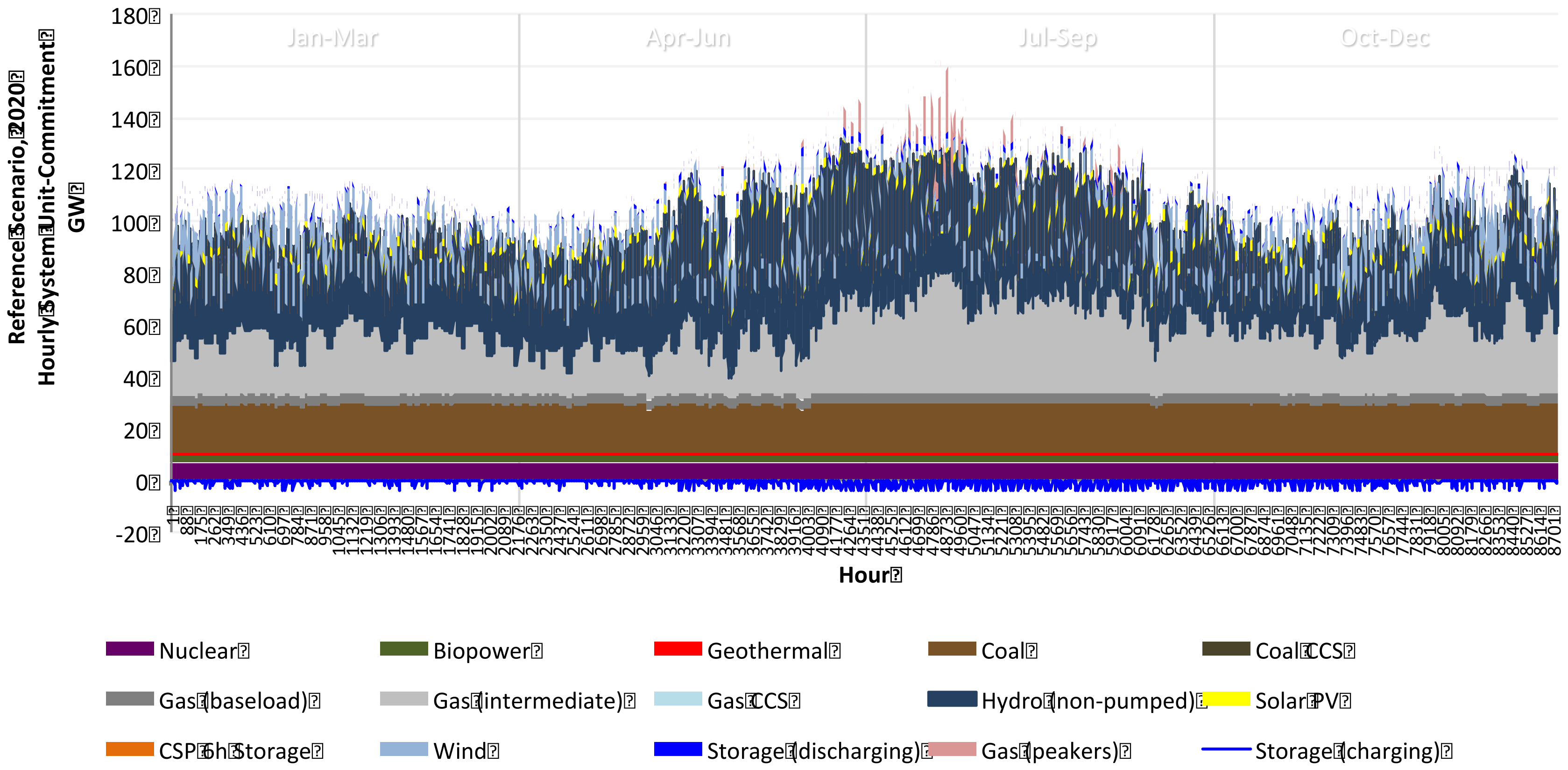
Storage Capacity, 2030

- New storage is installed in several scenarios in 2030



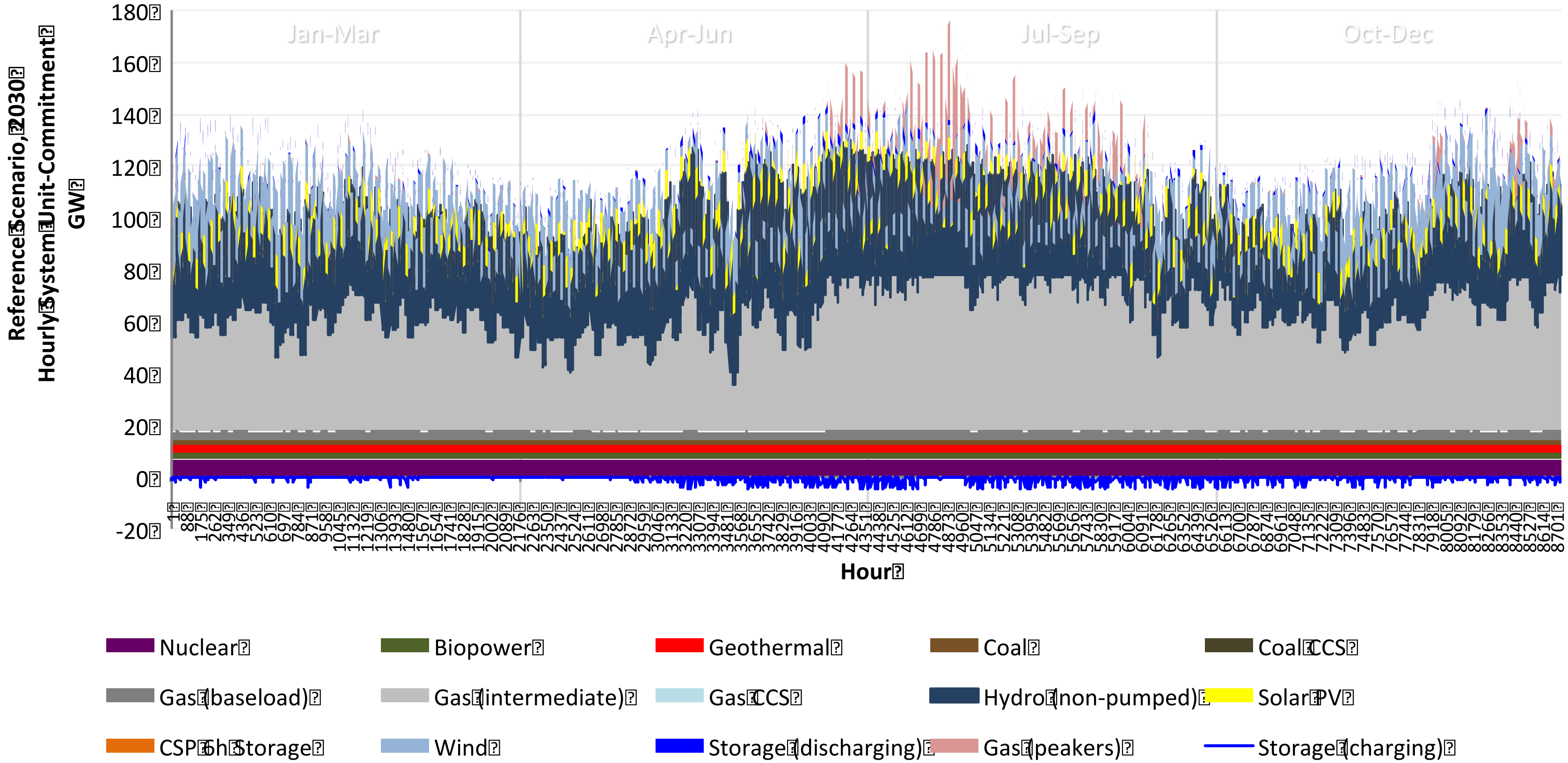
System Unit-Commitment, Reference Scenario, 2020

- The 2020 power system is dominated by coal, hydro, and gas generation
- Wind is the main source of renewable electricity
- Existing storage used regularly, charging at night and providing energy during the day



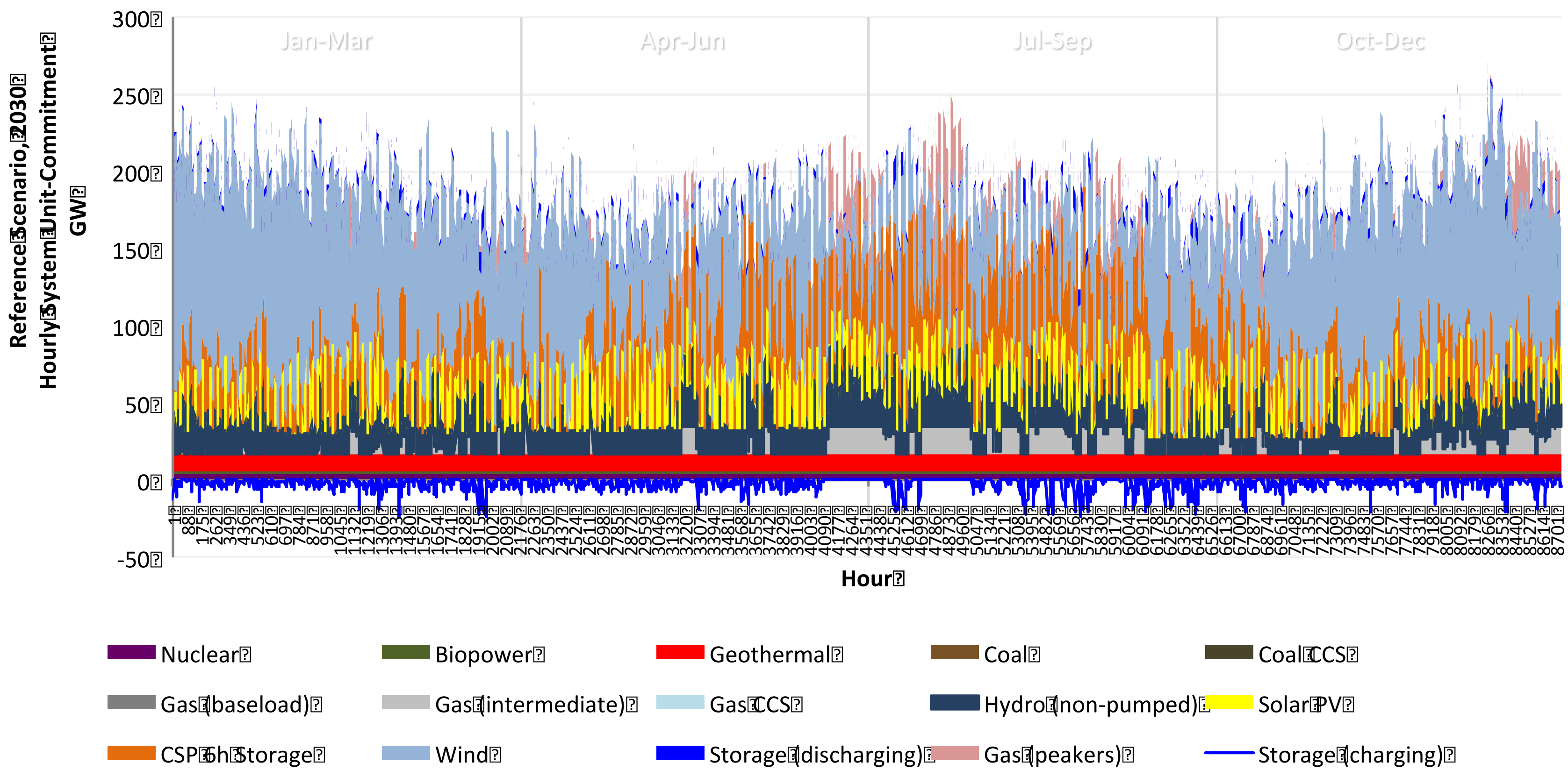
System Unit-Commitment, Reference Scenario, 2030

- By 2030, the share of renewables, both wind and solar, grows
- Combined-cycle gas generation replaces most baseload coal
- Storage is used less, especially in the spring and during the summer peak



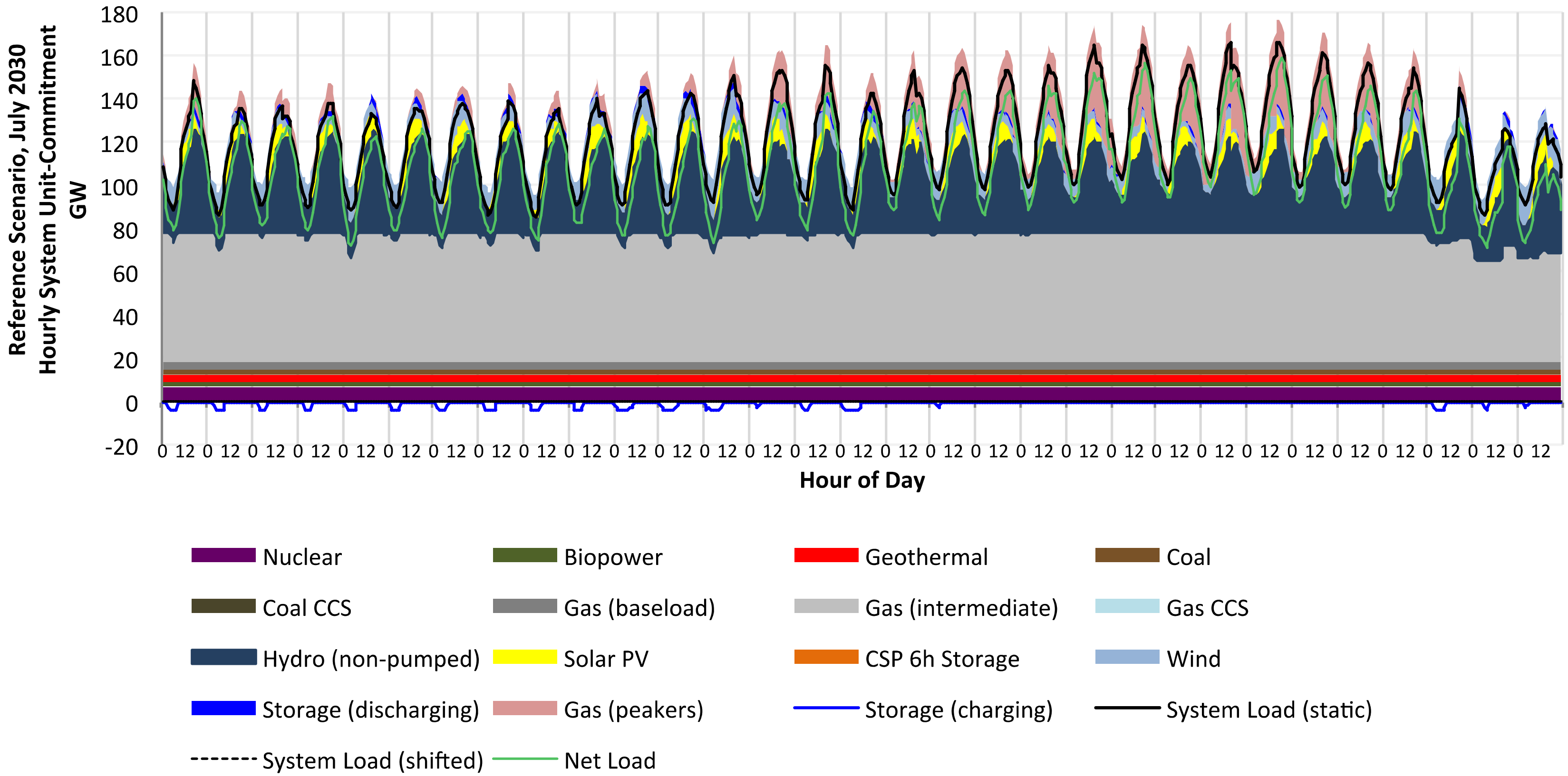
System Unit-Commitment, Reference Scenario, 2050

- Large differences in how load is met across seasons



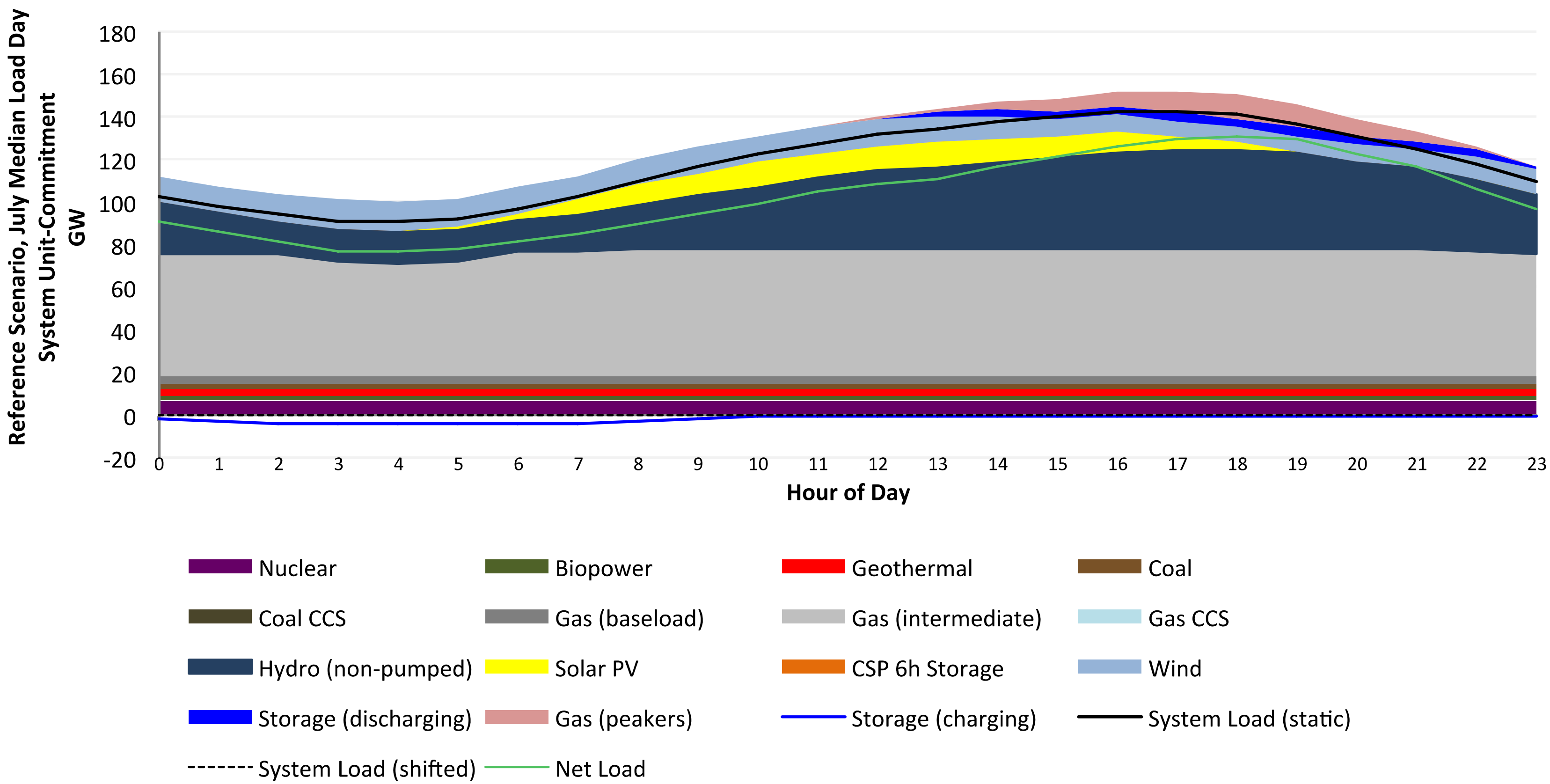
System Unit-Commitment, Reference Scenario, 2030

- For ~10 days in July, system is very stressed
- Intermediate gas generation is operating at maximum output and peakers are running for many consecutive hours



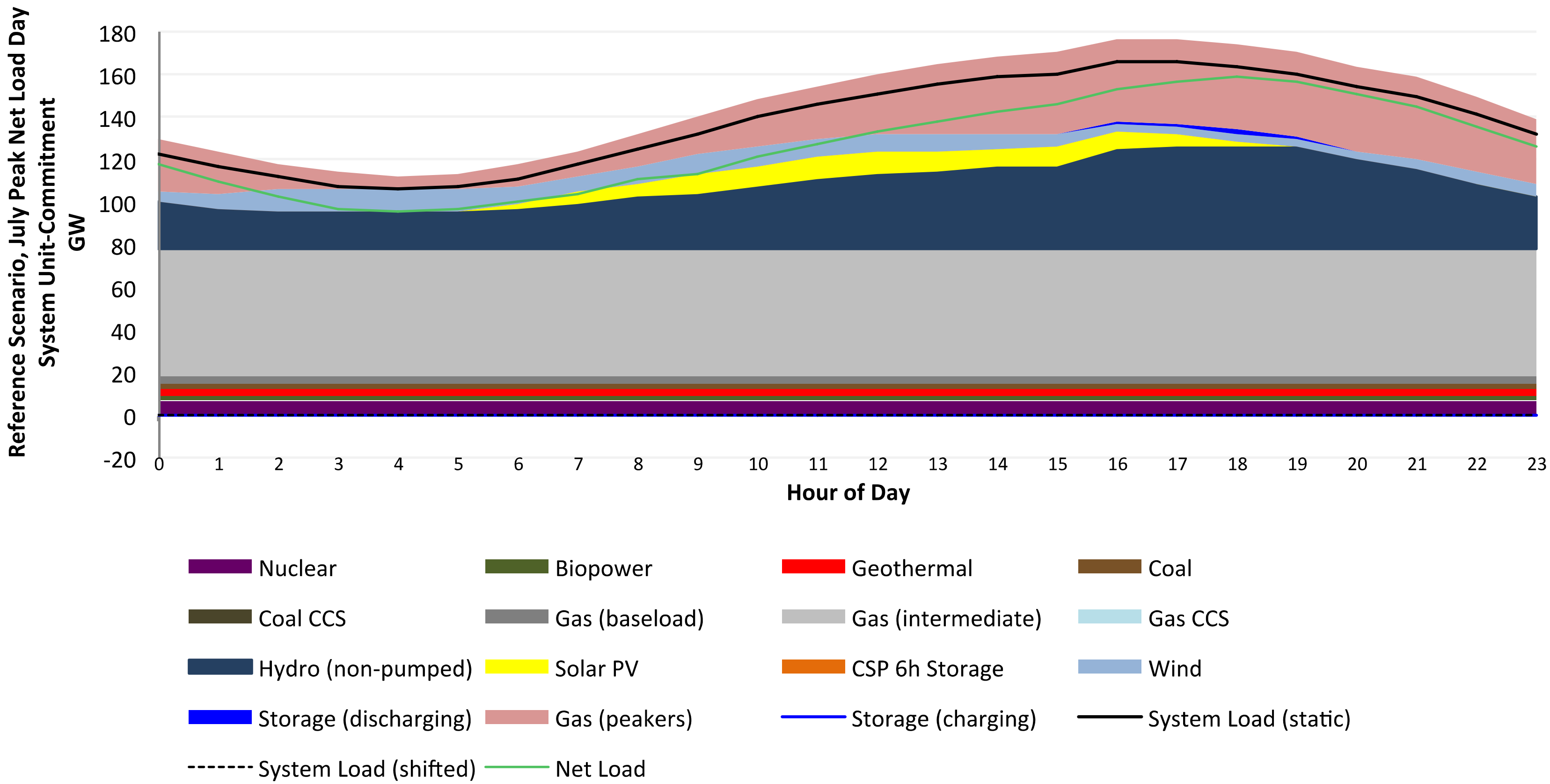
System Unit-Commitment, Reference Scenario, 2030

- The typical summer day has nighttime charging of storage, with the energy released back during the afternoon and evening hours



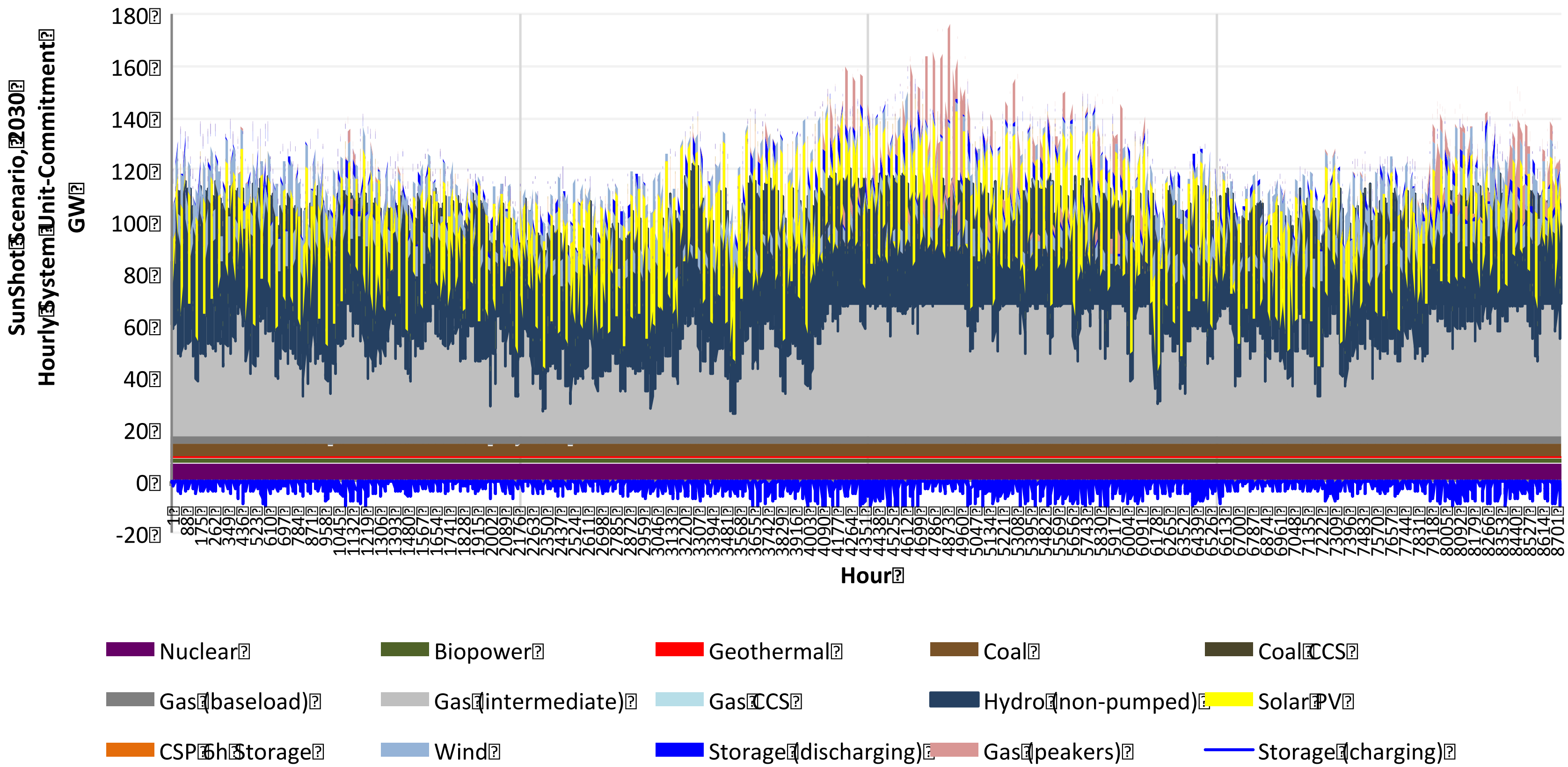
System Unit-Commitment, Reference Scenario, 2030

- On the peak net load day (in late July), nighttime load remains high and wind output is low throughout the day
- Storage is not used during that period of days with high load as there is little excess energy available to shuffle around



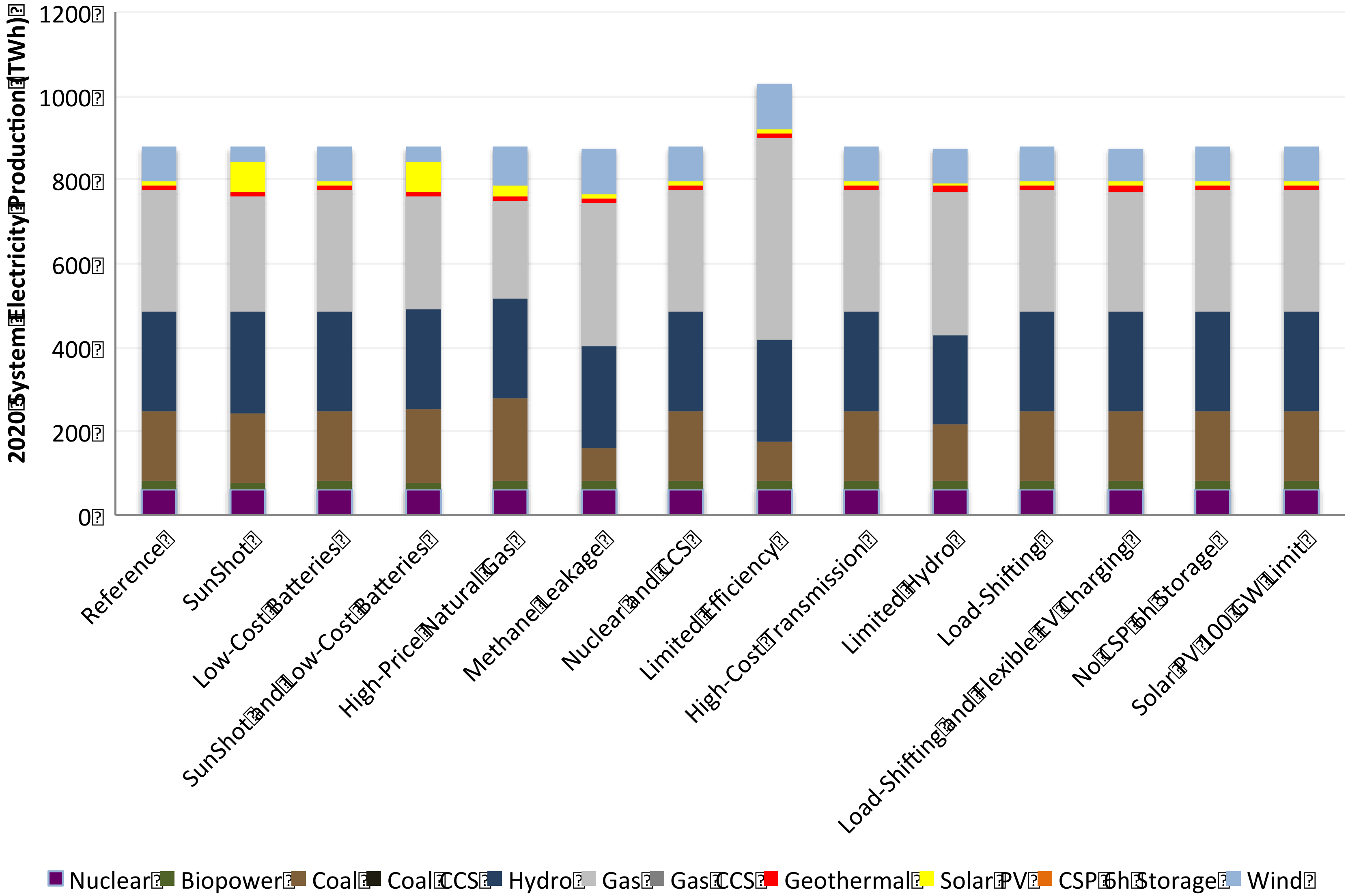
System Unit-Commitment, SunShot Scenario, 2030

- Most storage installed of all scenarios in 2030
- Storage used extensively throughout the year, mostly to shift daytime solar PV energy to the net-load peak in the evening – a pattern reversal



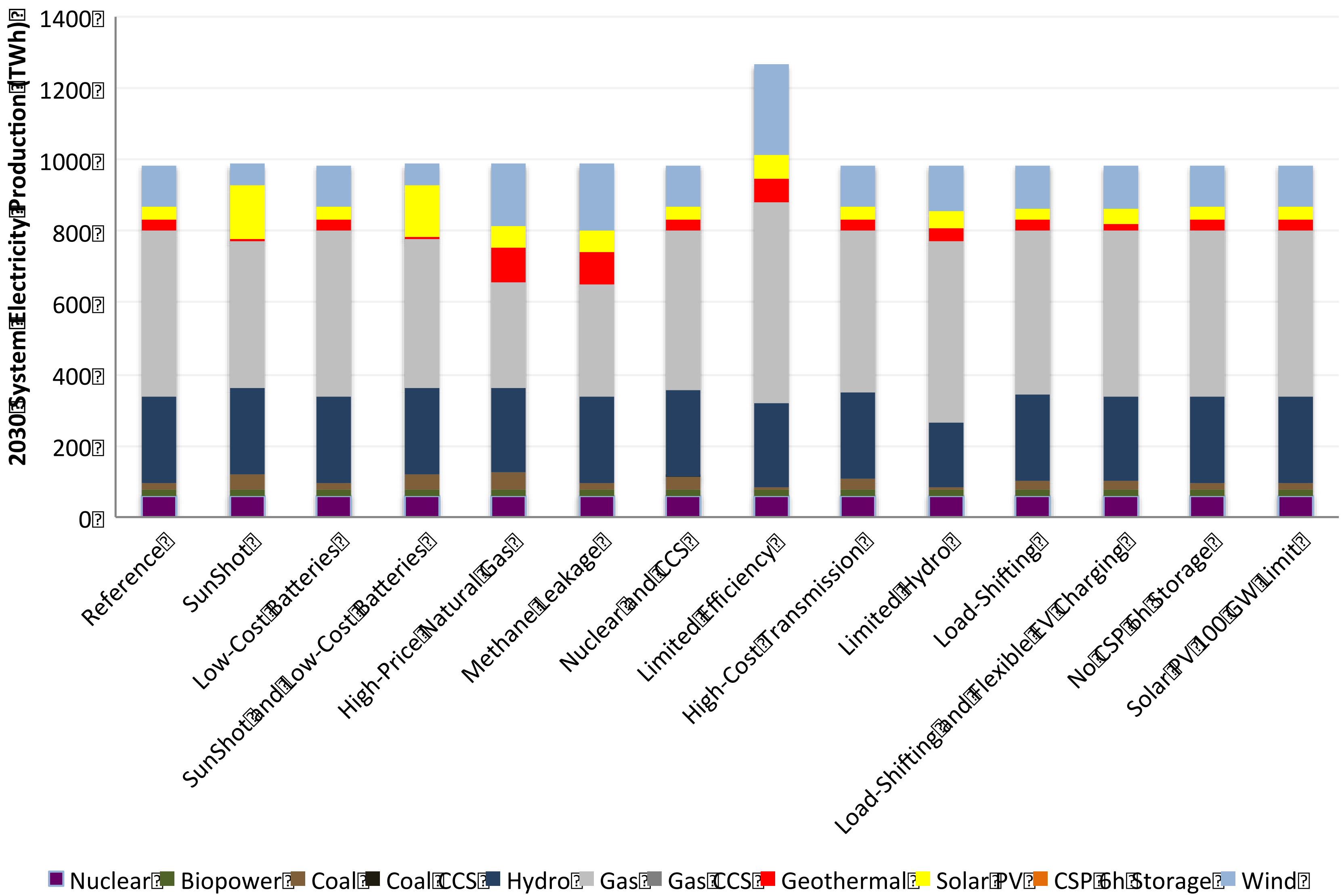
Electricity Mix in Western North America, 2020

- Coal, hydropower, and gas generation dominate the system



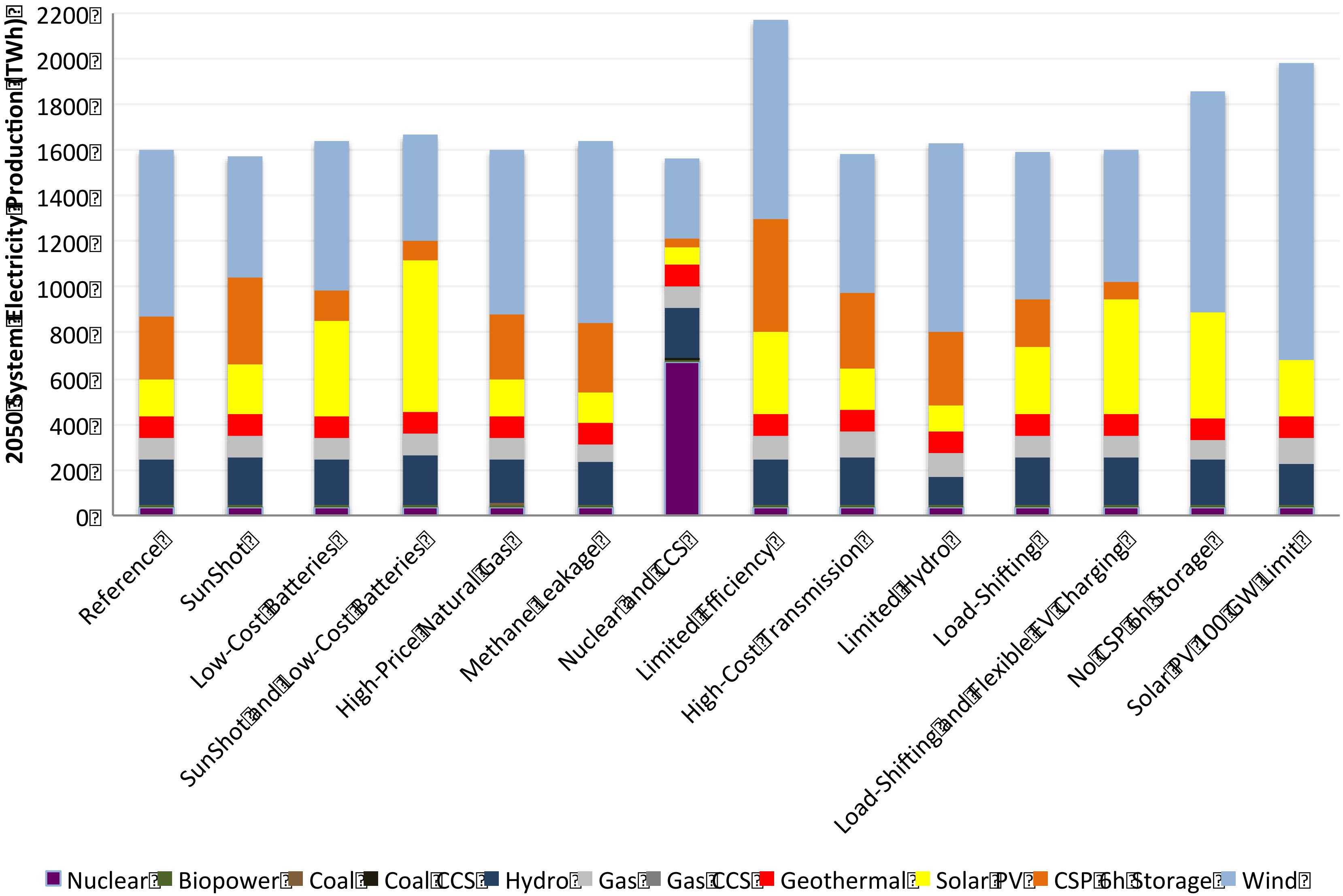
Electricity Mix in Western North America, 2030

- Electricity production heavily dominated by natural gas with rapid growth in renewables and storage

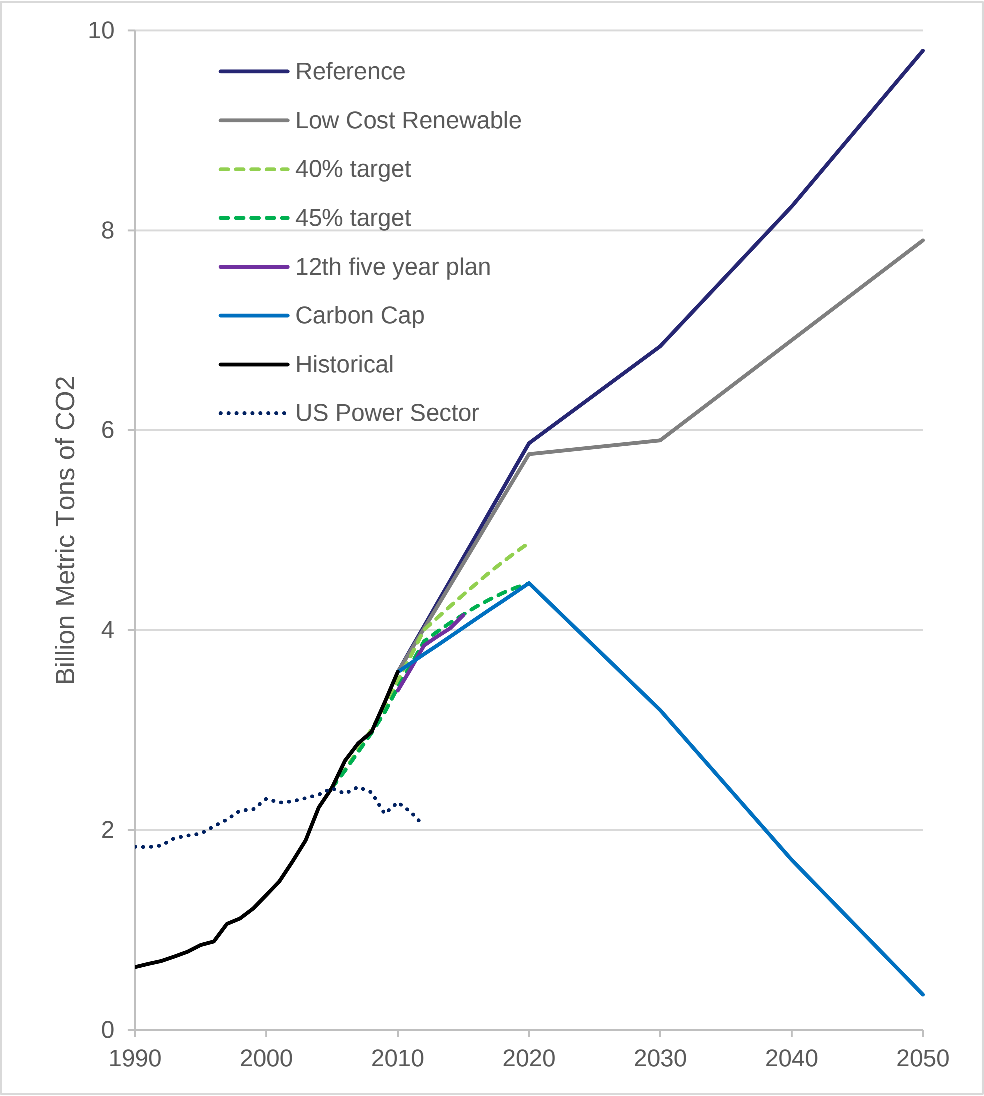


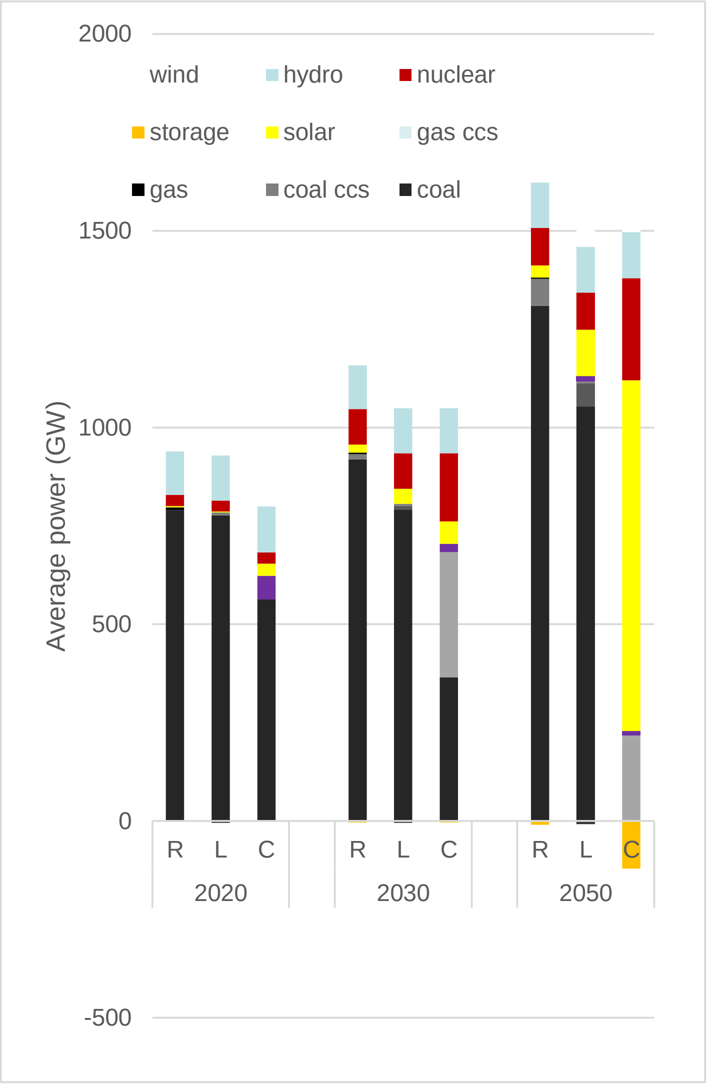
Electricity Mix in Western North America, 2050

- Electricity production is virtually *all* from zero carbon sources; system is resilient, flexible and smart



SWITCH-China (2050), Kammen, *et al., 2014*





R: reference | Low-cost renewable (current cost trends) | Carbon cap

CoolCalifornia.org
GOVERNMENT • UNIVERSITY • NGO PARTNERSHIP

Sign In | Sign up

Keyword Search: GO
Advanced Search

HOME | INDIVIDUALS | SMALL BUSINESS | LOCAL GOVERNMENT | YOUTH | COMMUNITY ORGANIZATIONS | SCHOOLS | ABOUT US

Shortcuts

- Money to Get You Started — LEARN MORE»
- California Success Stories — VIEW»
- Save Money & the Planet — LEARN MORE»
- Reduce Your Climate Impact — CALCULATE NOW»
- Climate Awards — LEARN MORE»
- Give us your Feedback — VIEW»

CoolCalifornia

Stay informed on our latest news!

Subscribe
Unsubscribe

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

So, come on, be "cool" and check out the resources on CoolCalifornia.org today!

Popular content

- Calculator
- 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

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

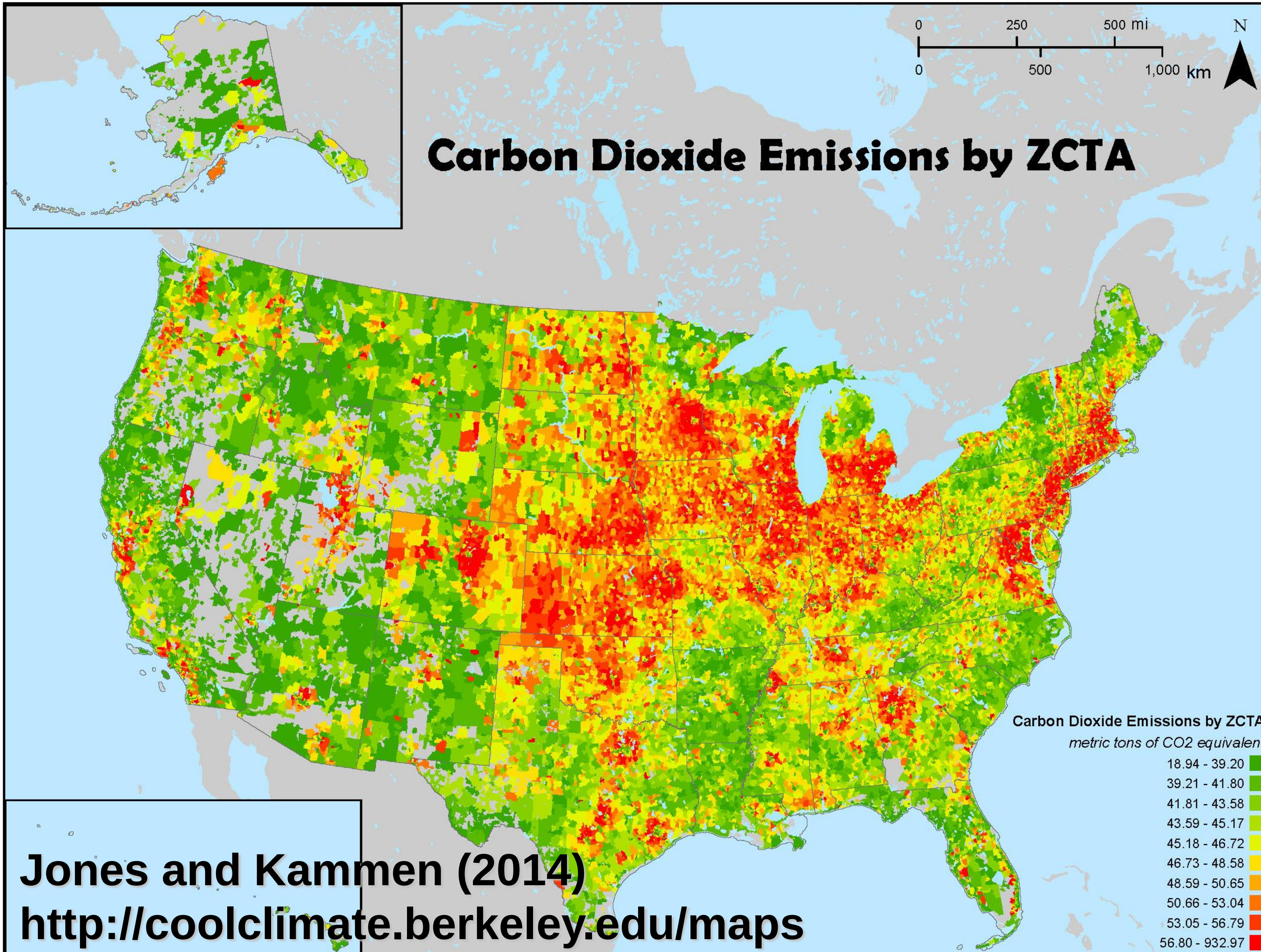
Climate Action Plan Summary

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	

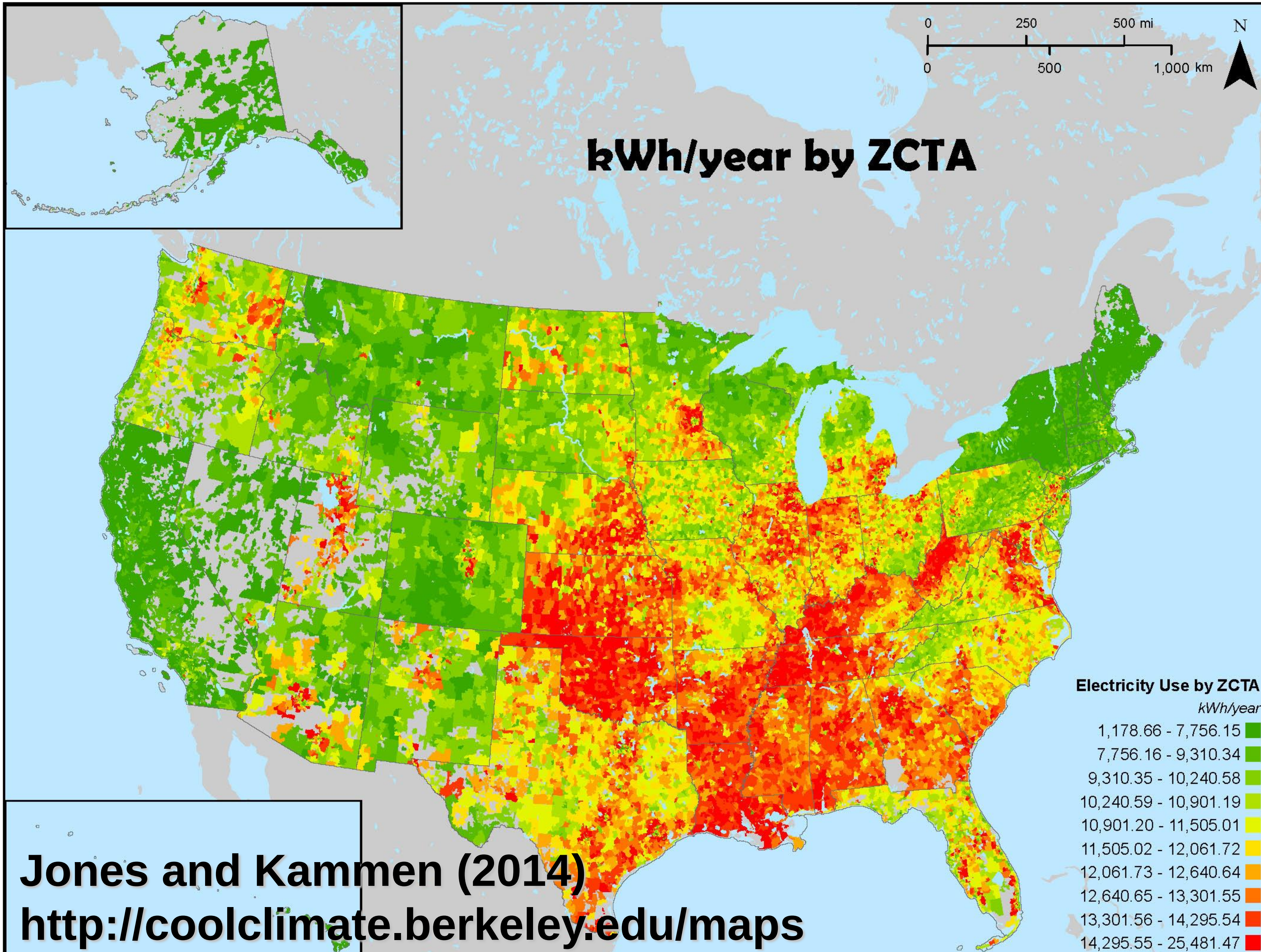
1) Click view / hide 2) Pledge 3) Save

☐ Assumptions
☐ Pledge all

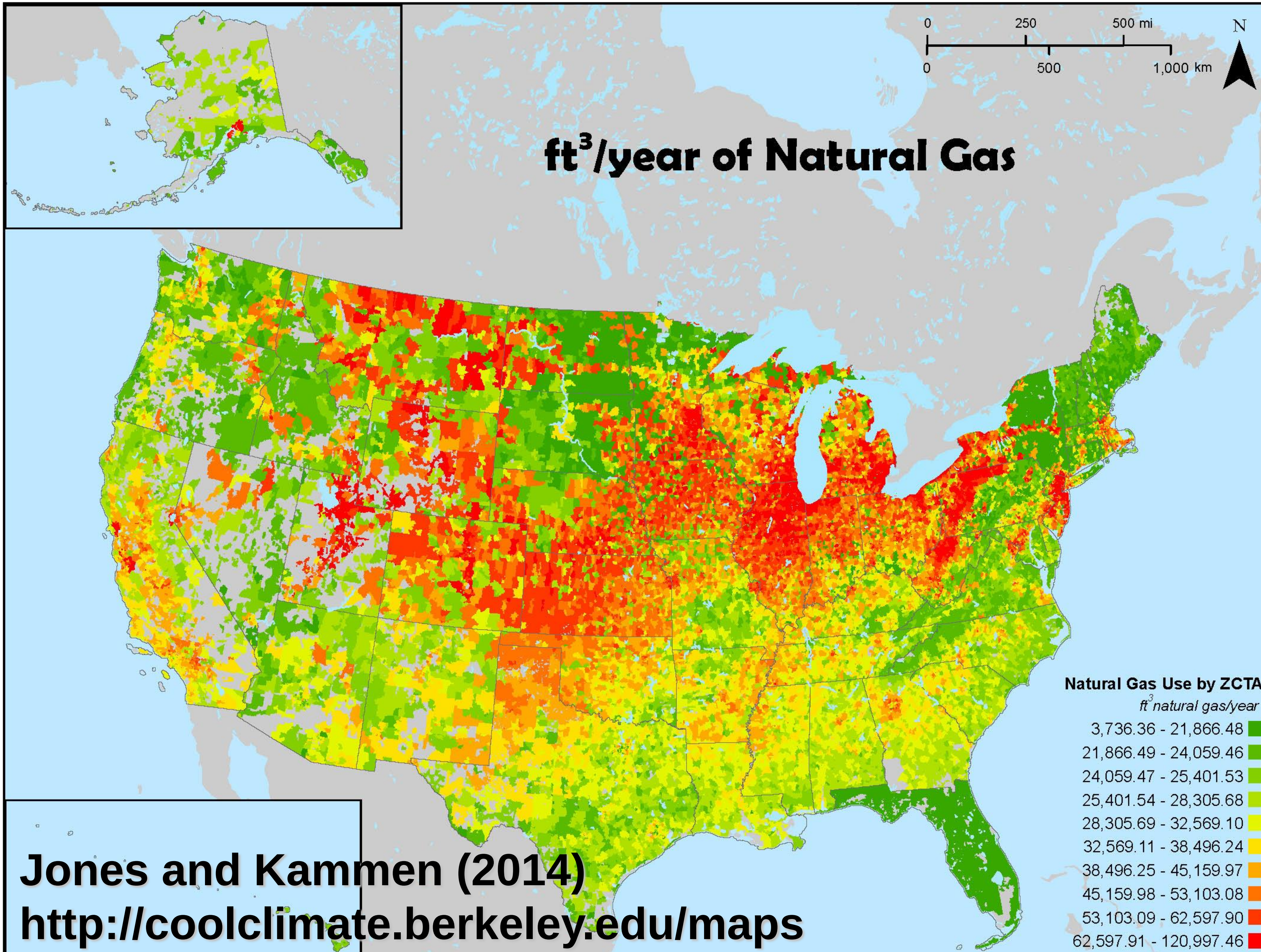
Pledged		Action	mt CO2e/yr reduced	$ / yr saved	10 year net savings
✔	view	Buy a More Efficient Vehicle	1.86	$500	$3000
✔	view	Telecommute to Work	1.07	$528	$5280
	view	Ride my Bike	0.58	$156	$1560
	view	Take Public Transportation	0.47	$156	$1560
	view	Practice Eco-Driving	0.93	$249	$2490
	view	Maintain 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



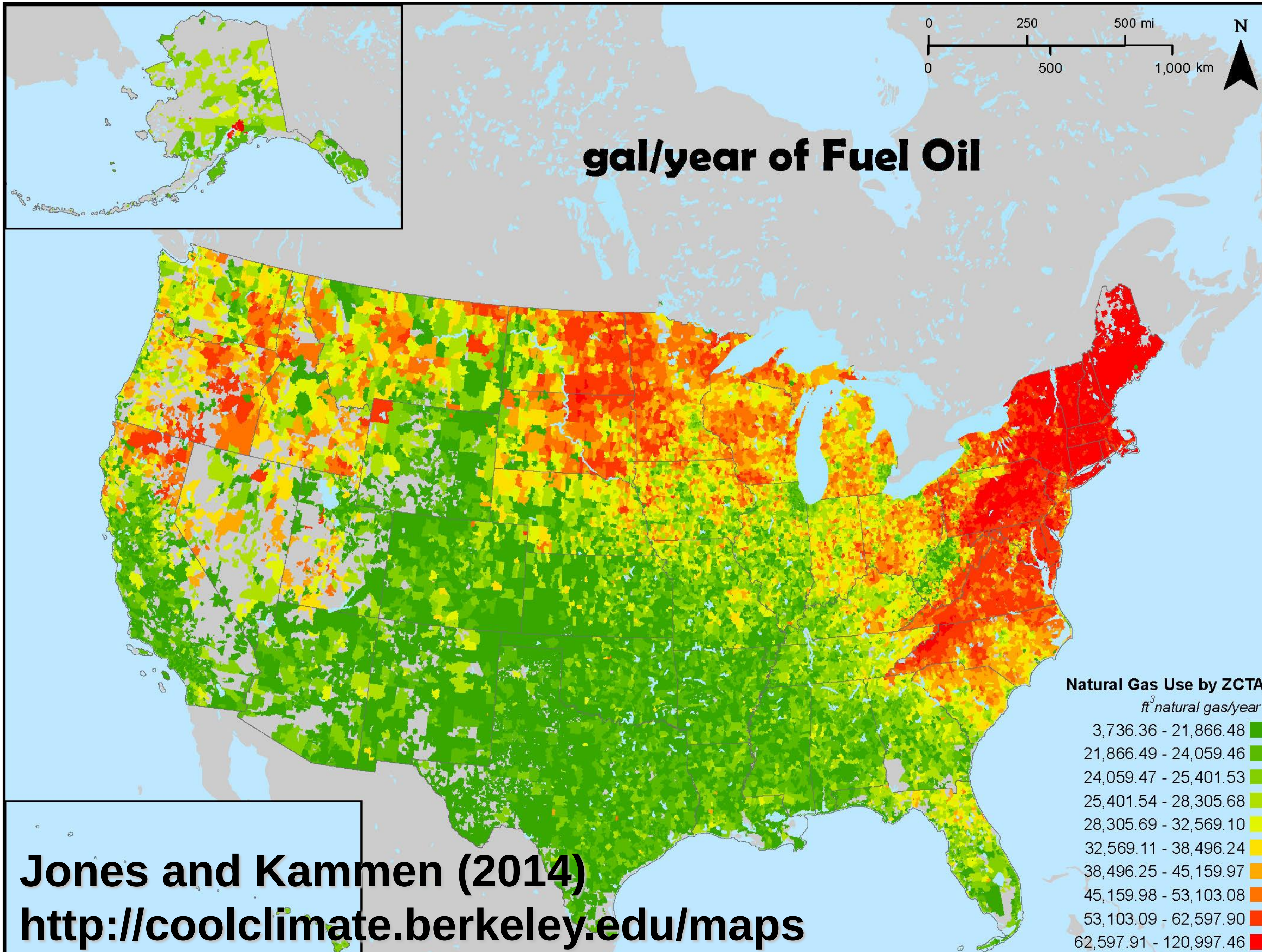
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps

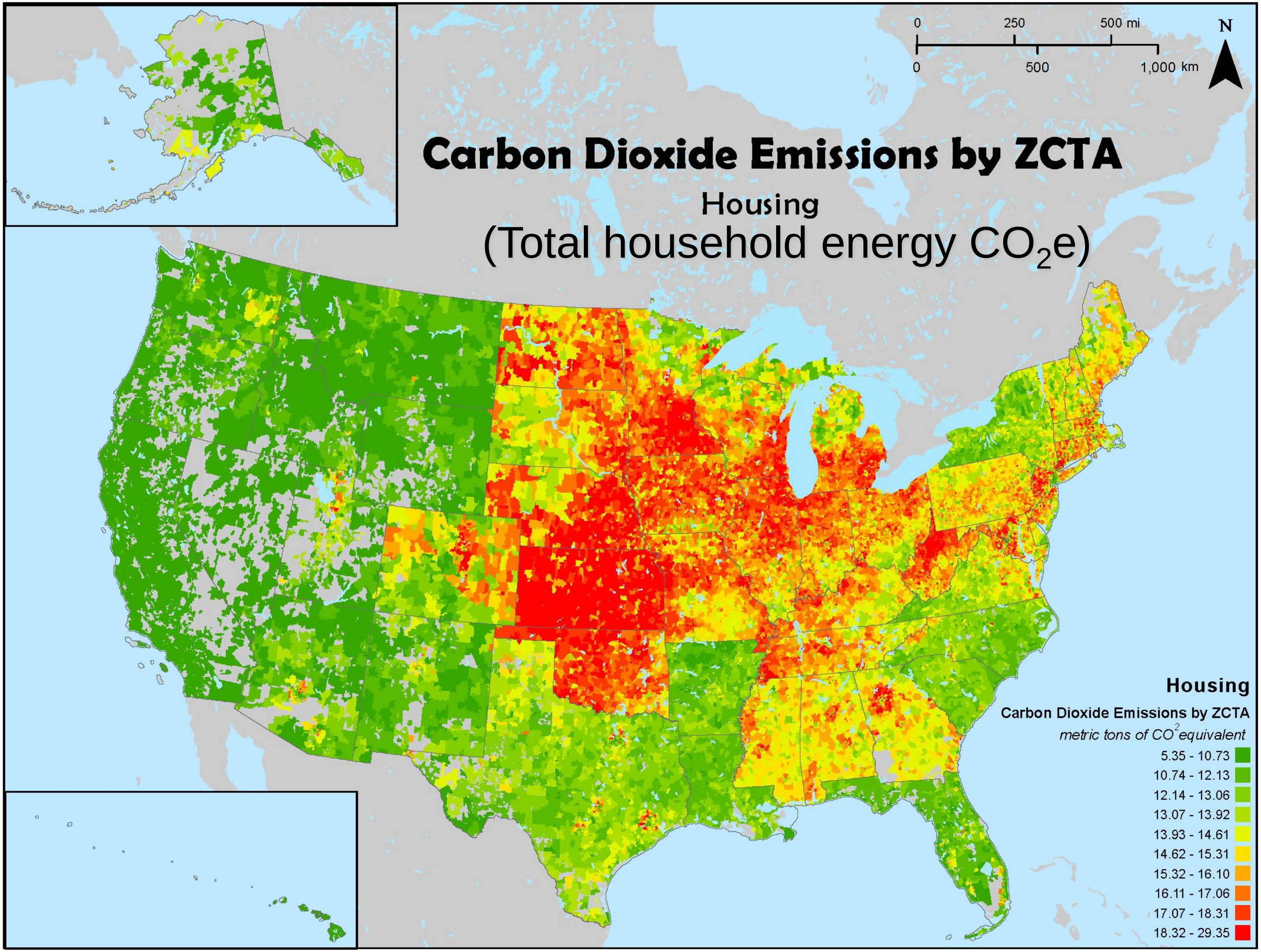


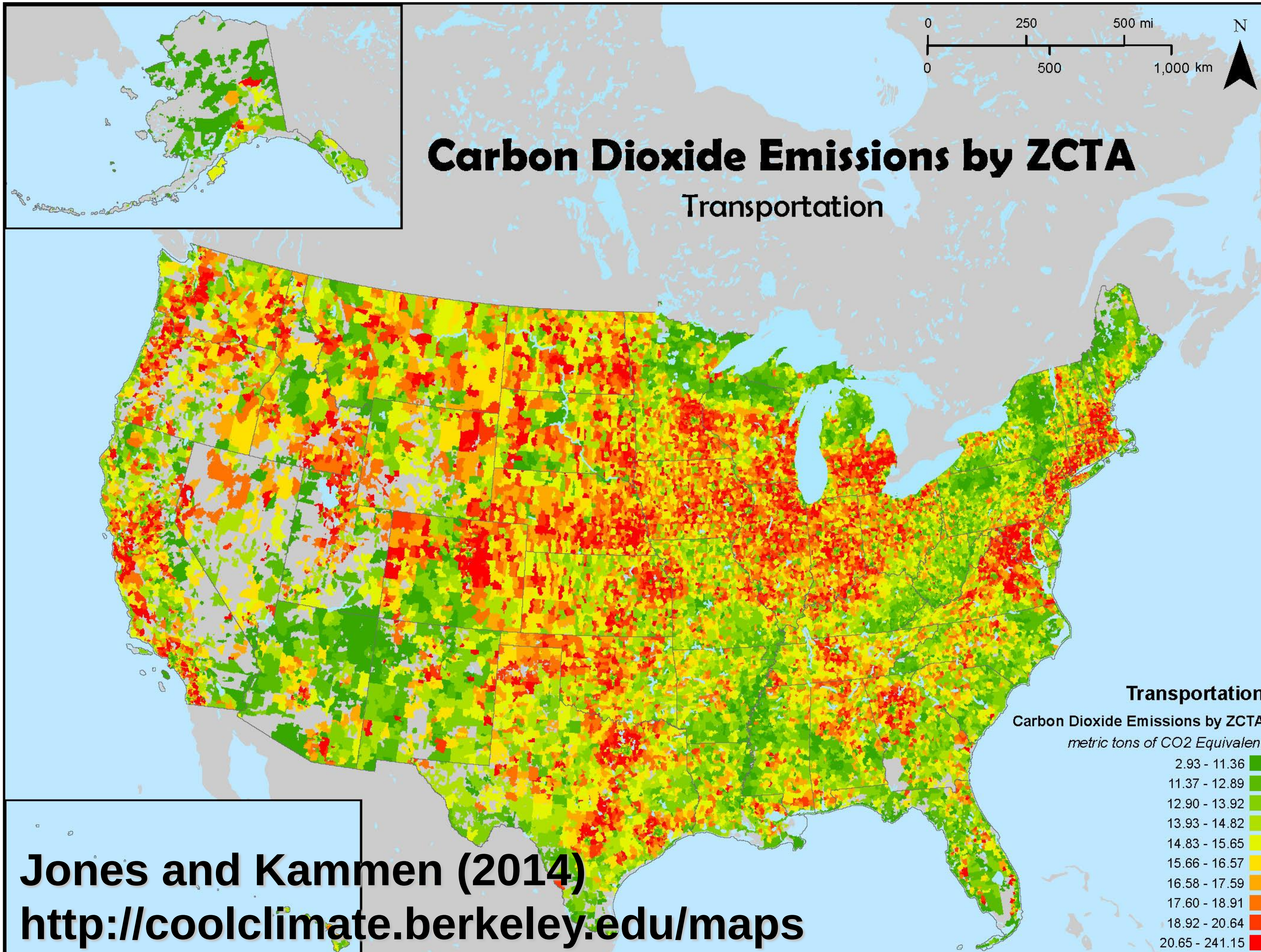
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps

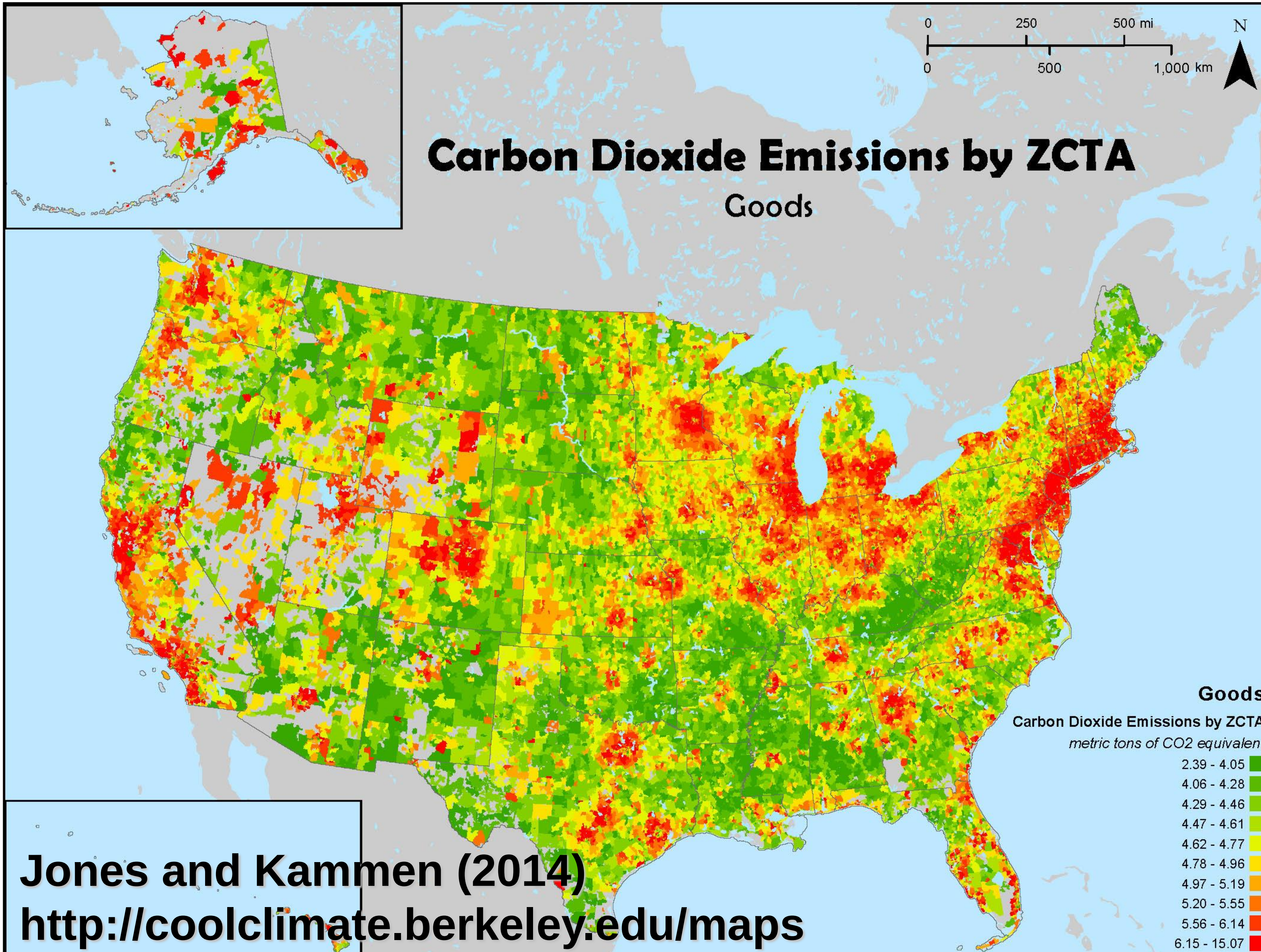


ft³/year of Natural Gas
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft³ natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps

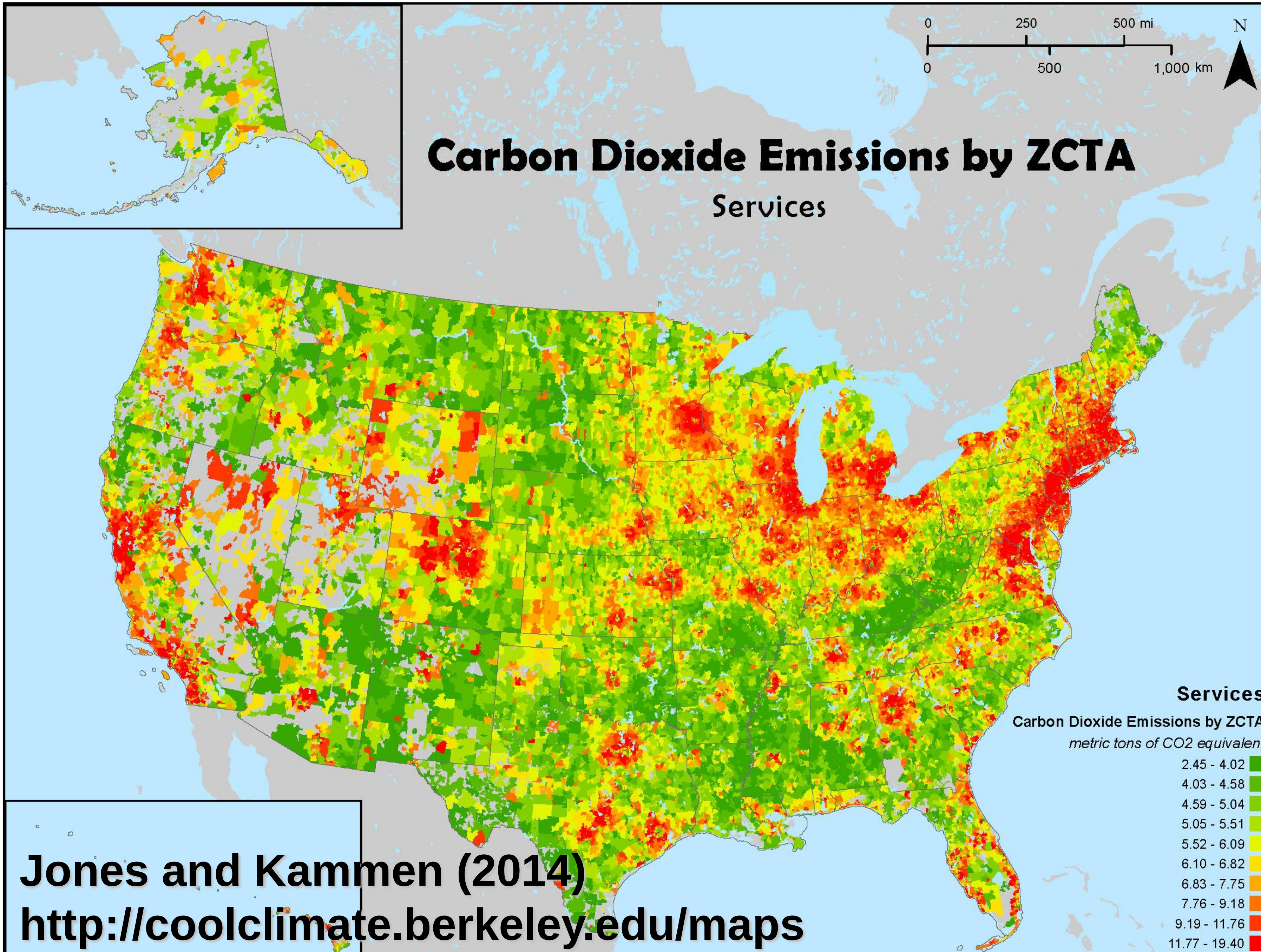

gal/year of Fuel Oil
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft3 natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps


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

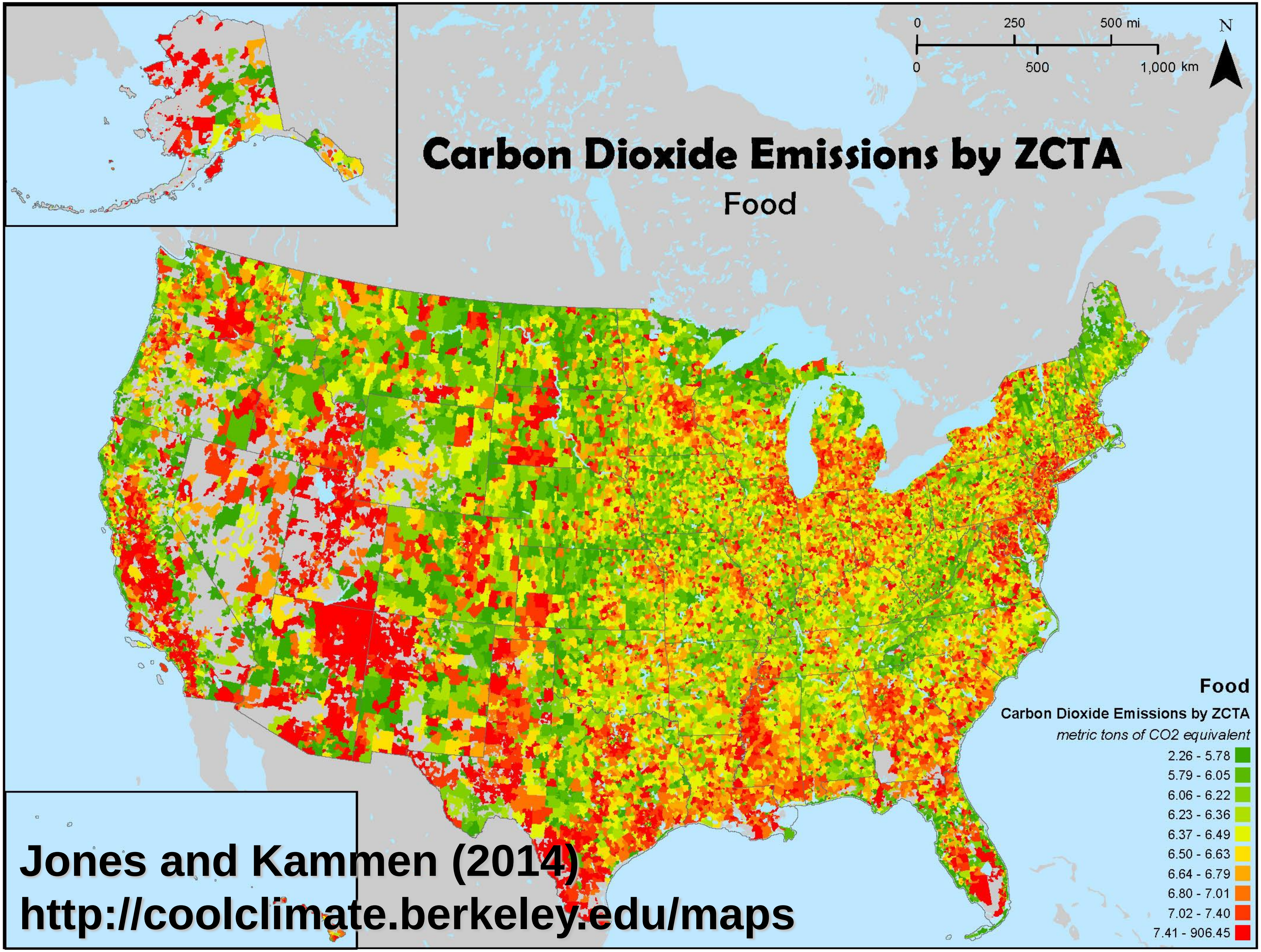

Carbon Dioxide Emissions by ZCTA
Transportation
0 250 500 mi
0 500 1,000 km
N
Transportation
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 Equivalent
2.93 - 11.36
11.37 - 12.89
12.90 - 13.92
13.93 - 14.82
14.83 - 15.65
15.66 - 16.57
16.58 - 17.59
17.60 - 18.91
18.92 - 20.64
20.65 - 241.15
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps



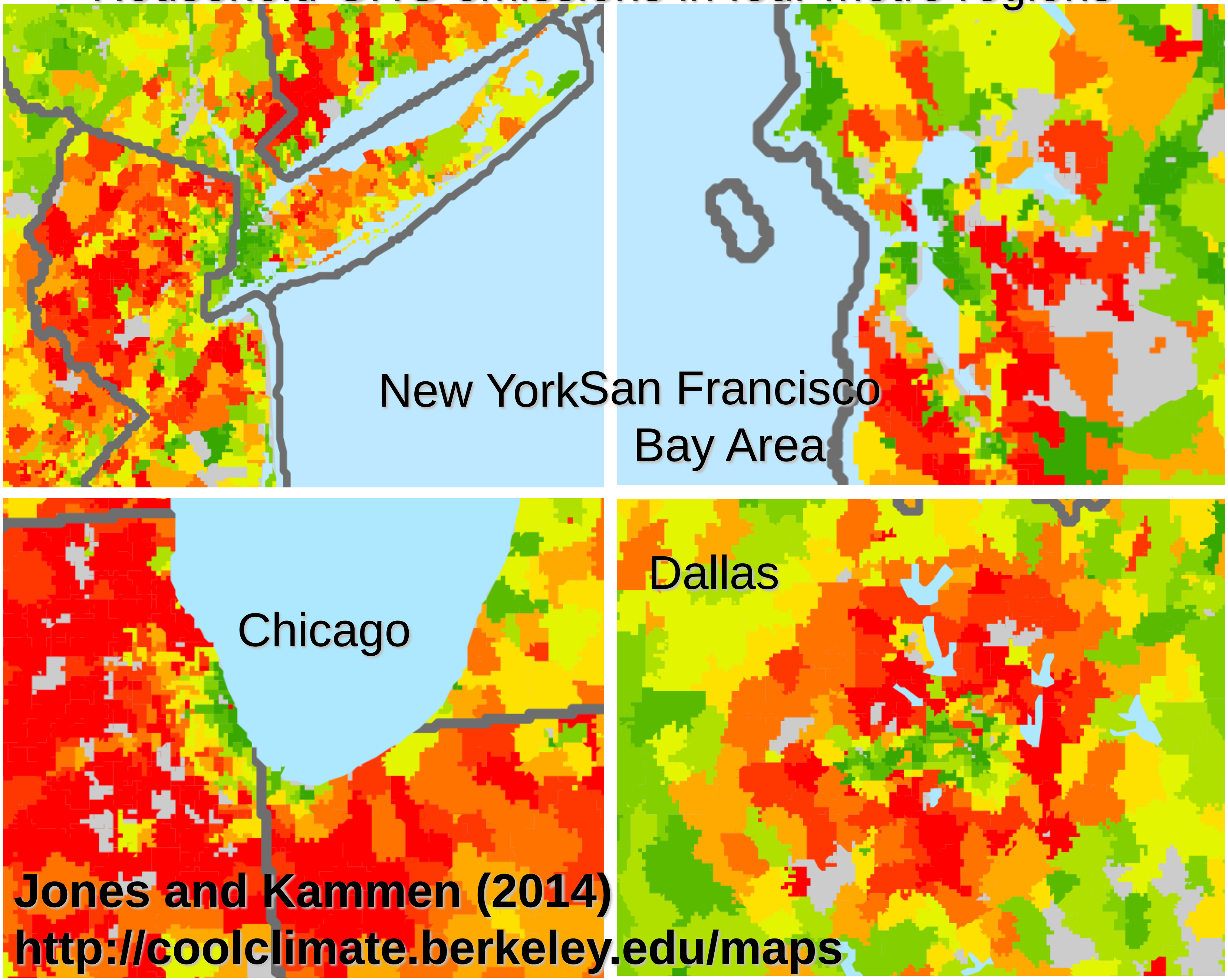
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps



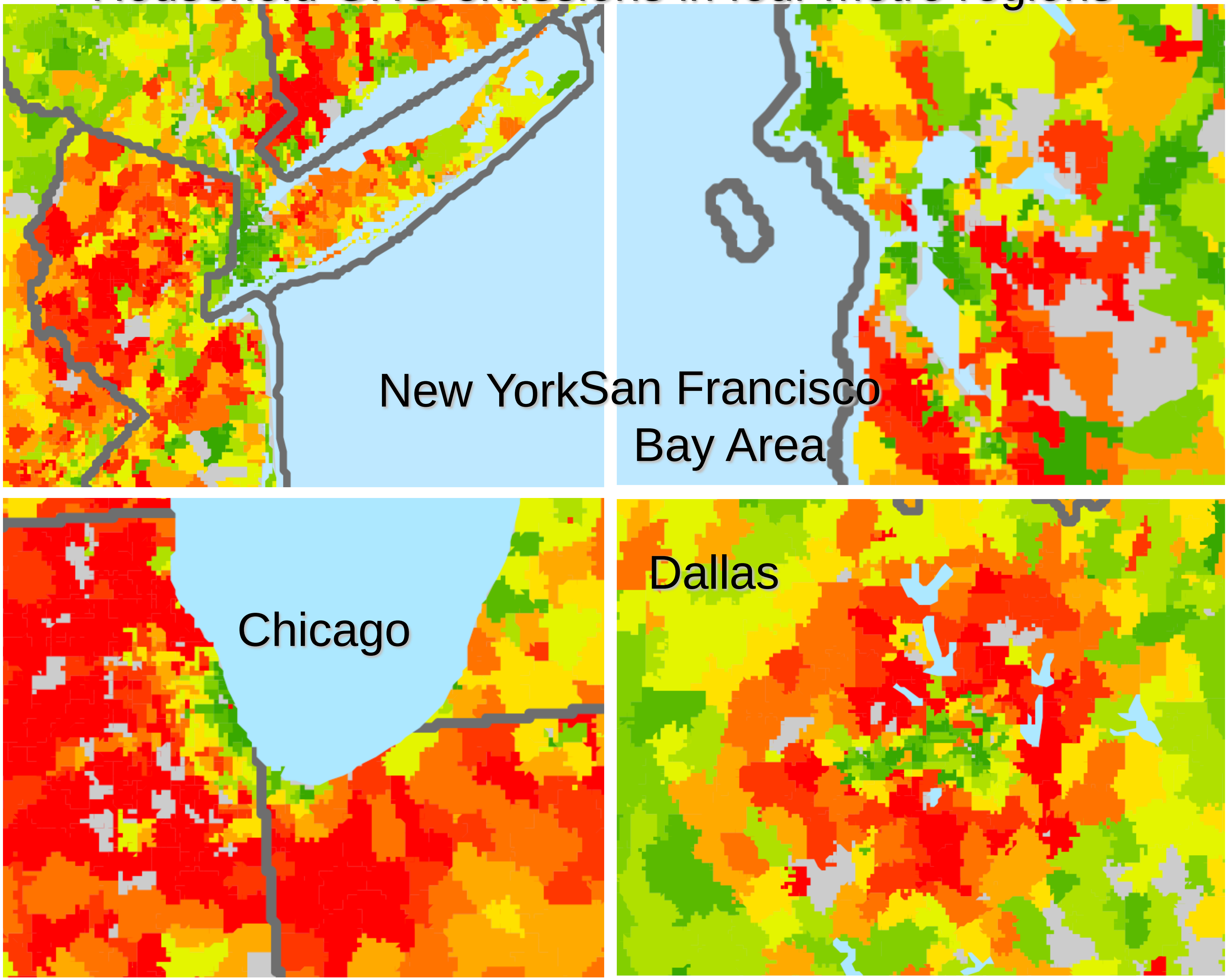
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps


0
250
500 mi
0
500
1,000 km
N
Carbon Dioxide Emissions by ZCTA
Food
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
Jones and Kammen (2014)
http://coolclimate.berkeley.edu/maps

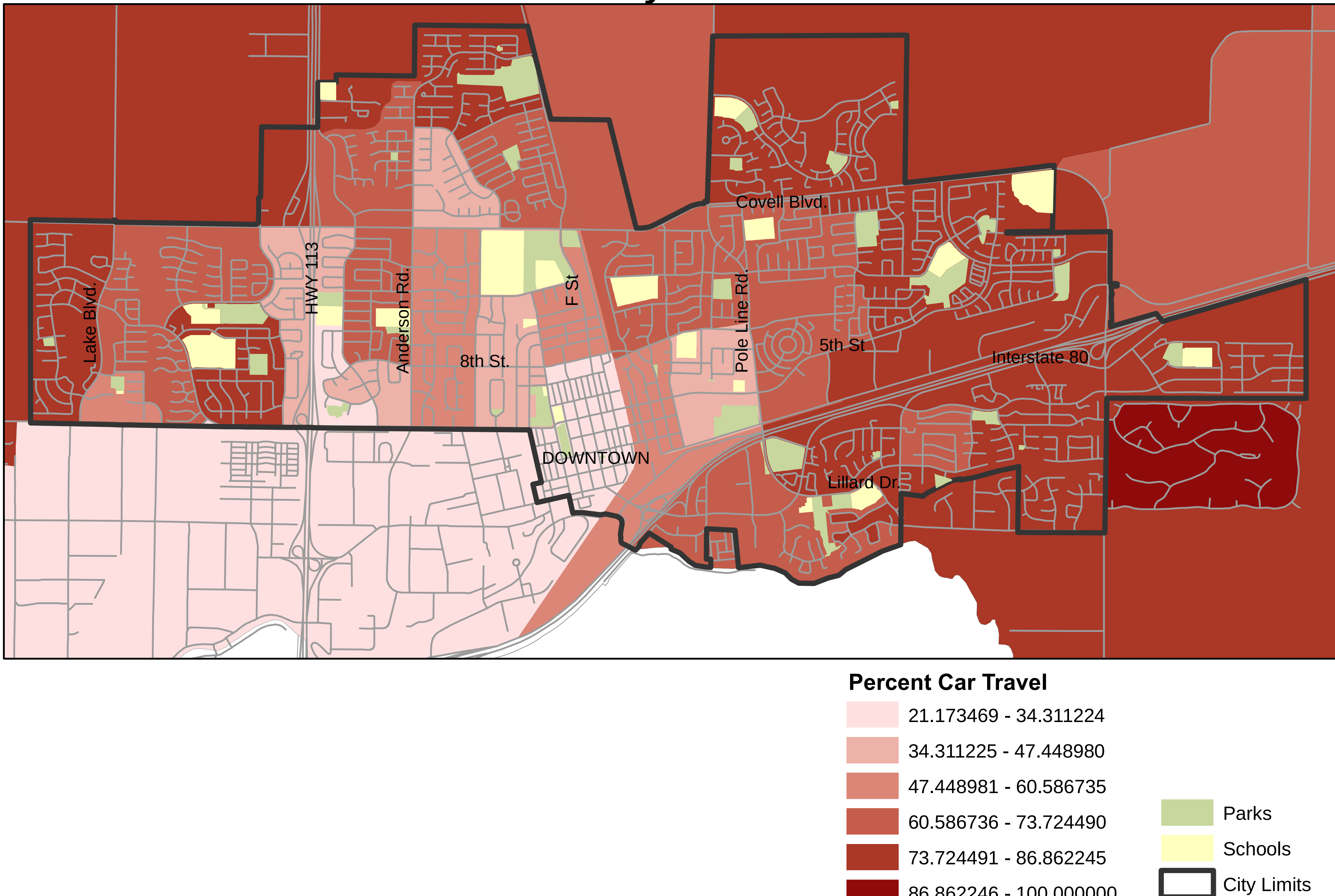
Household GHG emissions in four metro regions



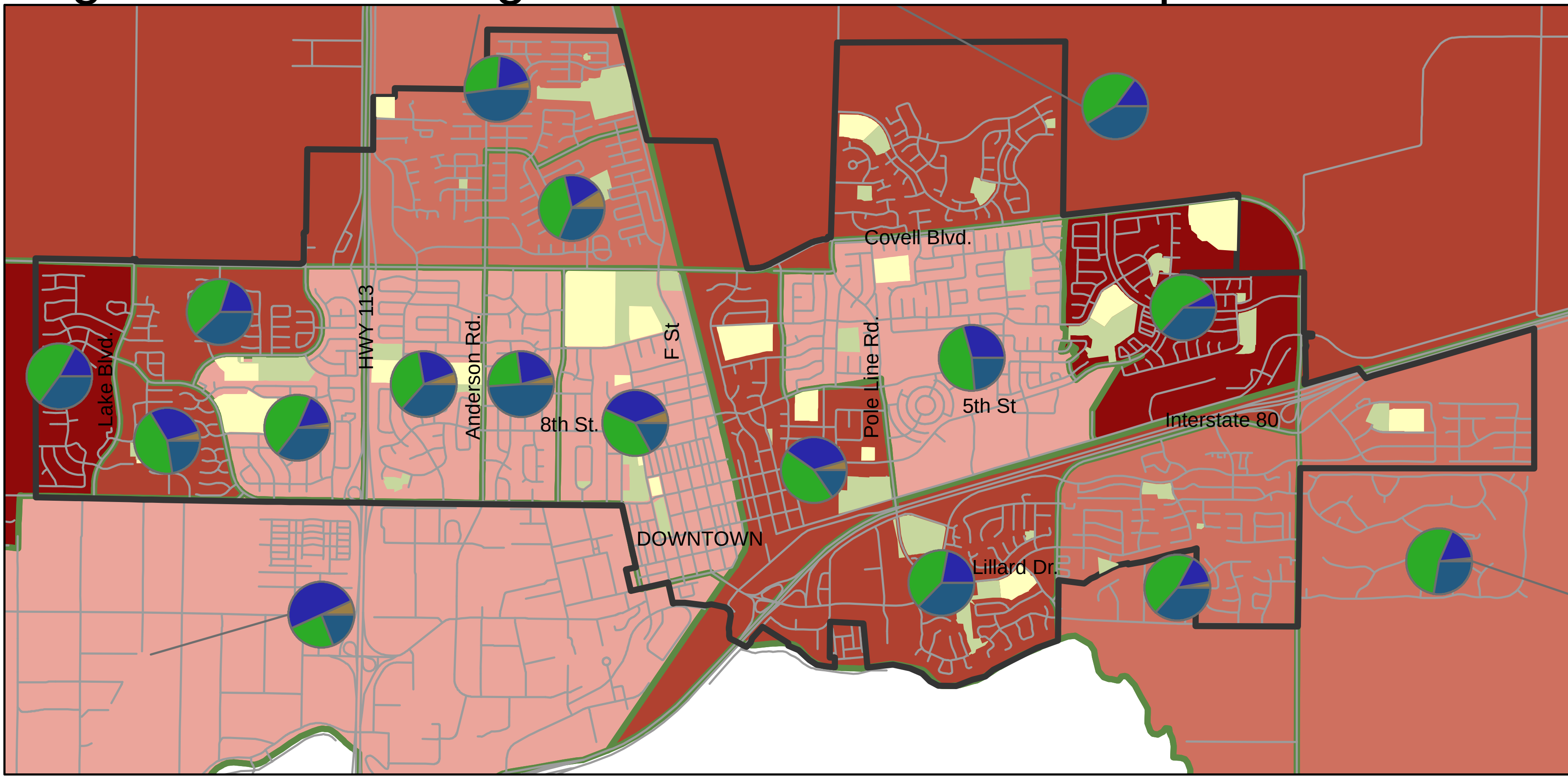
Household GHG emissions in four metro regions

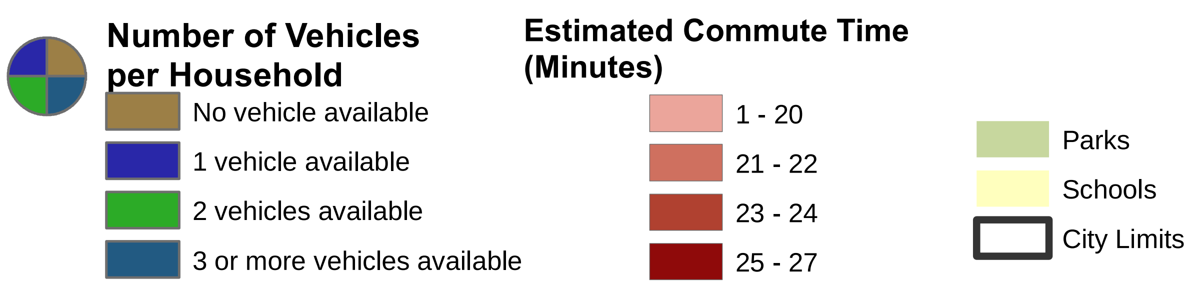


City of Davis
Percent of Work Commutes by Car

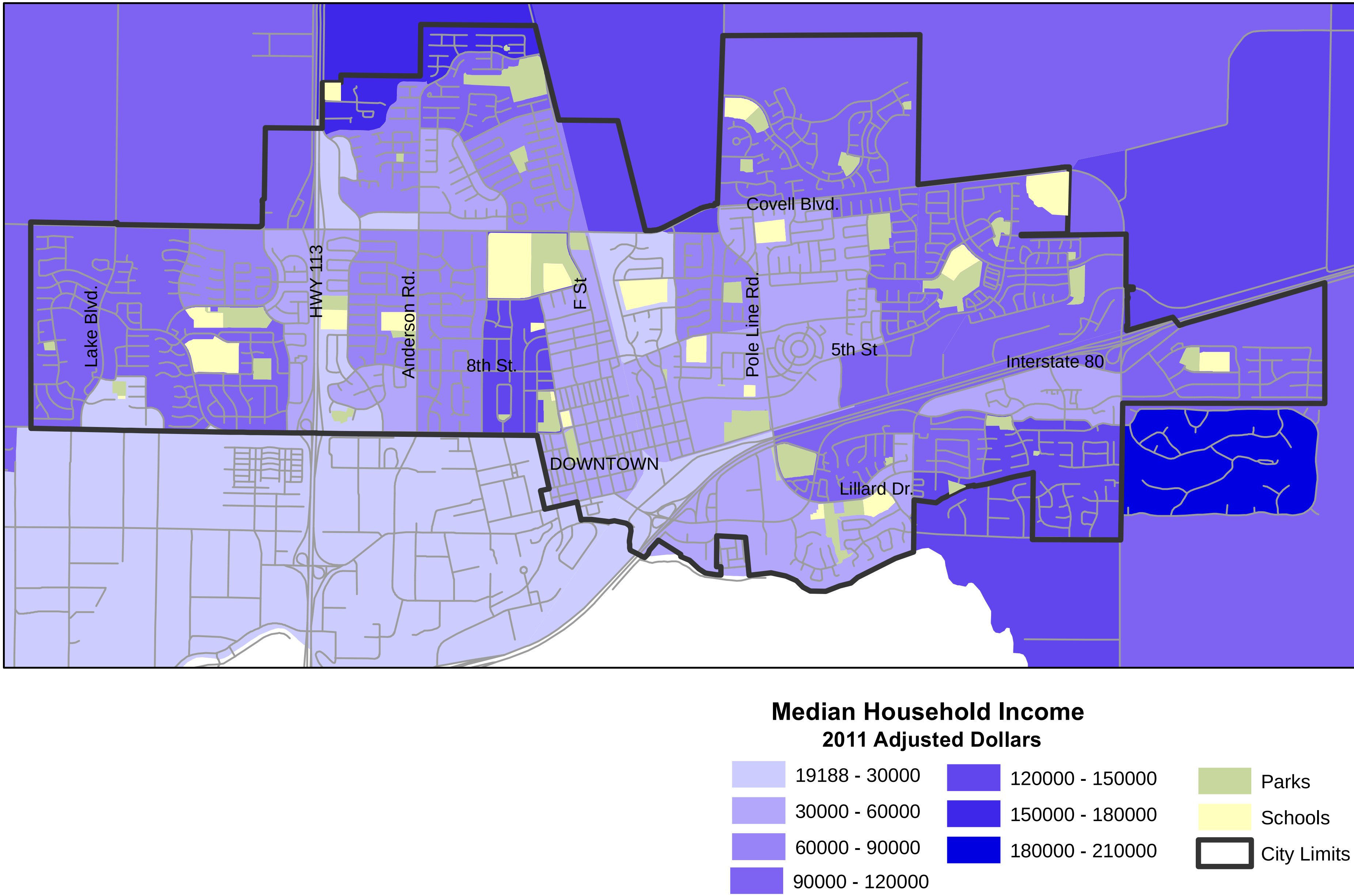


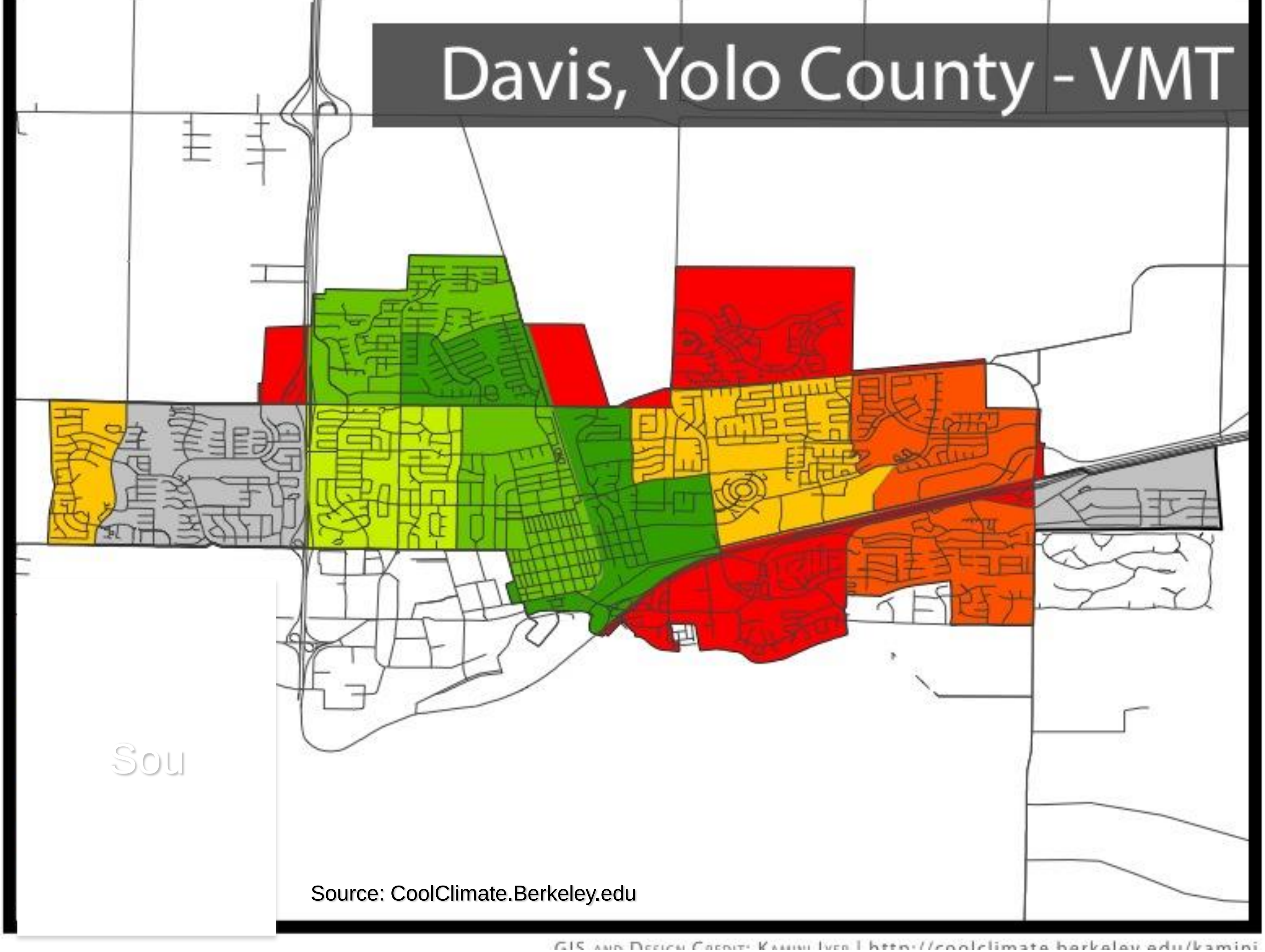
City of Davis
Avg. Commute Length & Number of Vehicles per Household

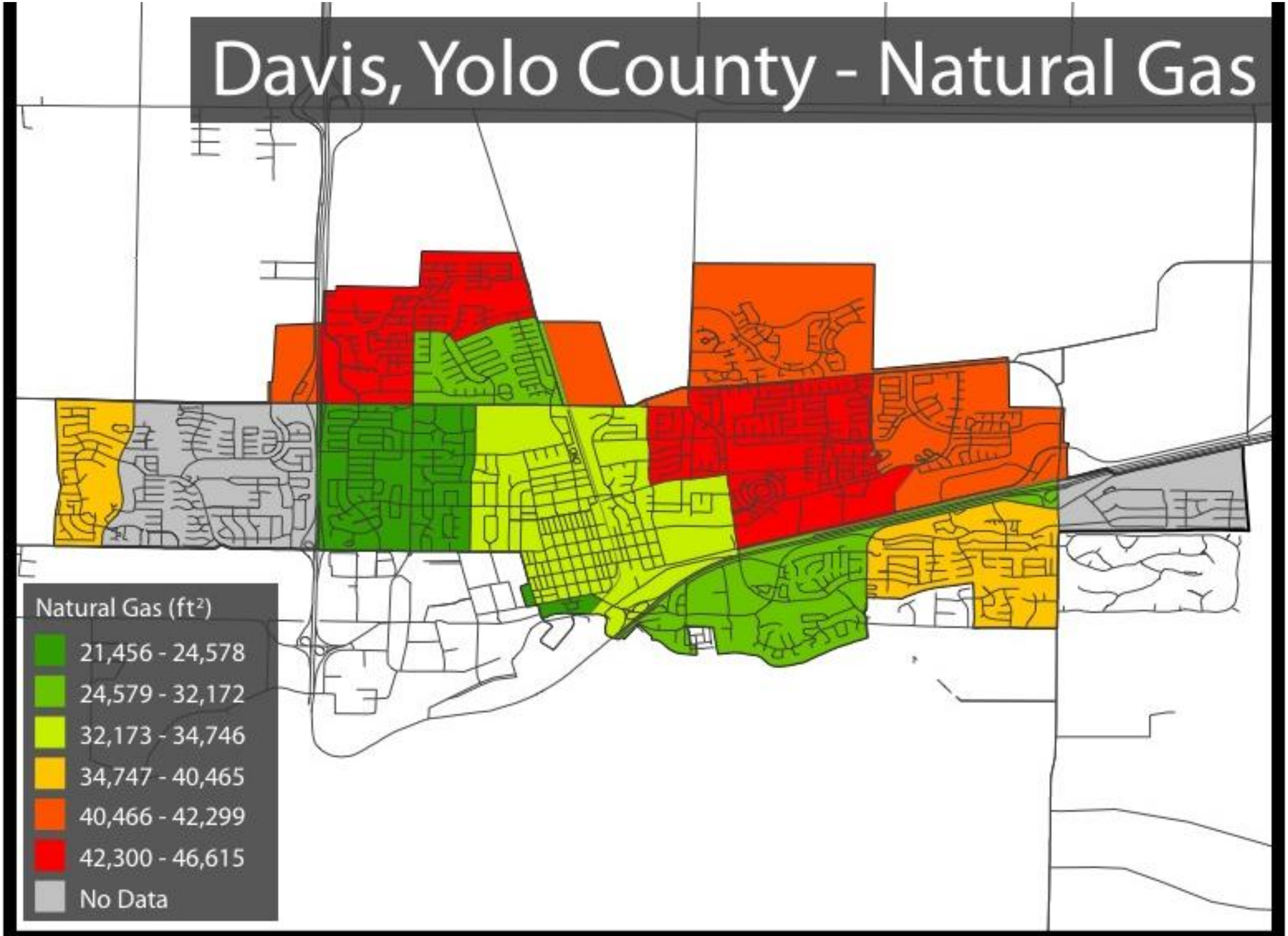




City of Davis
Median Household Income




Davis, Yolo County - VMT
Sou
Source: CoolClimate.Berkeley.edu
GIS and Design Credit: Kamini Iyer | http://coolclimate.berkeley.edu/kamini



GIS AND DESIGN CREDIT: KAMINI IYER | http://coolclimate.berkeley.edu/kamini

Greenhouse gas and sustainability calculators:

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