Renewable & Appropriate Energy Laboratory

RAEL

Data Science to Inform Sustainability

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Science Envoy for the U. S. State Department

Philomathia Forum on Energy and Environment
April 20, 2017

Big wisdom, making sense and innovating from big data

Renewable & Appropriate Energy Laboratory
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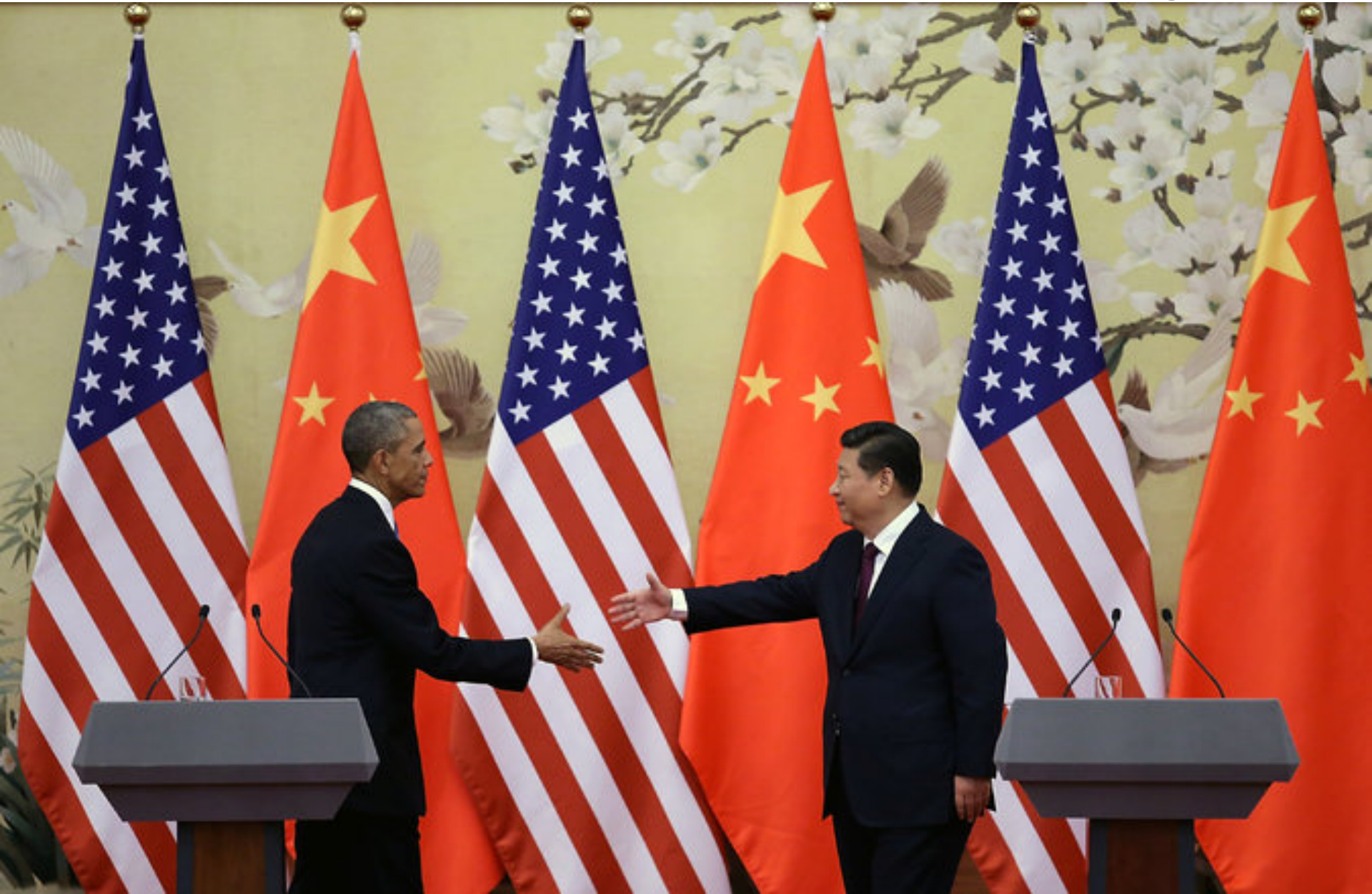
Takeaway *information rich* messages:

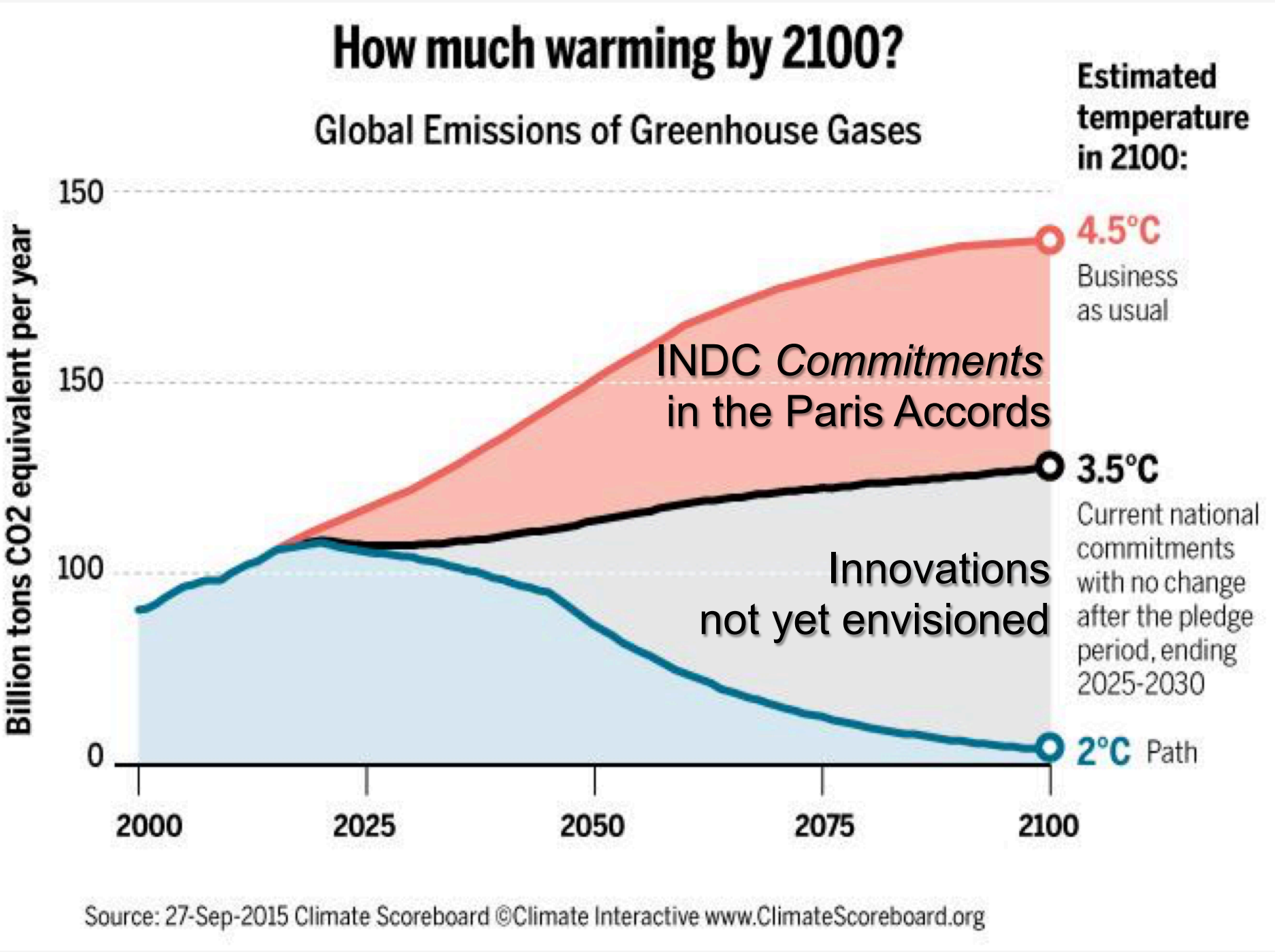
1. The '2 degree pathway' is still achievable

2. Scientific and technical transformations are critical to enabling a sustainable energy system, but it is social and policy innovation that provides the 'killer app' for innovation and change

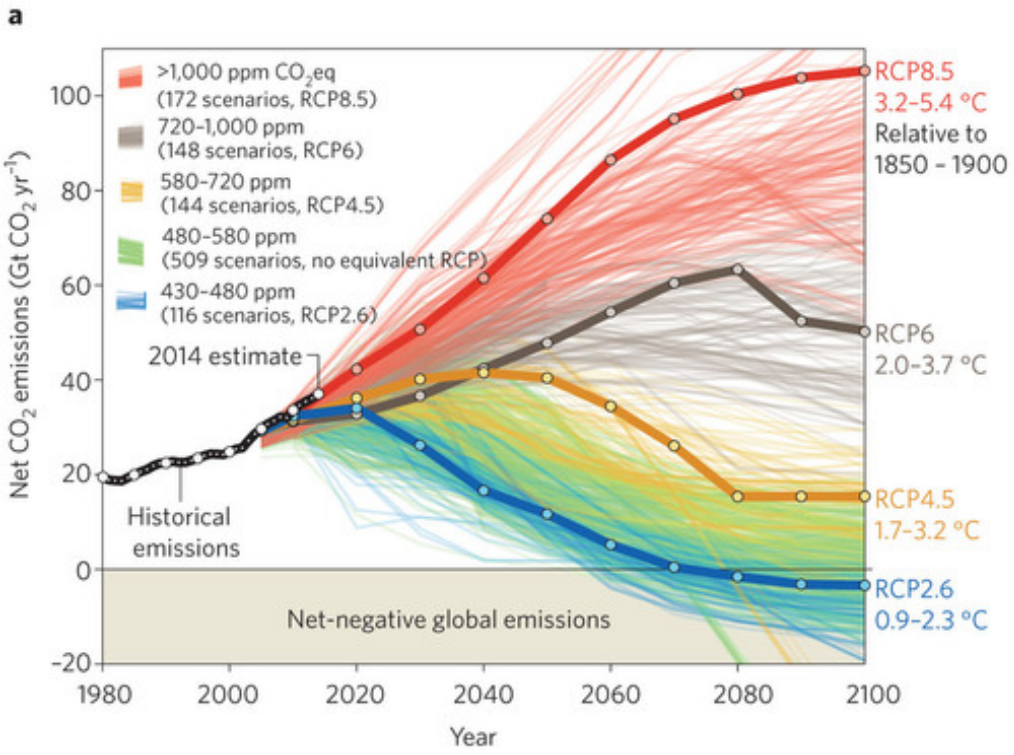
This is true on-grid *and* off-grid in both industrialized and industrializing nations

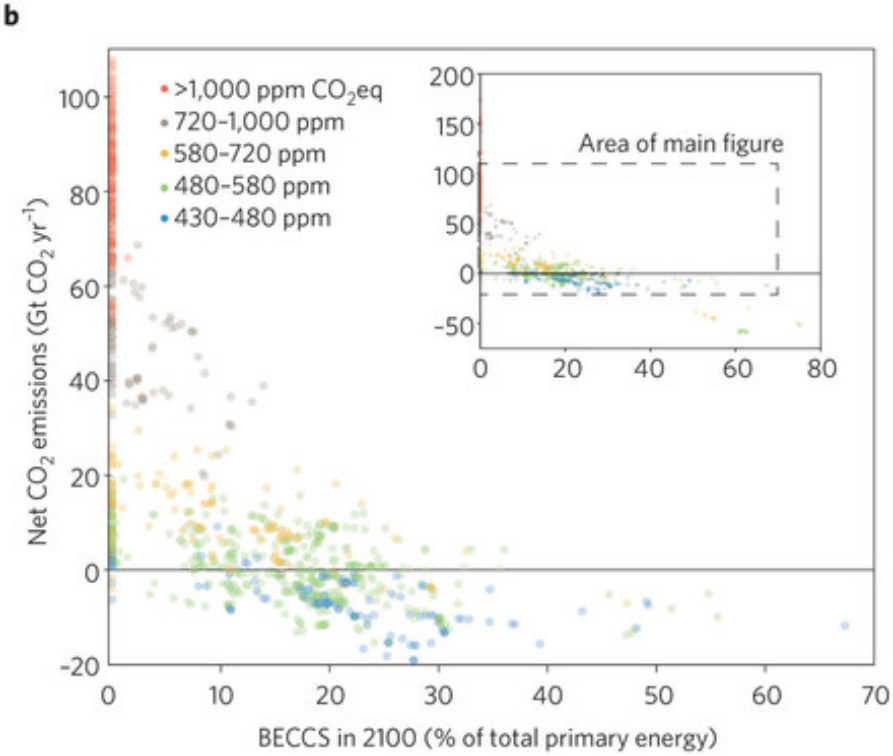
A revolution in climate politics
U.S.- China Joint Announcement on Climate Change, 2014




How much warming by 2100?
Global Emissions of Greenhouse Gases
Billion tons CO2 equivalent per year
150
150
100
0
2000
2025
2050
2075
2100
Estimated temperature in 2100:
4.5°C
Business as usual
INDC Commitments in the Paris Accords
3.5°C
Current national commitments with no change after the pledge period, ending 2025-2030
Innovations not yet envisioned
2°C Path
Source: 27-Sep-2015 Climate Scoreboard ©Climate Interactive www.ClimateScoreboard.org

What we need to do:

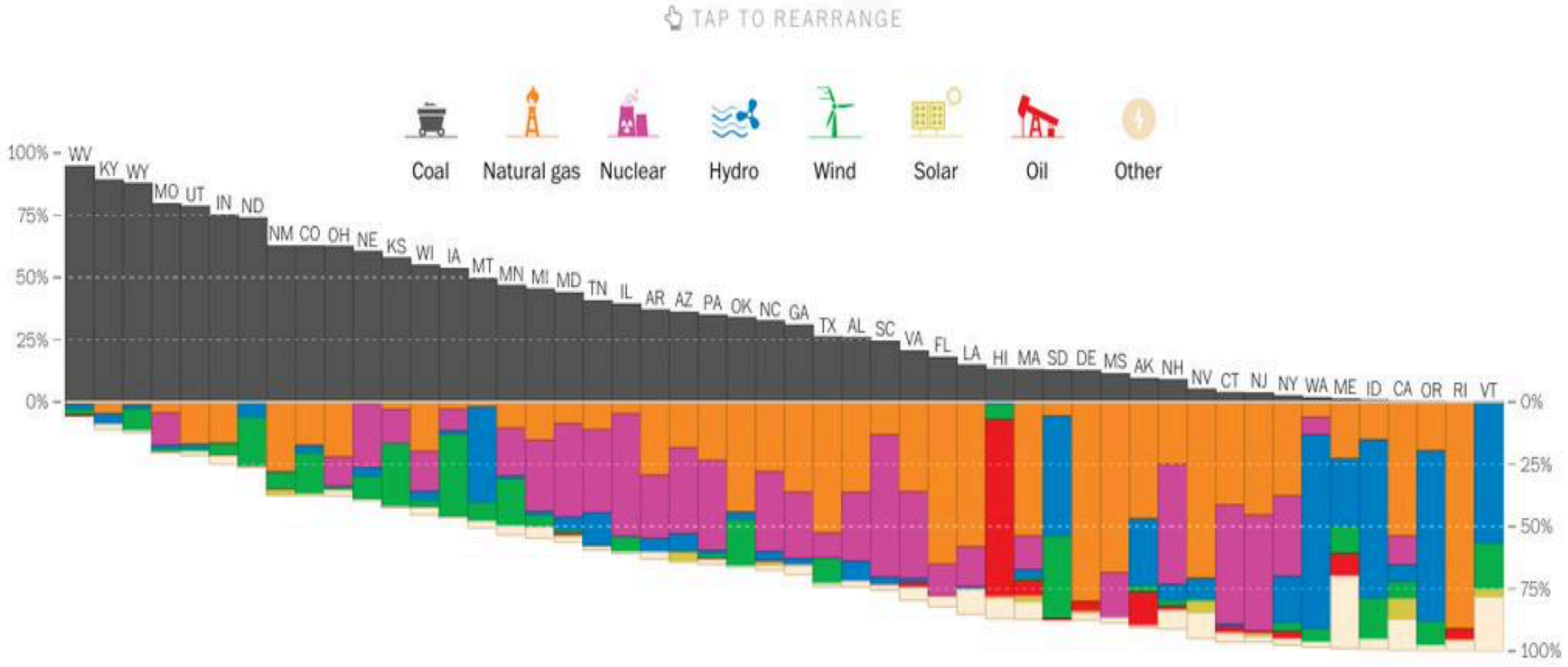




Fuss et al. (2014)

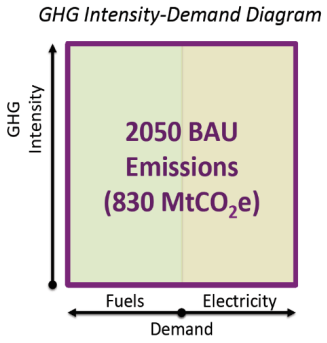
Electricity generation by power source, January to May 2015

Local electric utilities take advantage of the power sources most accessible to them: coal mines, dammed rivers, new supplies of natural gas or nuclear plants to generate the bulk of the nation's electricity. This shows the source of electricity generation in each state in 2015.

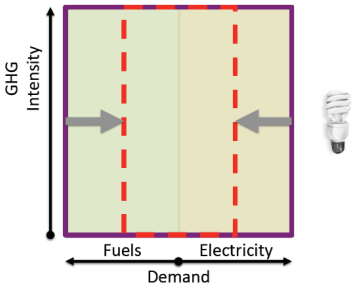


A pathway to sustainability

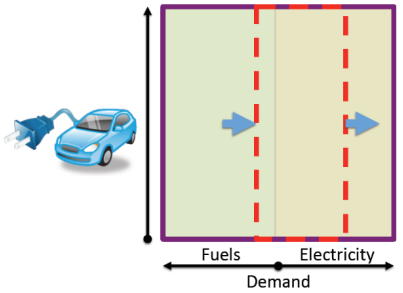
Four Actions to Reduce Emissions



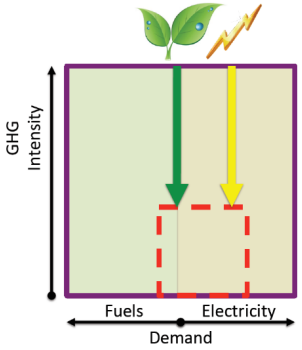
1. Efficiency



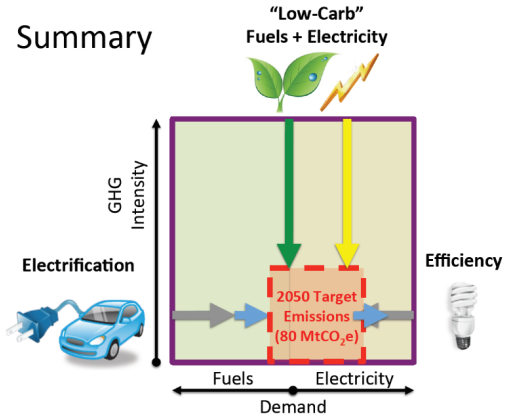
2. Electrification



3. "Low-Carb" Fuels + Electricity



Summary



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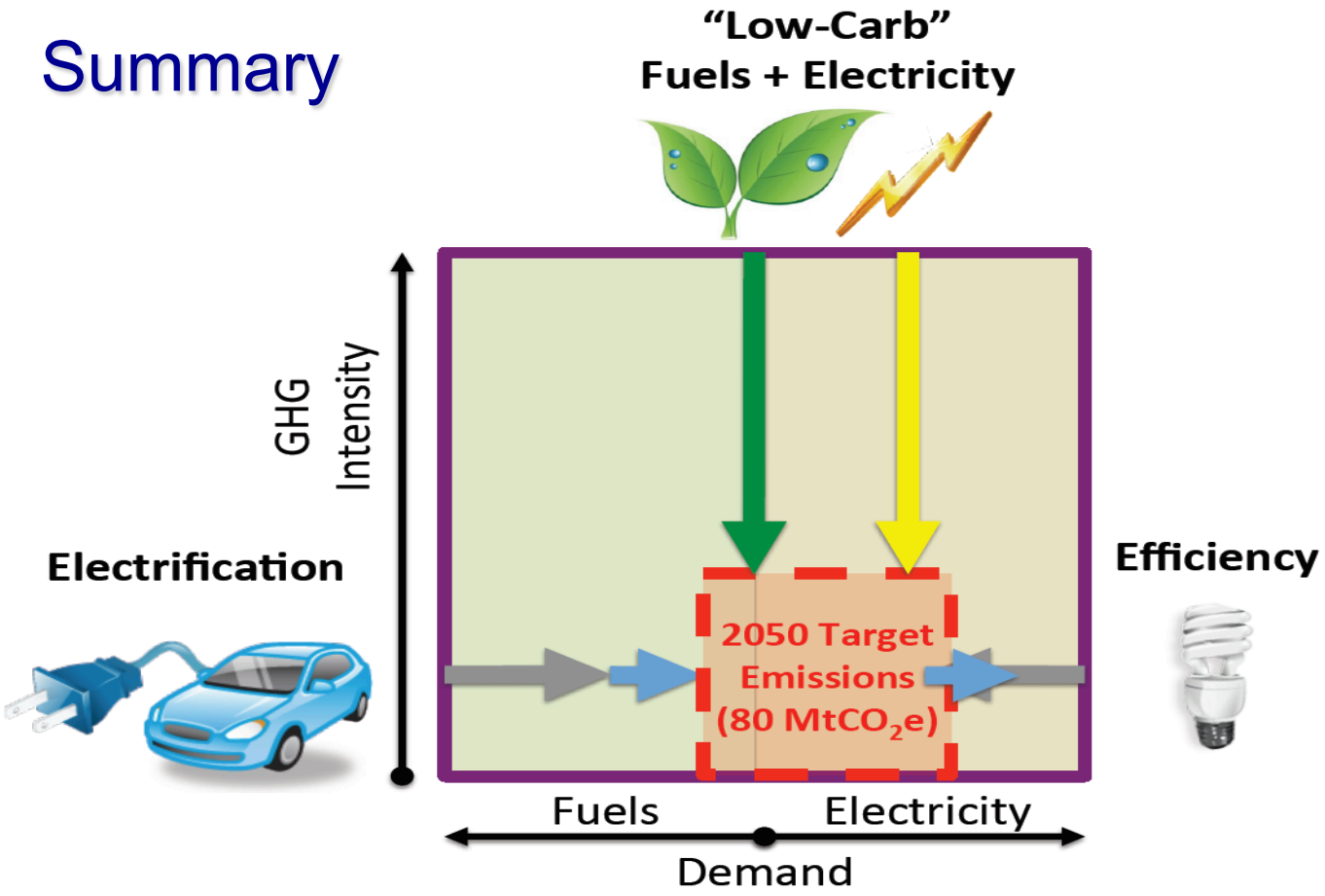
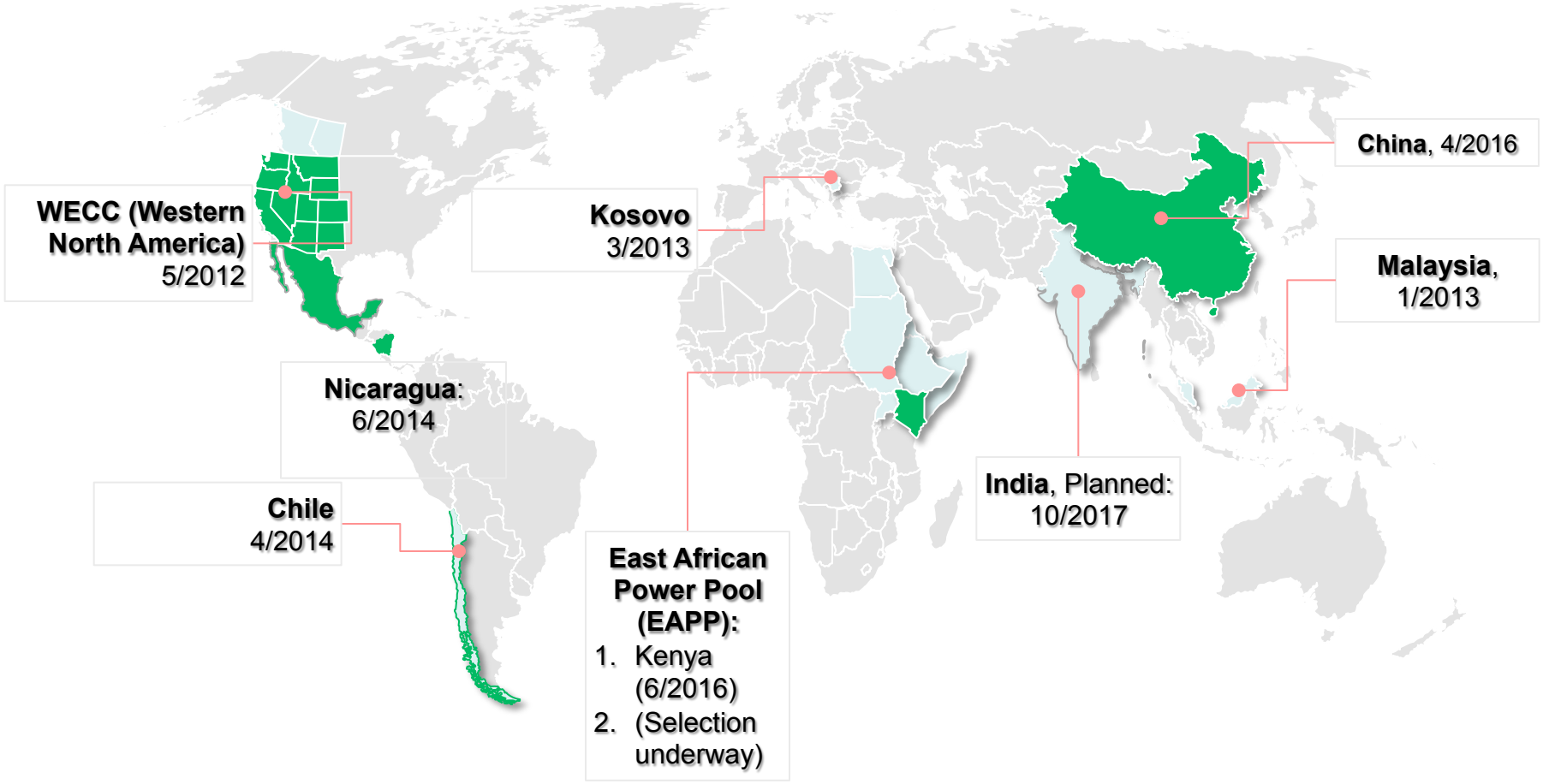
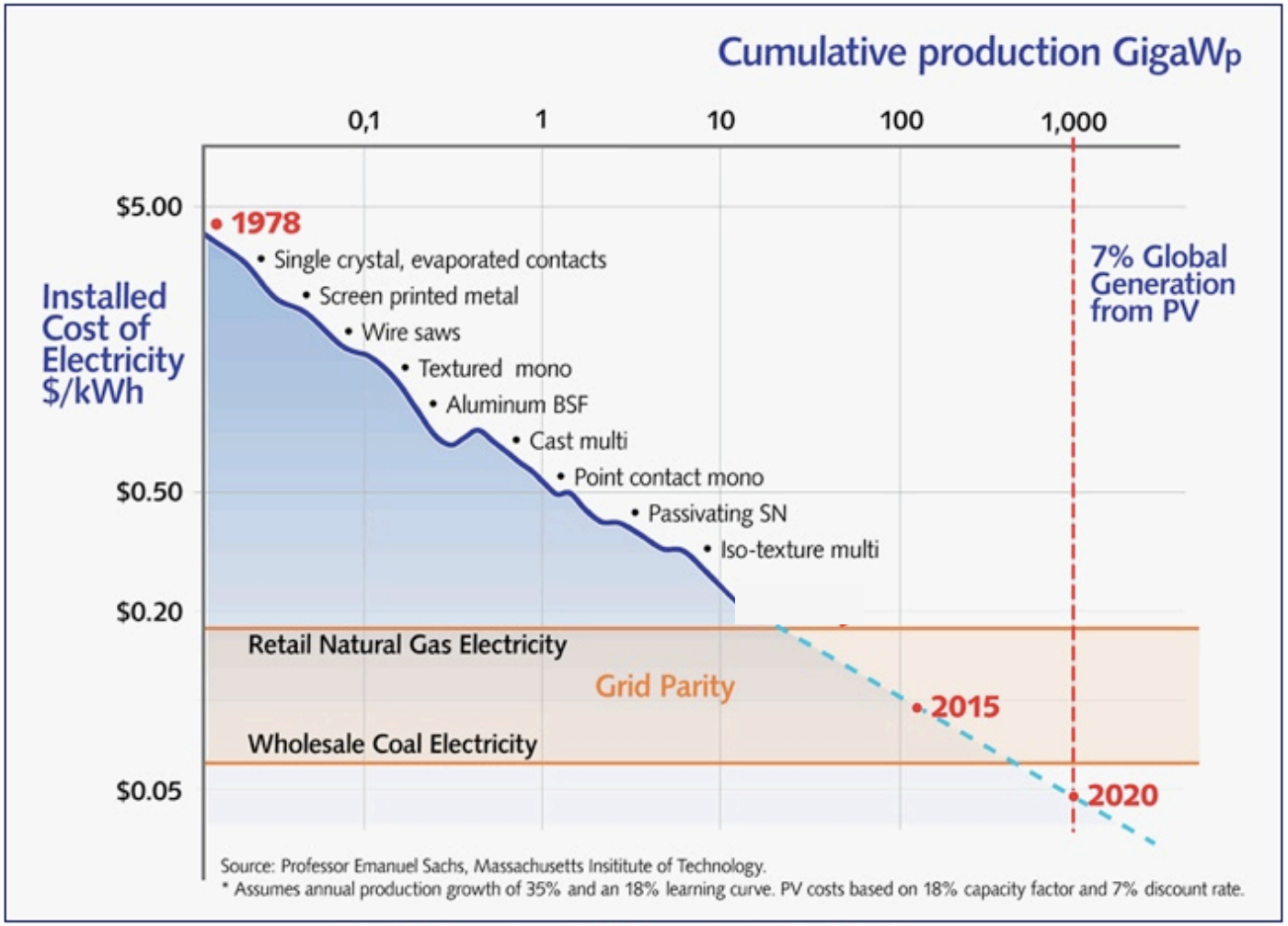
Summary


"Low-Carb"
Fuels + Electricity
GHG
Intensity
Electrification
Efficiency
2050 Target
Emissions
(80 MtCO2e)
Fuels
Electricity
Demand

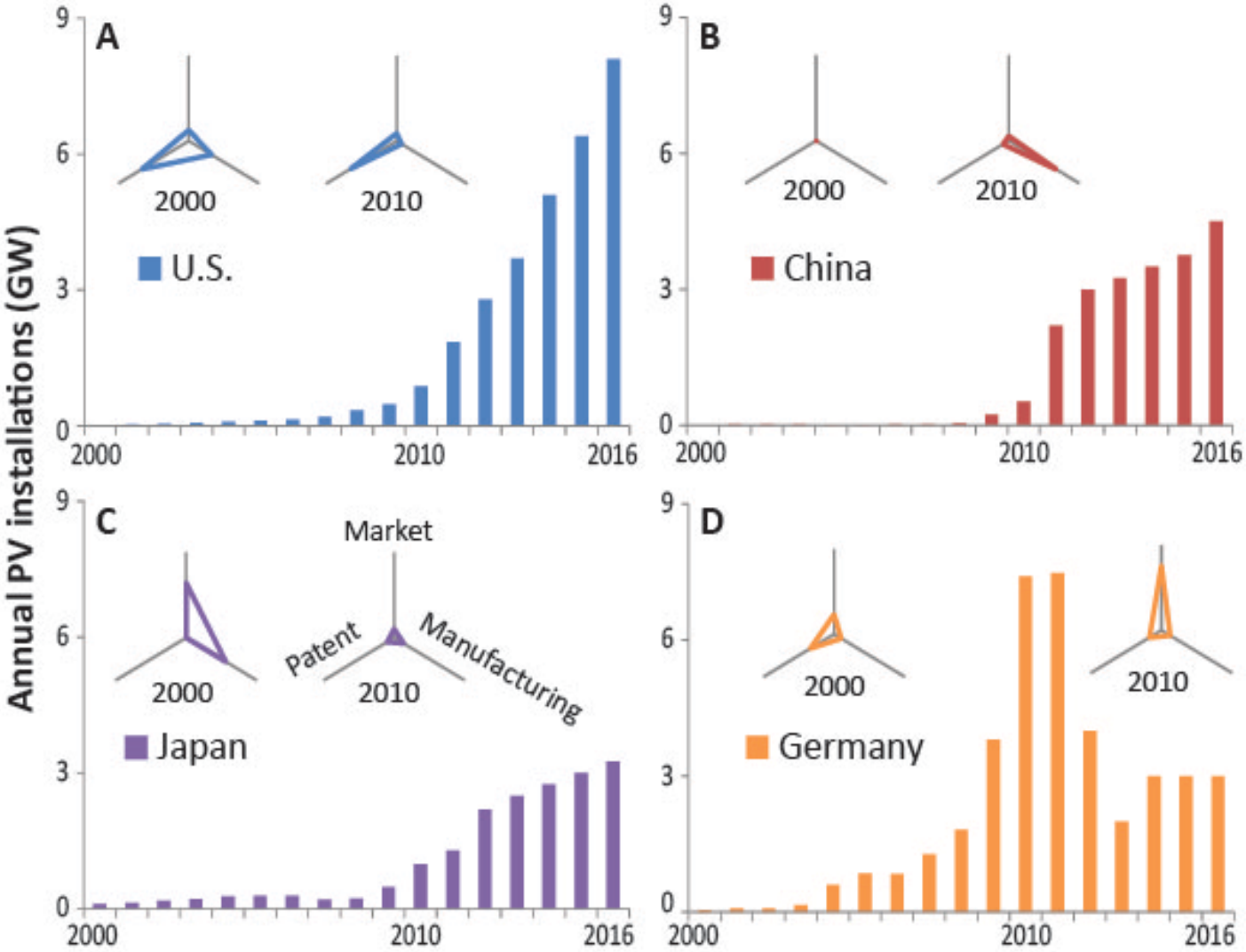
Power System Models
http://rael.berkeley/edu/project/SWITCH



Solar cost decreases 10% per year



The Solar Energy Industry is an International Partnership

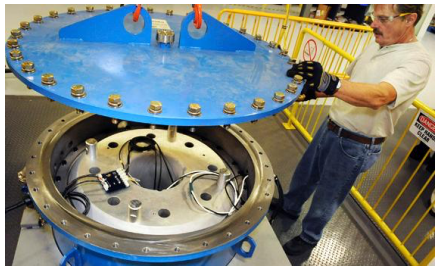


Energy Storage is Not Just Batteries

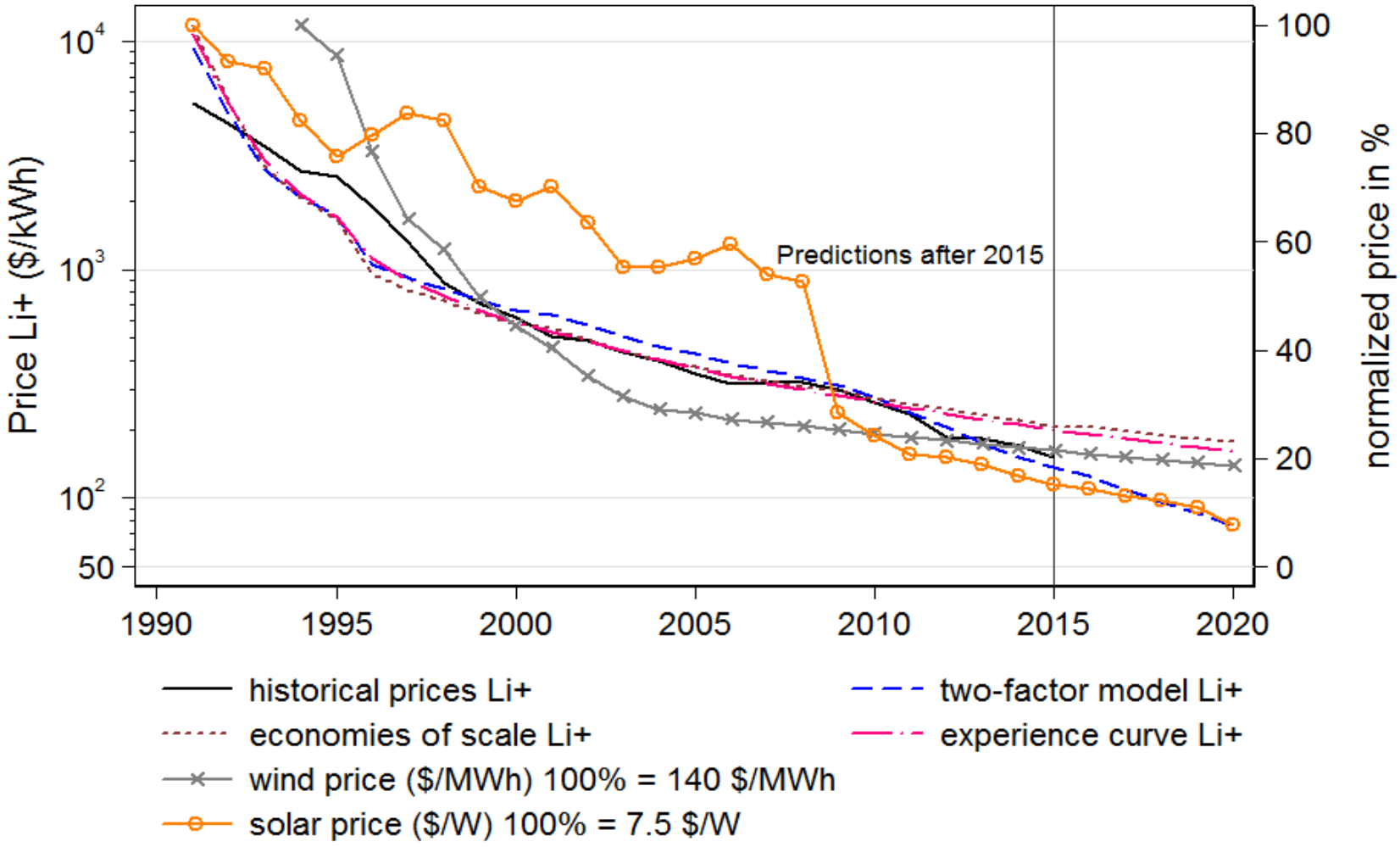
Natural gas (without or with storage)

Traditional and pumped hydropower

Flywheels

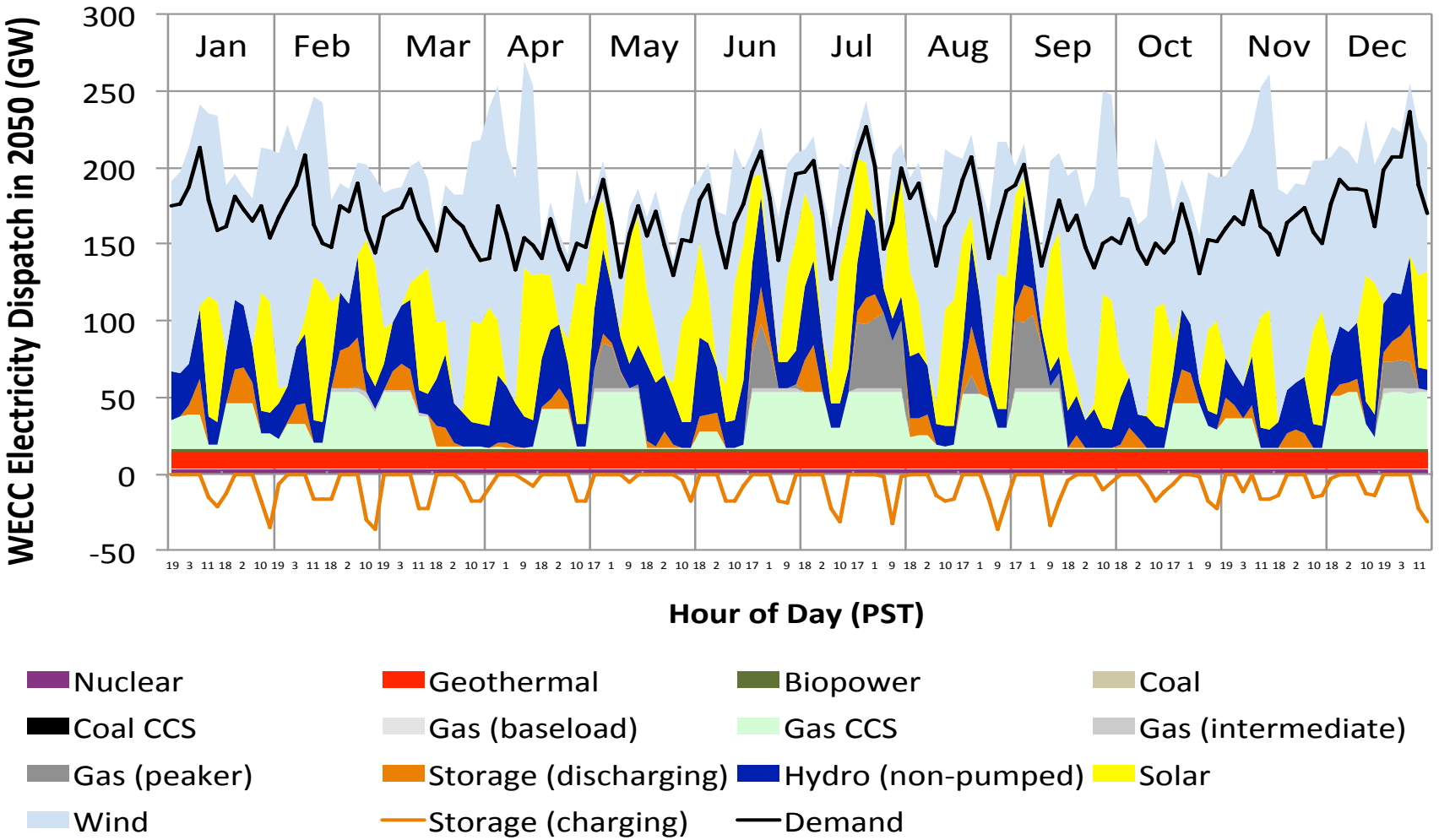


Flow batteries

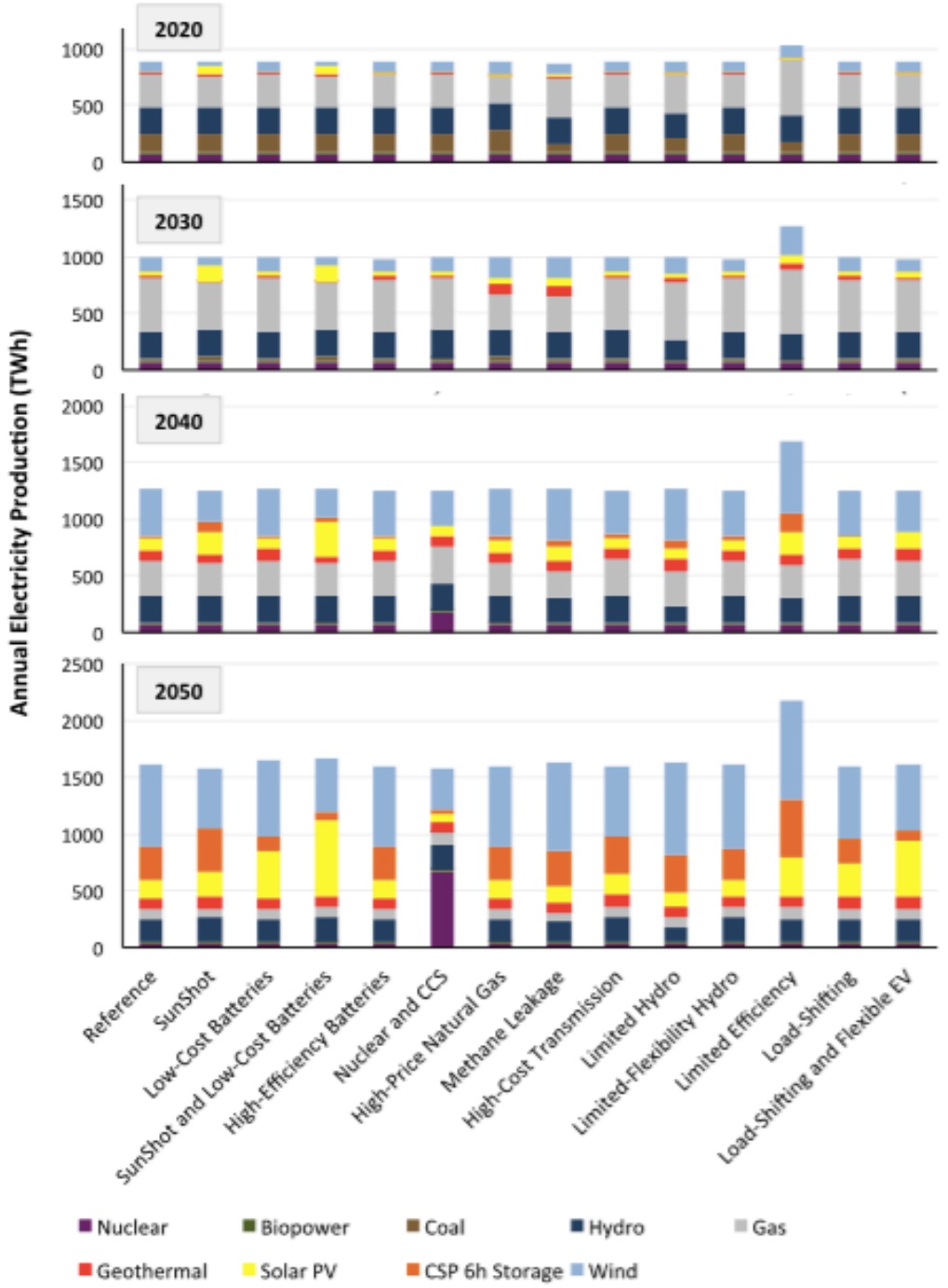

Price Li+ ($/kWh)
10^4
10^3
10^2
50
normalized price in %
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
2020
Predictions after 2015
historical prices Li+
economies of scale Li+
wind price ($/MWh) 100% = 140 $/MWh
solar price ($/W) 100% = 7.5 $/W
two-factor model Li+
experience curve Li+

Dispatch in 2050: Flexibility and variable renewables dominate

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

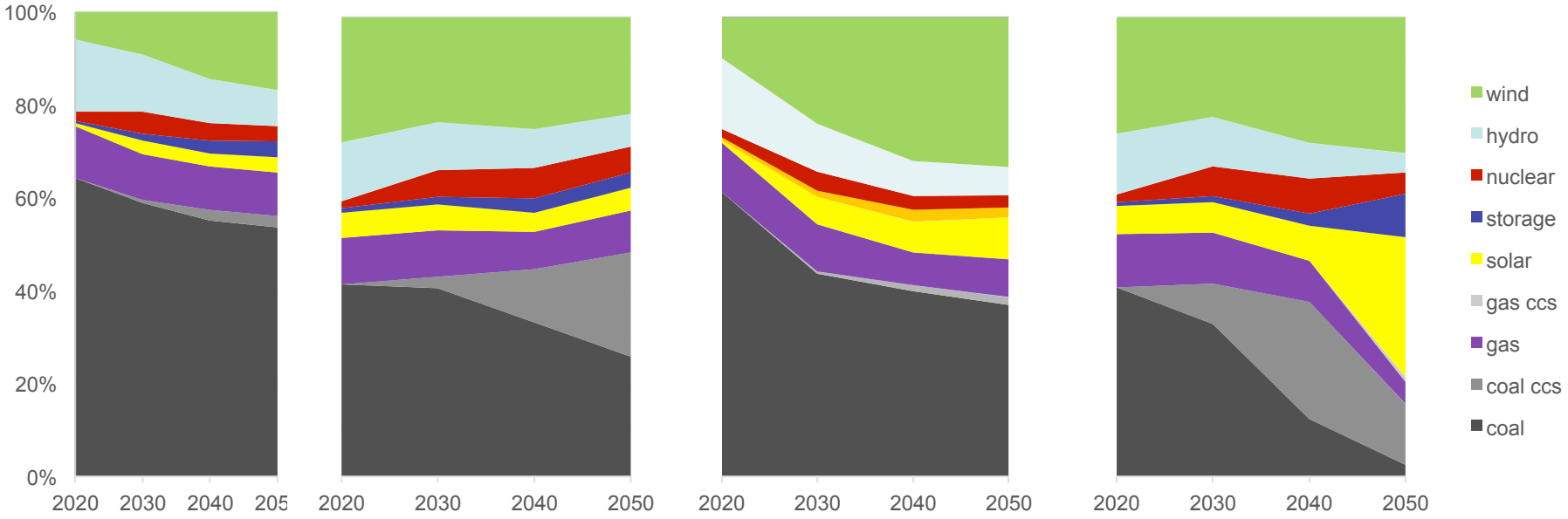


Pathways for Western North America



In China even aggressive wind, solar and storage learning alone is not enough to phase out coal

http://rael.berkeley.edu/project/SWITCH



Business as Usual

BAU with Carbon cap

Current aggressive solar and wind continued

IPCC 2050 (80% cut in carbon)

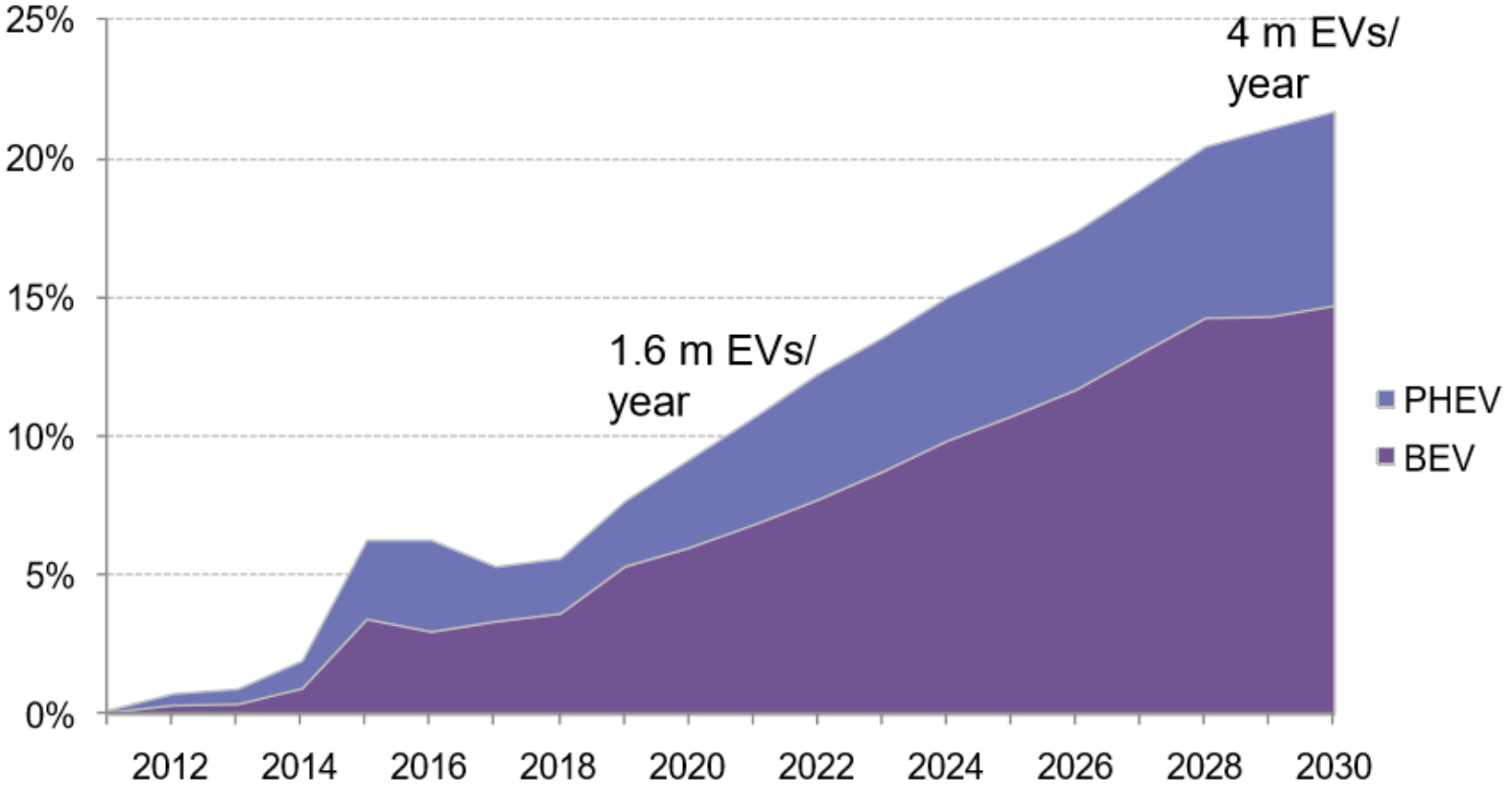
SWITCH-China: A Systems Approach to Decarbonizing China's Power System

Gang He,*,†,‡,§ Anne-Perrine Avrin,‡,§ James H. Nelson,⊥ Josiah Johnston,‡,§ Ana Mileva,⊥ Jianwei Tian,# and Daniel M. Kammen*,‡,§,∥

Figure 4. Generation, transmission, and storage capacity needed to achieve an 80% carbon reduction in 2050. All represented lines are new transmission expansion. Inner Mongolia emerges as a major center of clean energy generation thanks to the combination of its location (a few hundred kilometers from major demand centers) and high-quality renewable energy resources.

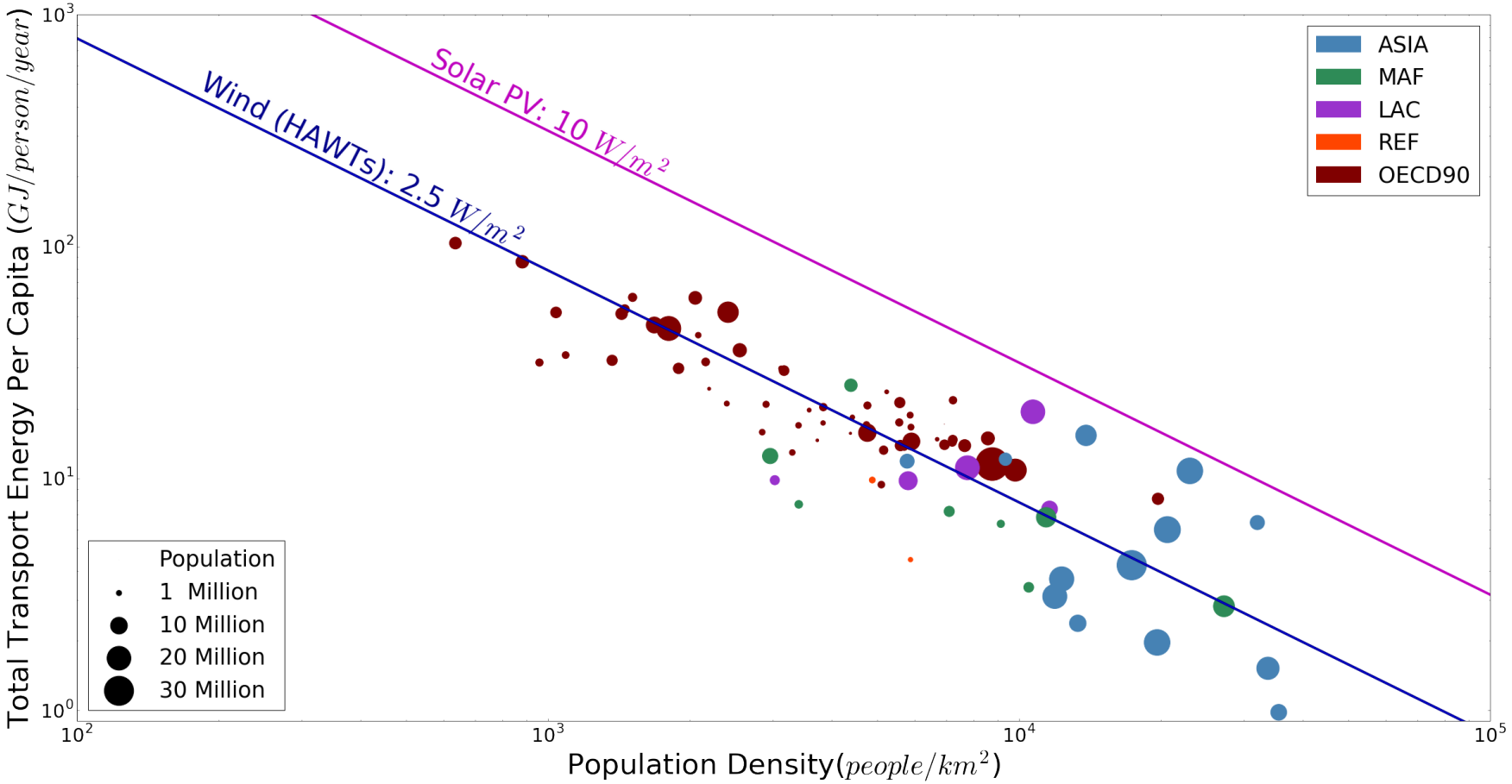
Case Study: Photovoltaics to Satisfy Urban Transportation Needs

Urban Transport Electrification



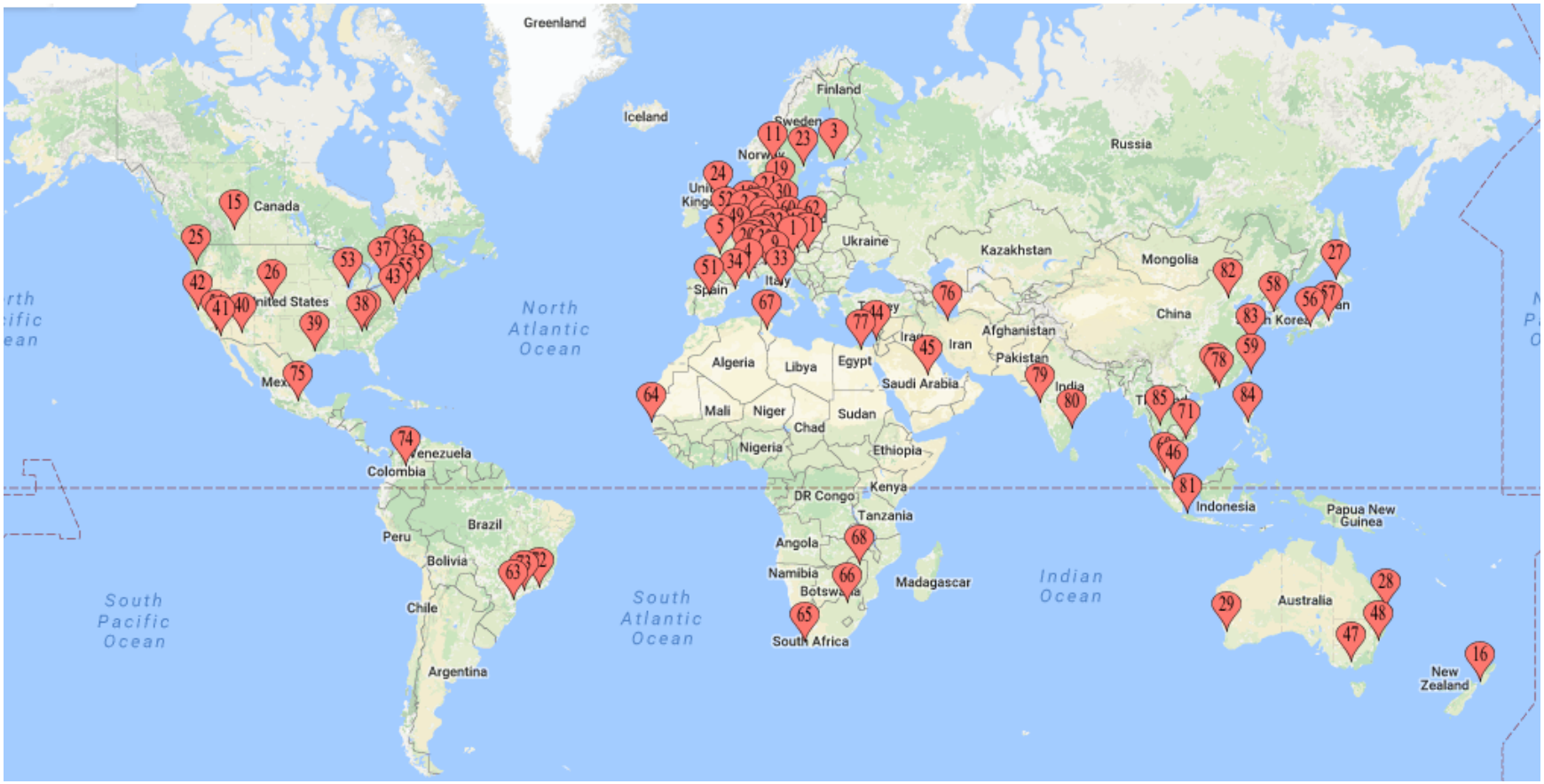
Bloomberg New Energy Finance. "Electric Vehicles: Revolutionizing Energy." 2011.

Urban Transportation Energy Consumption



Kammen, Daniel M., and **Deborah A. Sunter**. "City-integrated renewable energy for urban sustainability." *Science* 352.6288 (2016): 922-928.

87 Global Cities Considered



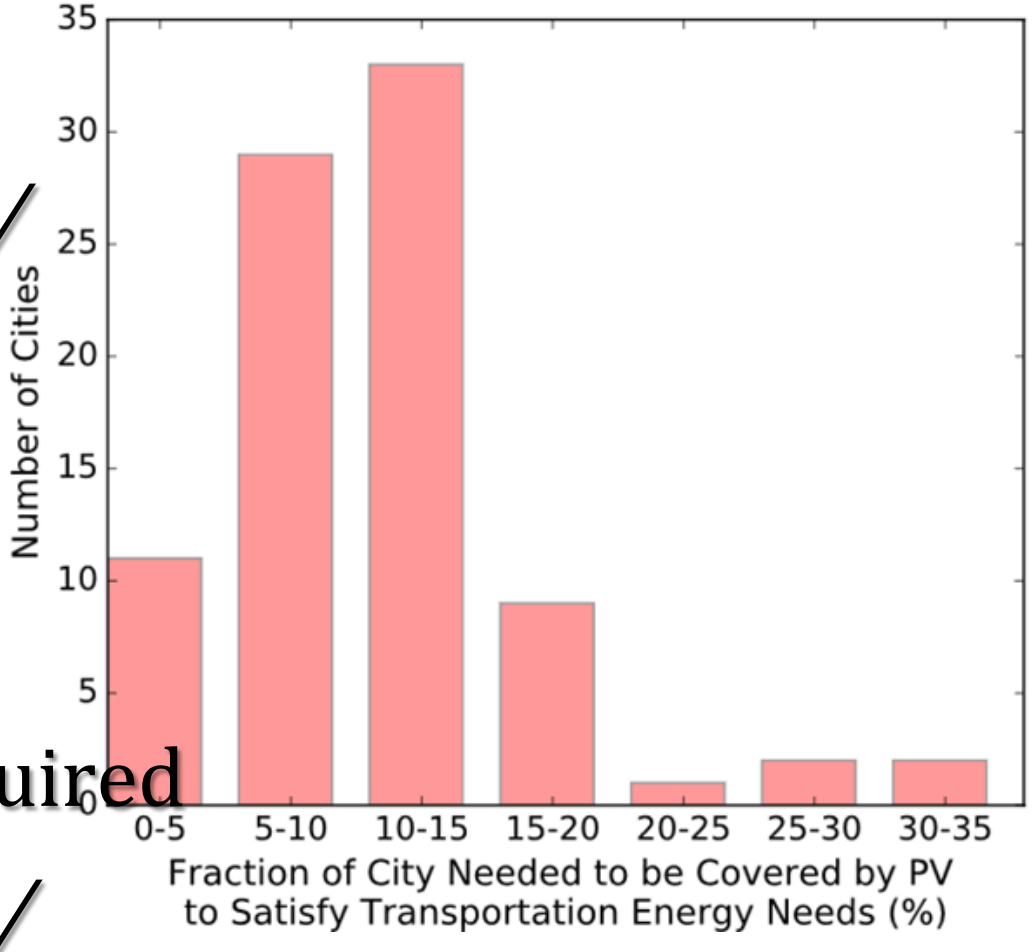
GoogleMaps: UITP Millenium Cities

Photovoltaic Coverage Needs

$u\downarrow transport = e\downarrow transport / \rho\downarrow urban$

$u\downarrow solar = \eta\downarrow PV \, G$

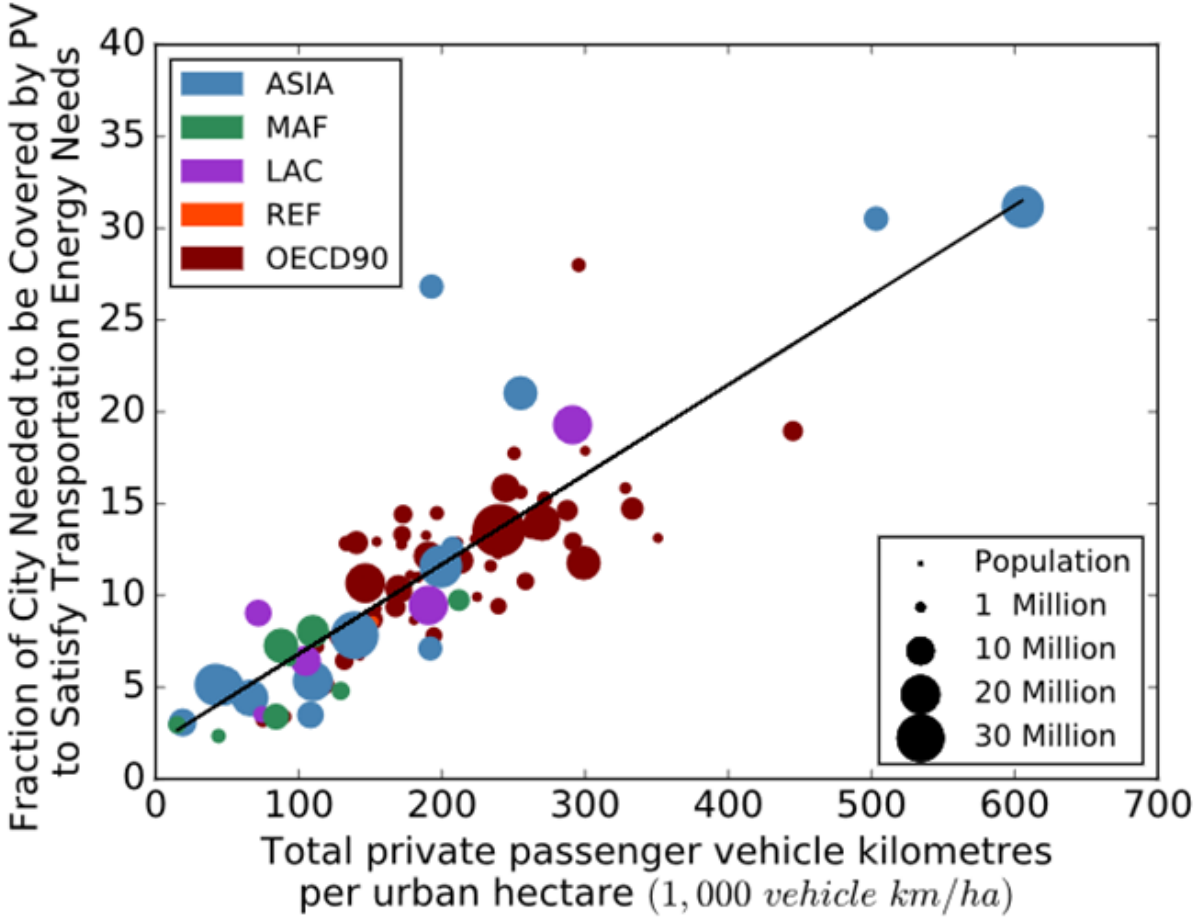
% PV Coverage Required $= u\downarrow transport / u\downarrow solar$



Sunter, D., Berkeley, P., and Kammen, D., "City-Integrated Photovoltaics to Satisfy Urban Transportation Energy Needs," *IOP Conference Series on Ecology and the Environment*, **204** (2016): 559-567.

u = energy density

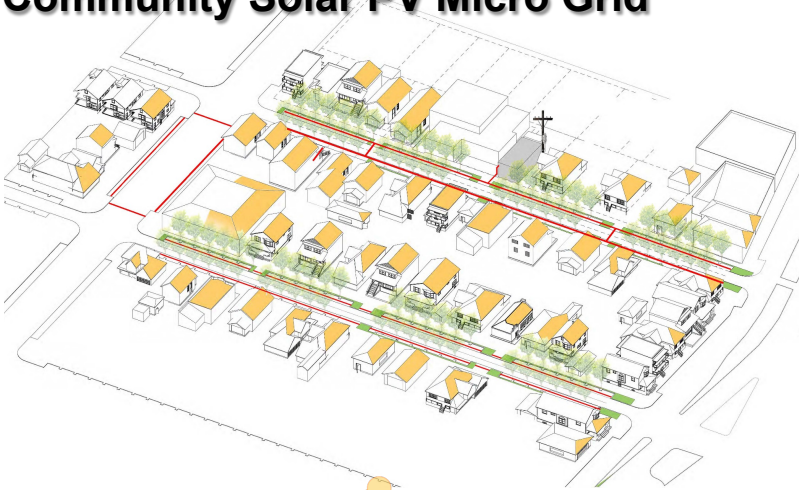
Private Passenger Vehicle Use Predicts Feasibility of PV-Powered Transportation

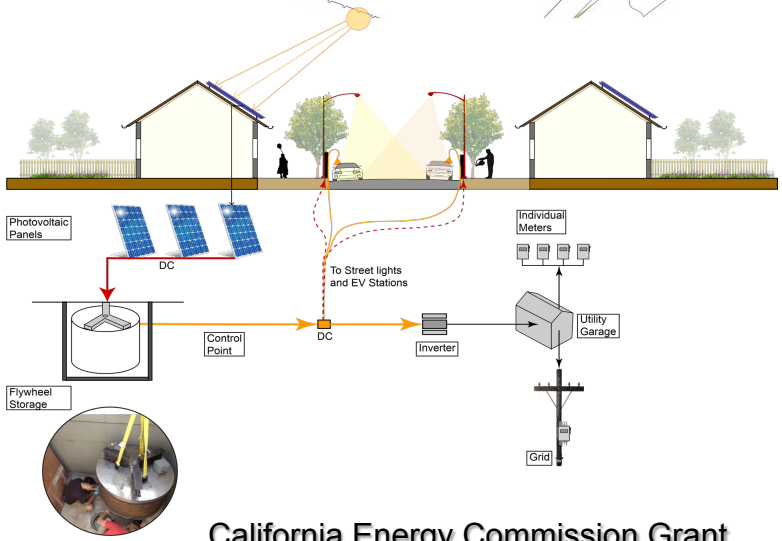


Sunter, D., Berkeley, P., and Kammen, D., "City-Integrated Photovoltaics to Satisfy Urban Transportation Energy Needs," *WIT Transactions on Ecology and the Environment*, **204** (2016): 559-567.

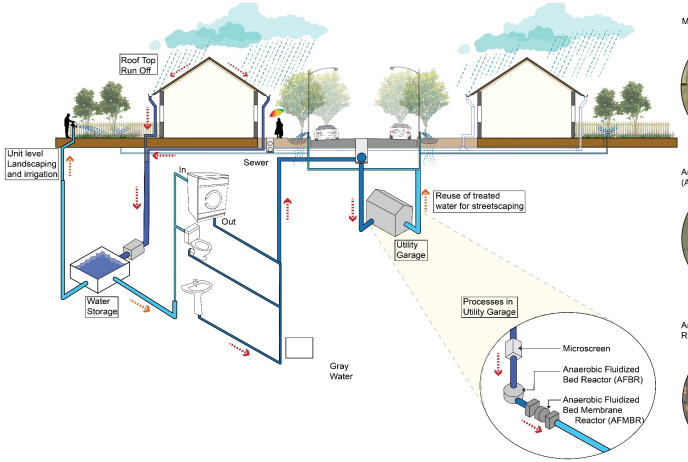
Oakland EcoBlock - ZNE and Zero Carbon Retrofit Pilot Project

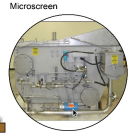
Community Solar PV Micro Grid





Waste Water Capture/Reuse

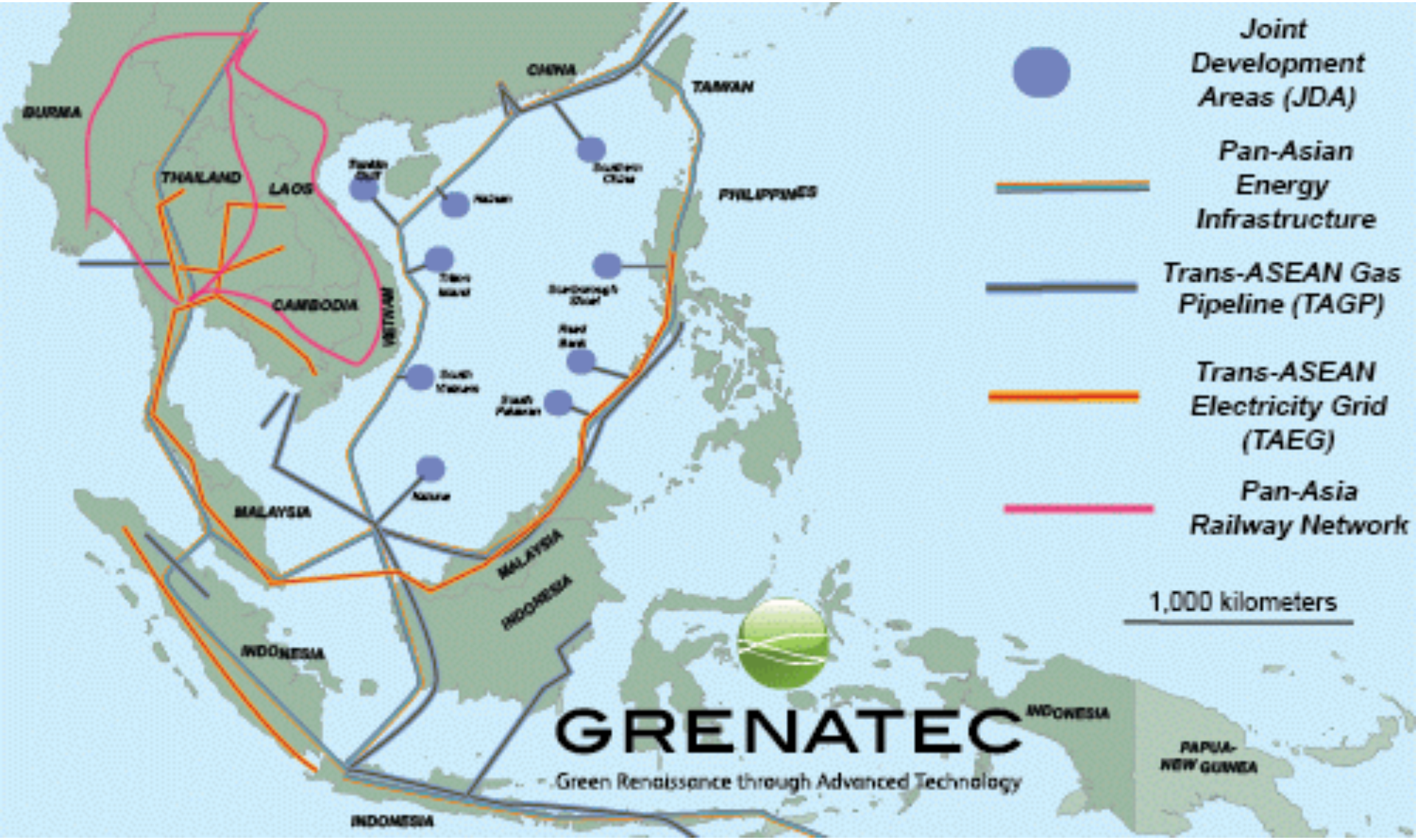




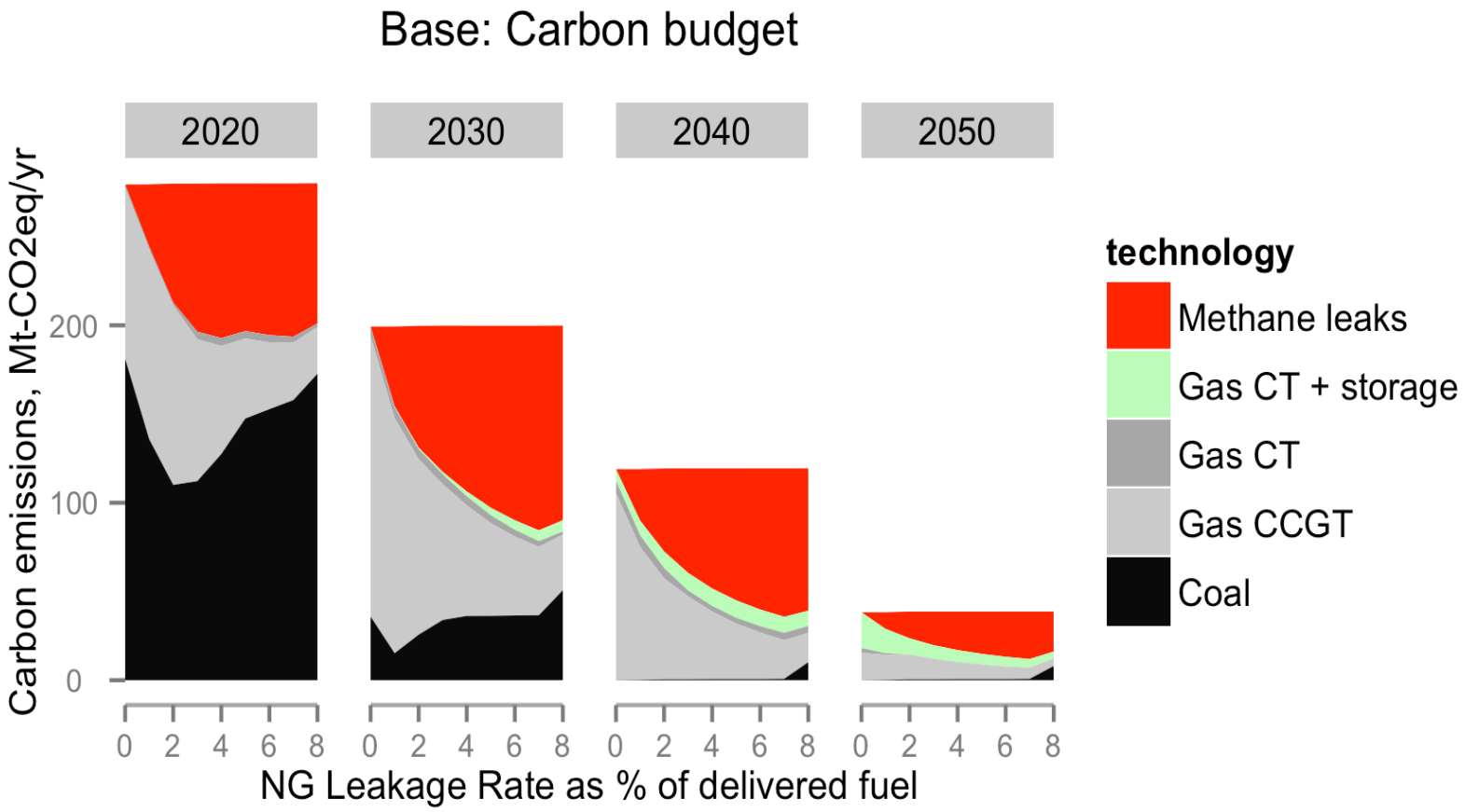
California Energy Commission Grant

http://rael.berkeley.edu/project/the-eco-block-project

Berkeley UNIVERSITY OF CALIFORNIA


Joint Development Areas (JDA)
Pan-Asian Energy Infrastructure
Trans-ASEAN Gas Pipeline (TAGP)
Trans-ASEAN Electricity Grid (TAEG)
Pan-Asia Railway Network
1,000 kilometers
BURMA
THAILAND
LAOS
CAMBODIA
VIETNAM
CHINA
TAIWAN
PHILIPPINES
MALAYSIA
INDONESIA
PAPUA-NEW GUINEA
GRENATEC
Green Renaissance through Advanced Technology

Example: the impact of Natural Gas Leakage on carbon budgets

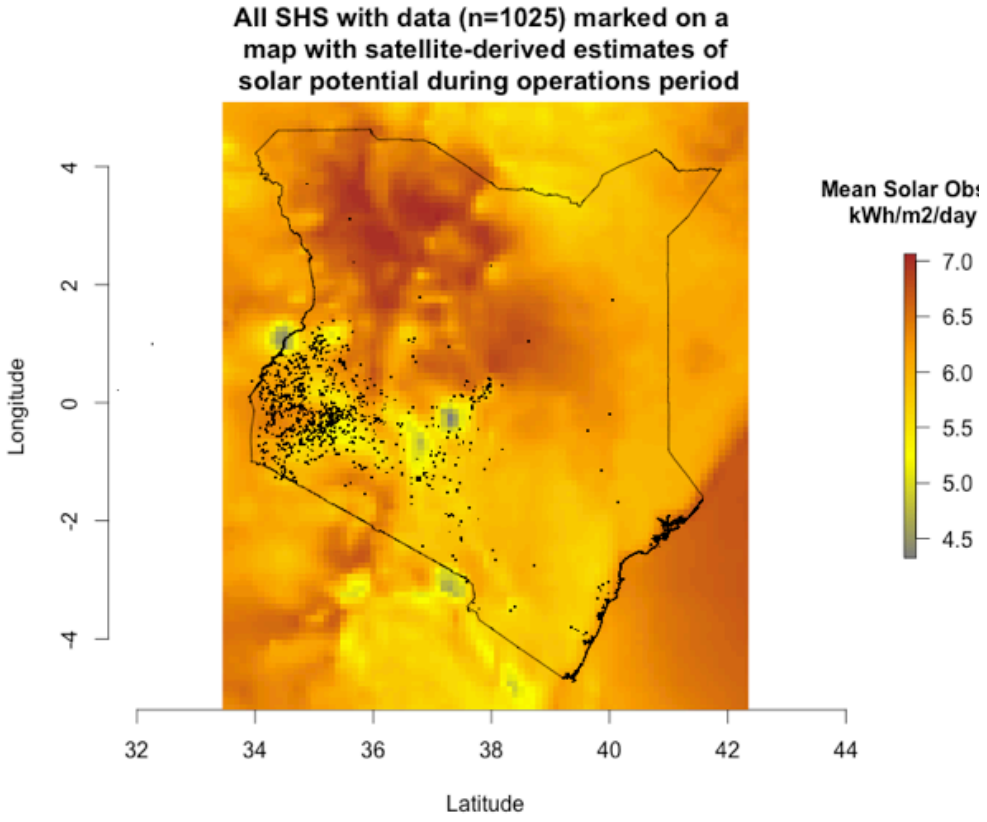


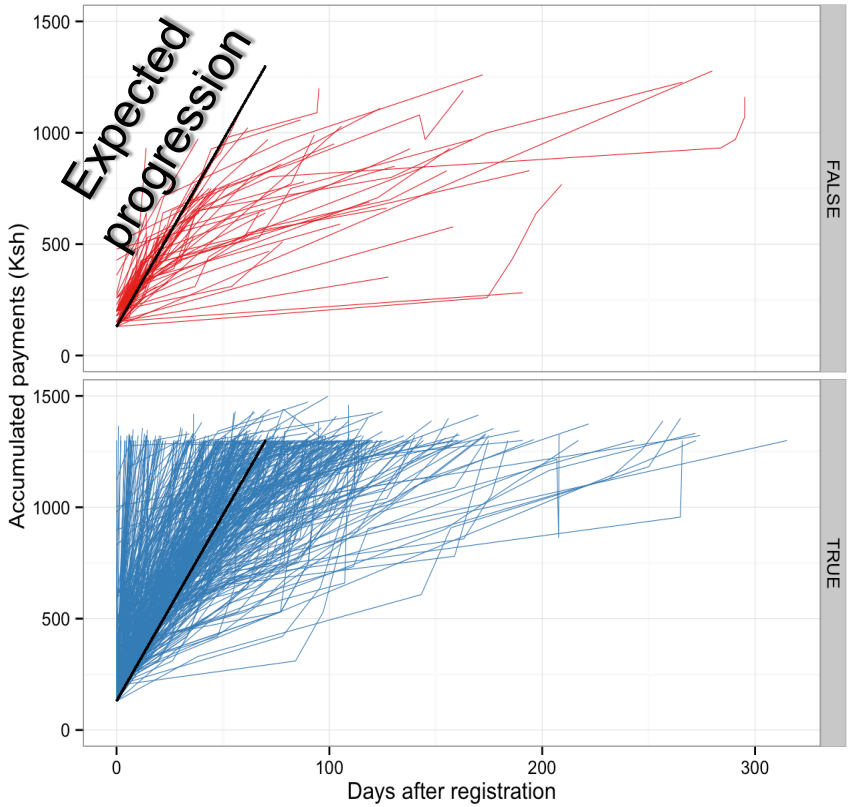
Johnstone and Kammen, 2017 in press

Off-grid Electricity Enabled by Storage and Efficient Lights, but …

Impossible without secure mobile money

Information Technology Enables Transformative Energy Access Technologies





Environmental Science & Technology

Policy Analysis

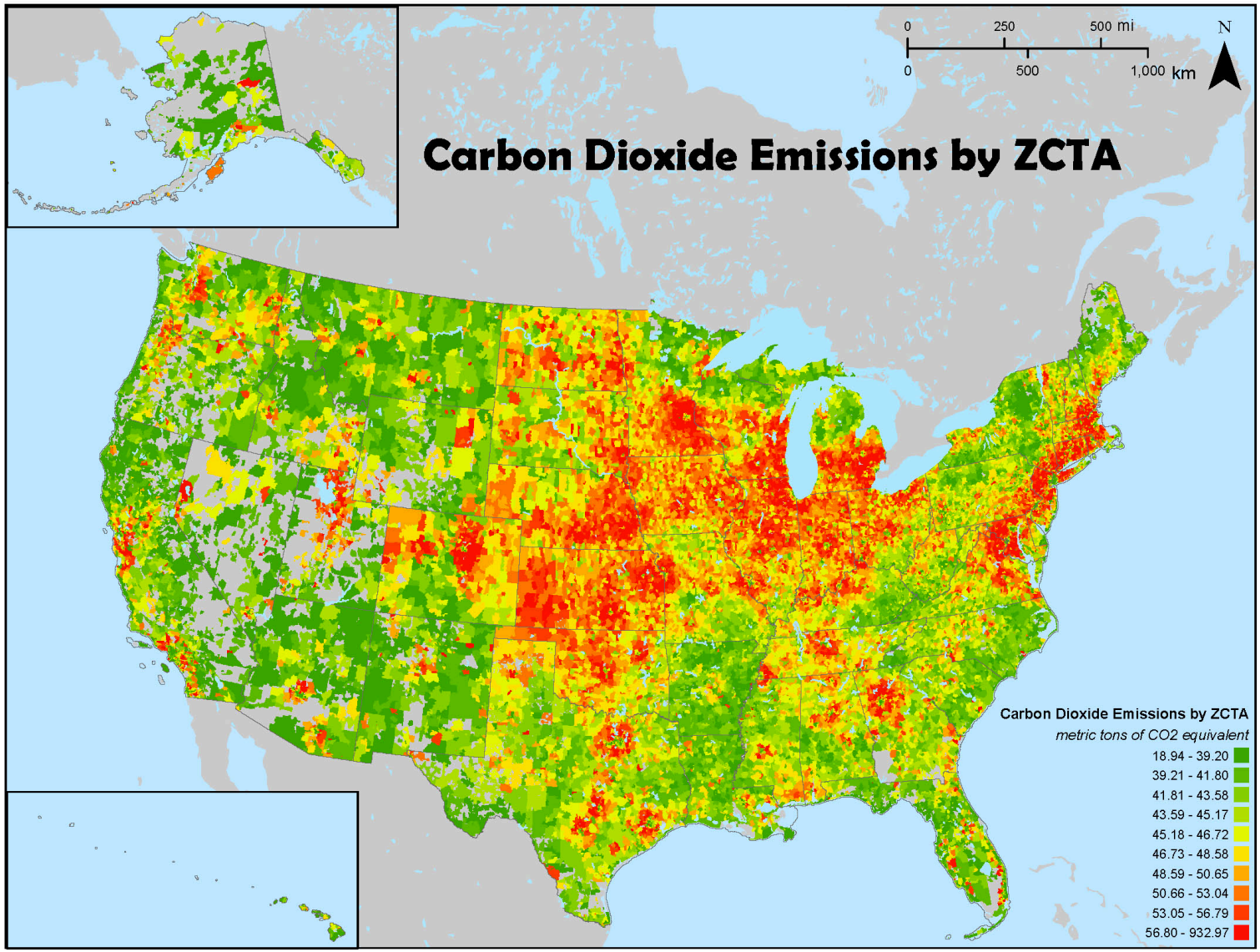
pubs.acs.org/est

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

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

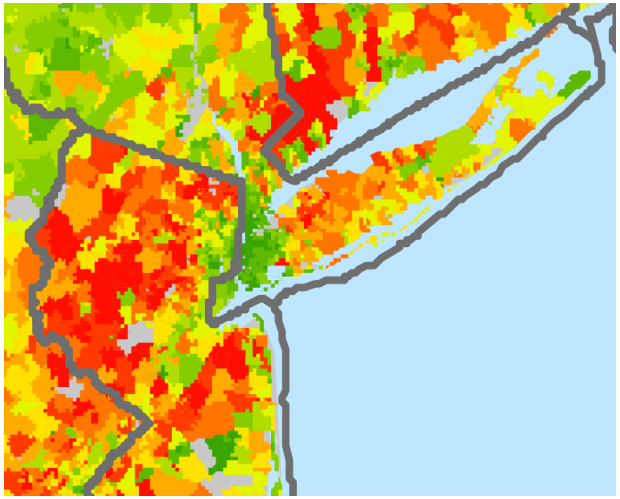
†Energy and Resources Group, ‡Goldman School of Public Policy, and §Department of Nuclear Engineering, University of California, Berkeley, California 94720, United States

http://coolclimate.berkeley.edu/maps

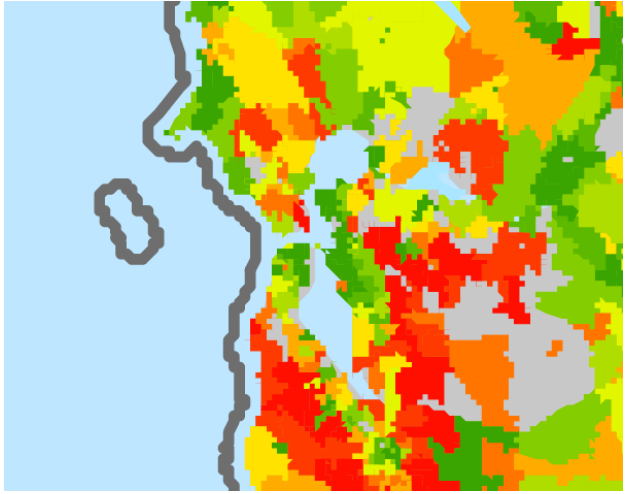


Jones and Kammen, 2014

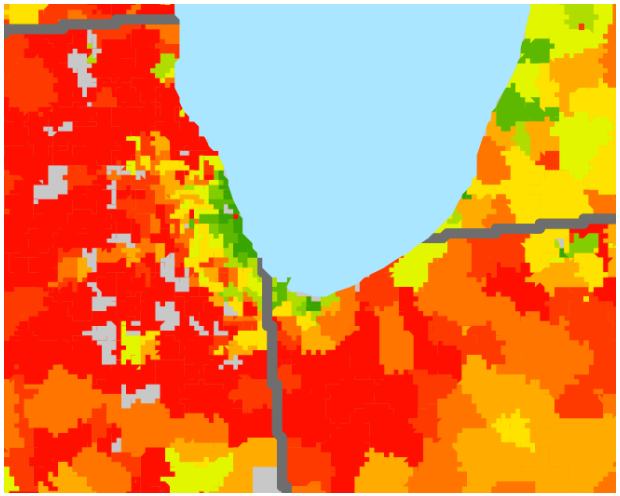
http://coolclimate.berkeley.edu/maps



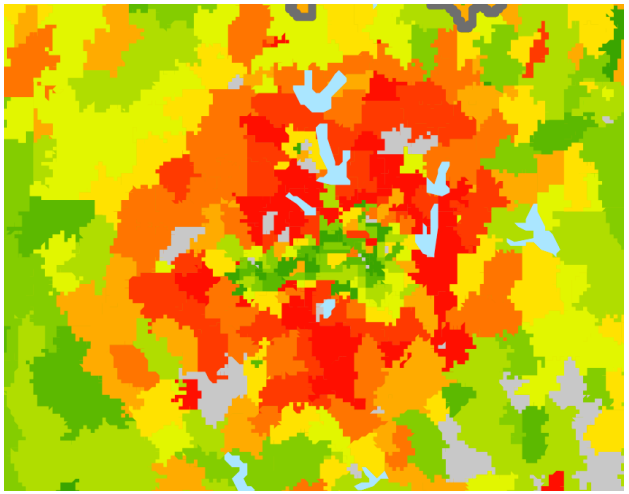
New York



San Francisco
Bay Area



Chicago



Dallas

Jones and Kammen, 2014

http://coolclimate.berkeley.edu/maps

Takeaway message:

Scientific and technical transformations are critical to enabling a sustainable energy system, but it is the energy-information nexus that provides the 'killer app' for change

Resources:

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Twitter: @dan_kammen