Webinar:
The Future of Renewable Energy

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Science Envoy for the U. S. State Department (former)

International Renewable Energy Academy (IREA)
1.5 hour webinar on January 30 at 11AM EST

Context for the Future of Renewable Energy:

1. Pre-2015: A long (often un-recognized today) technical run-up
2. After a long infancy, we are now Post-2015: An exponential realization of both the need and the possibility of entirely clean energy economies
3. And the daunting task of 80% clean energy by 2050 (per the IPCC and the Paris Climate Accord)

Resources:

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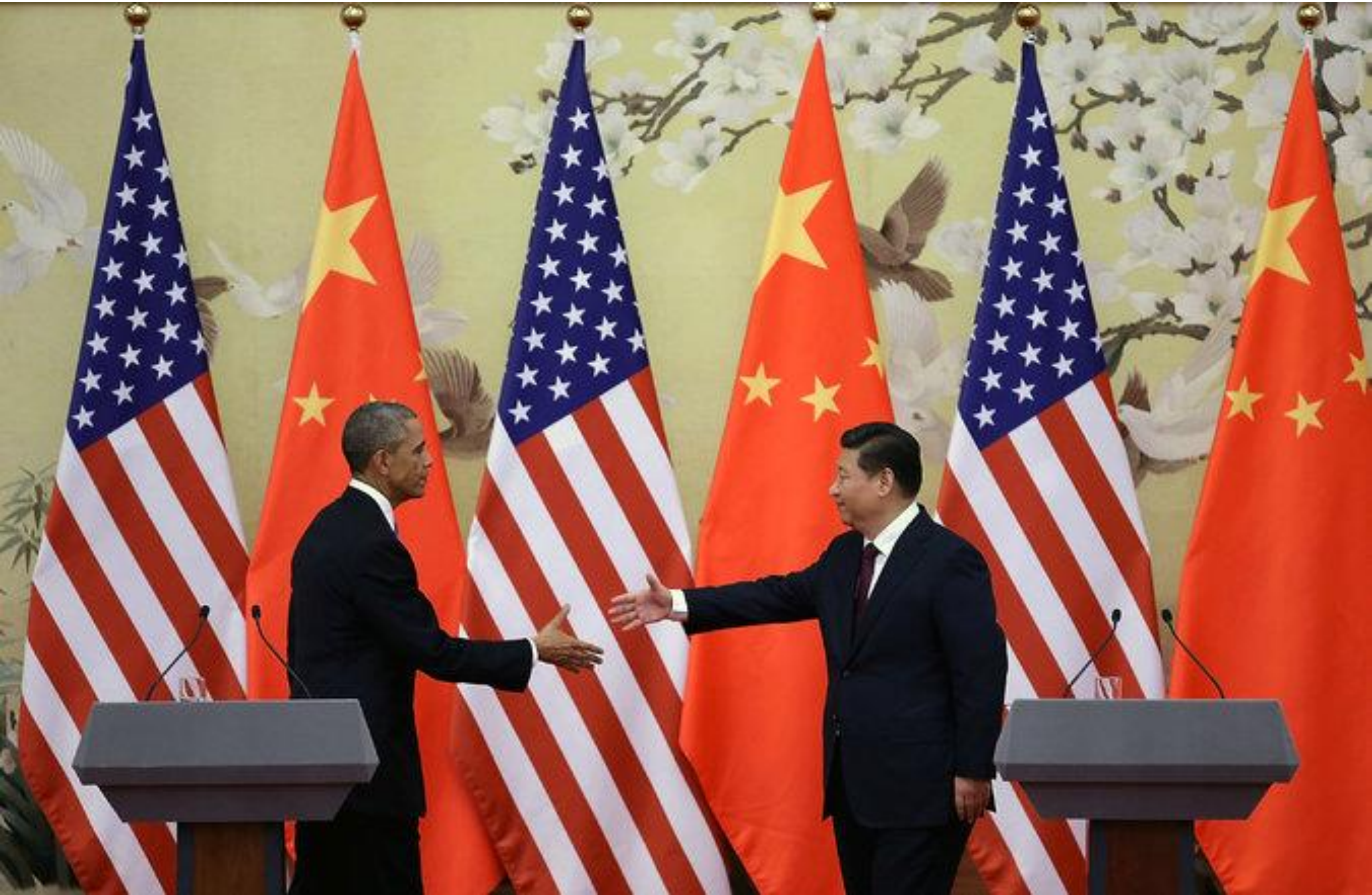
Event Details:
https://www.eventbrite.com/e/innovation-in-the-renewable-energy-sector-where-do-we-go-from-here-tickets-4215678808

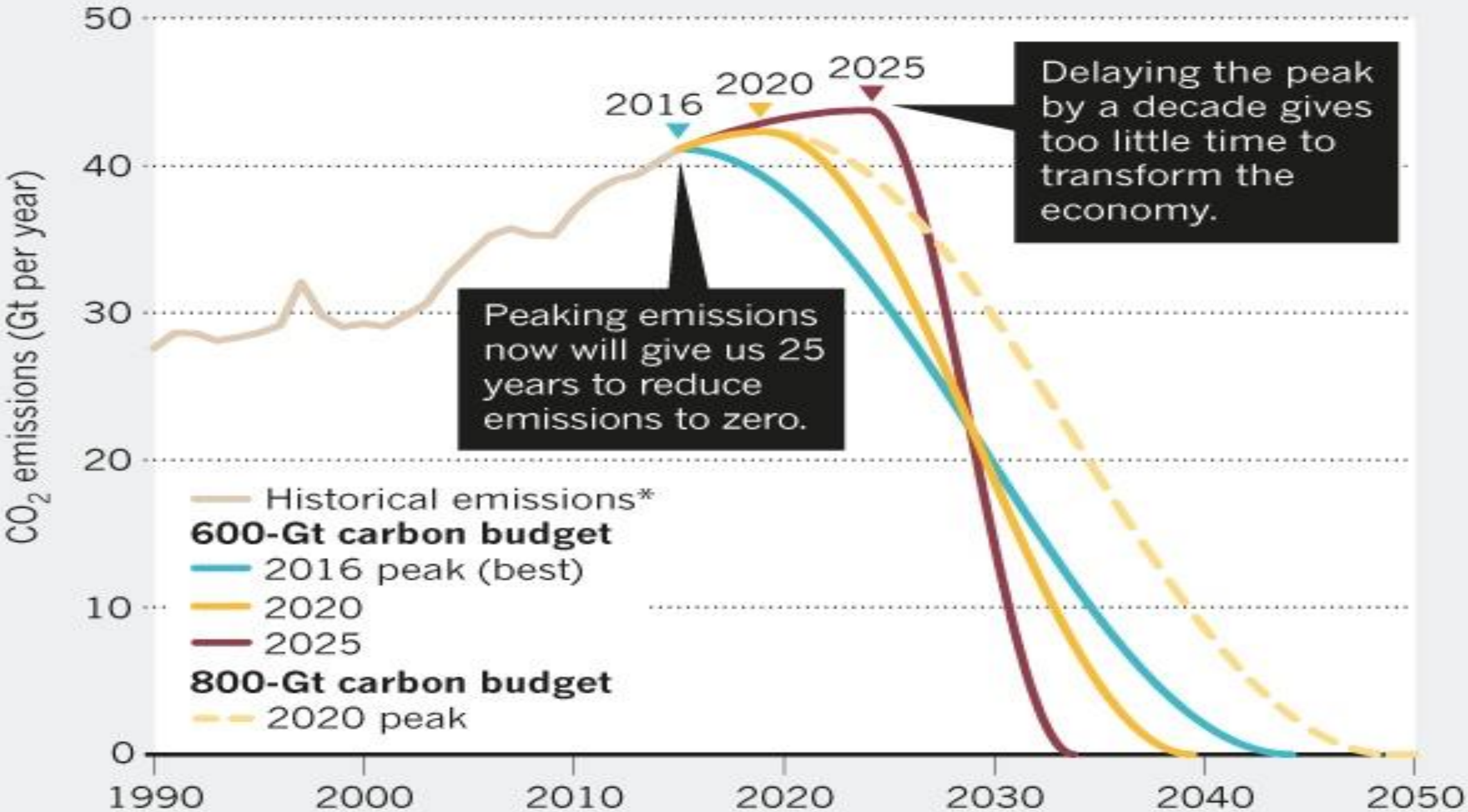
Political Context
U.S.- China Joint Announcement on Climate Change, 2014



Figueres, et al, 2017, *Nature*

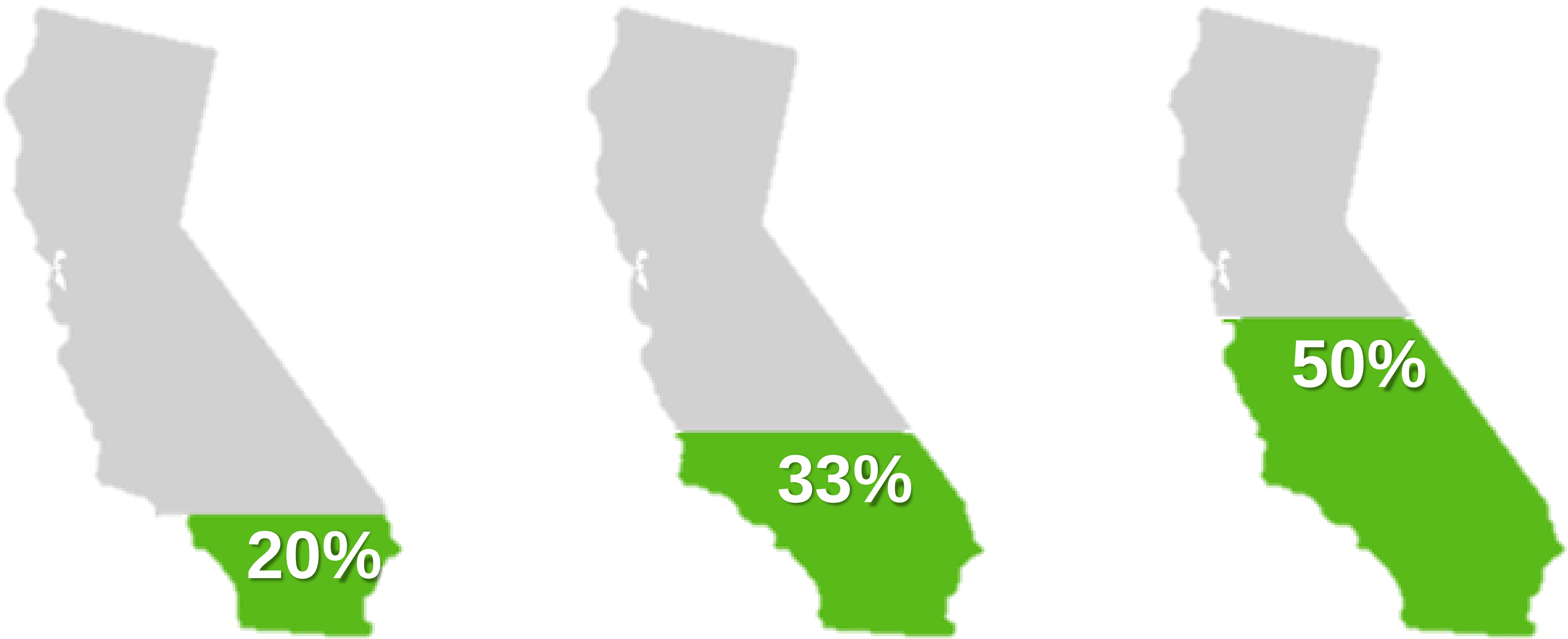
CARBON CRUNCH

There is a mean budget of around 600 gigatonnes (Gt) of carbon dioxide left to emit before the planet warms dangerously, by more than 1.5–2°C. Stretching the budget to 800 Gt buys another 10 years, but at a greater risk of exceeding the temperature limit.



*Data from The Global Carbon Project.

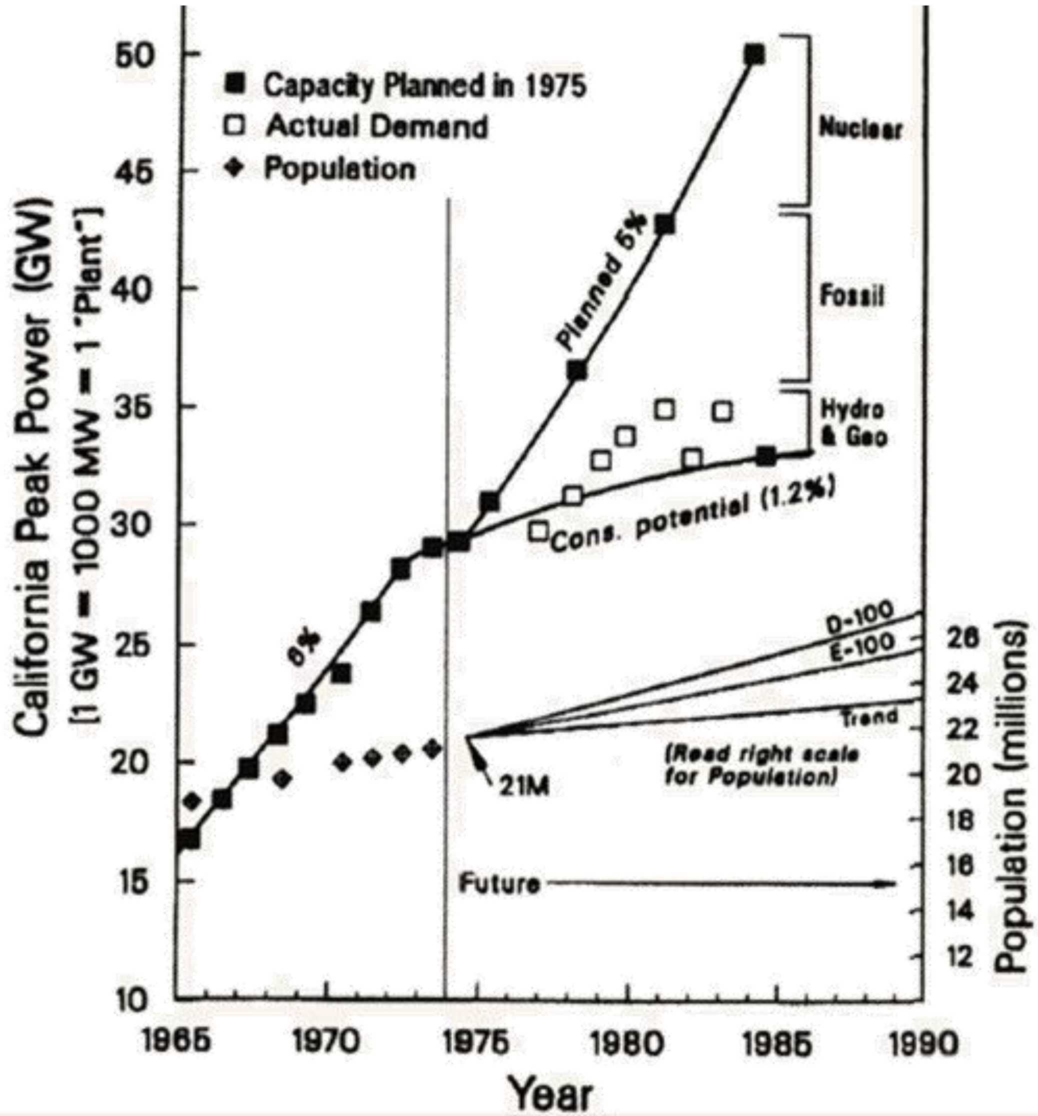
The California Example: Ambitious Clean Energy Goals



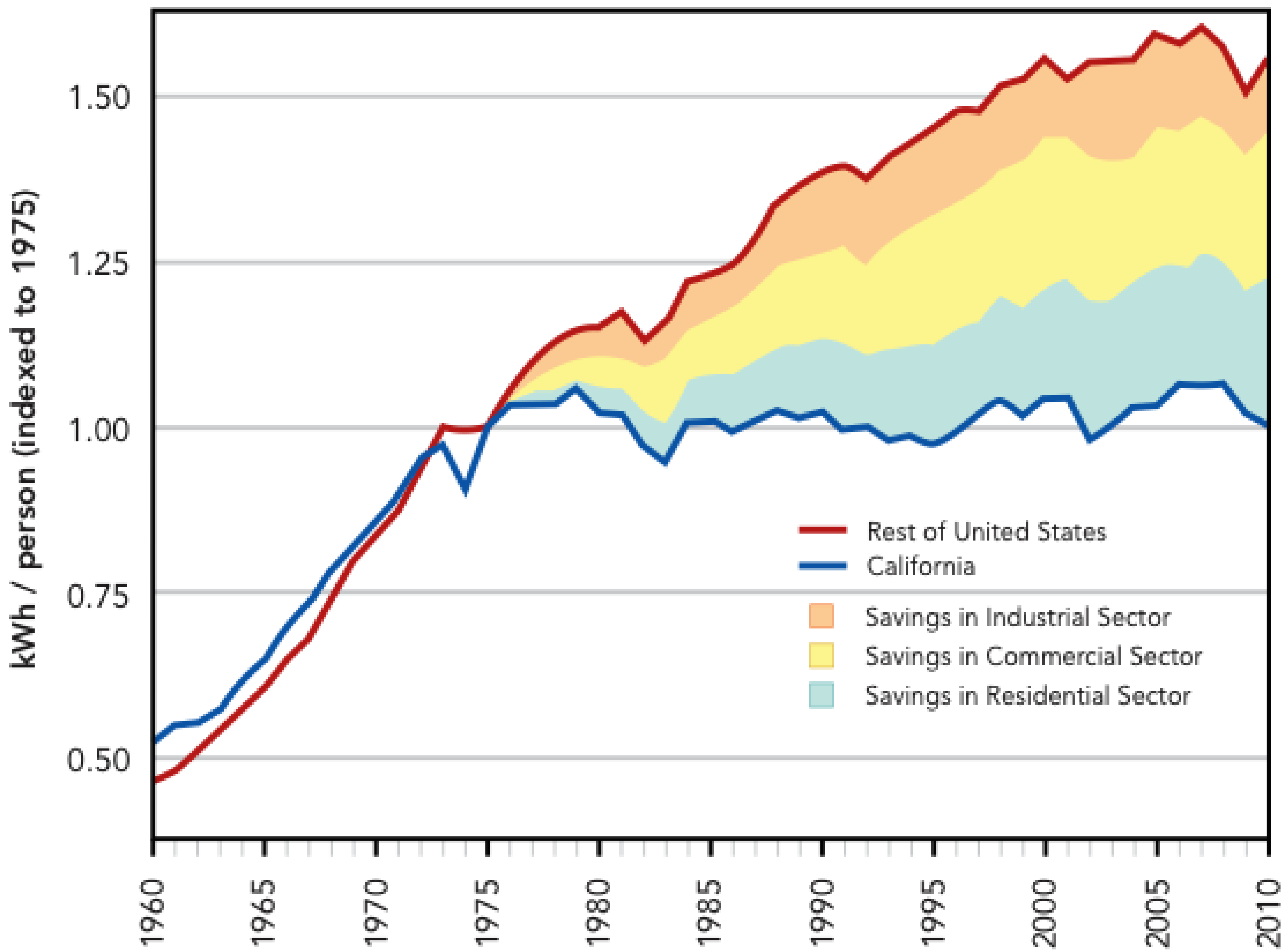
2013 **2020** **2030**

The 2045 goal will be100% clean energy

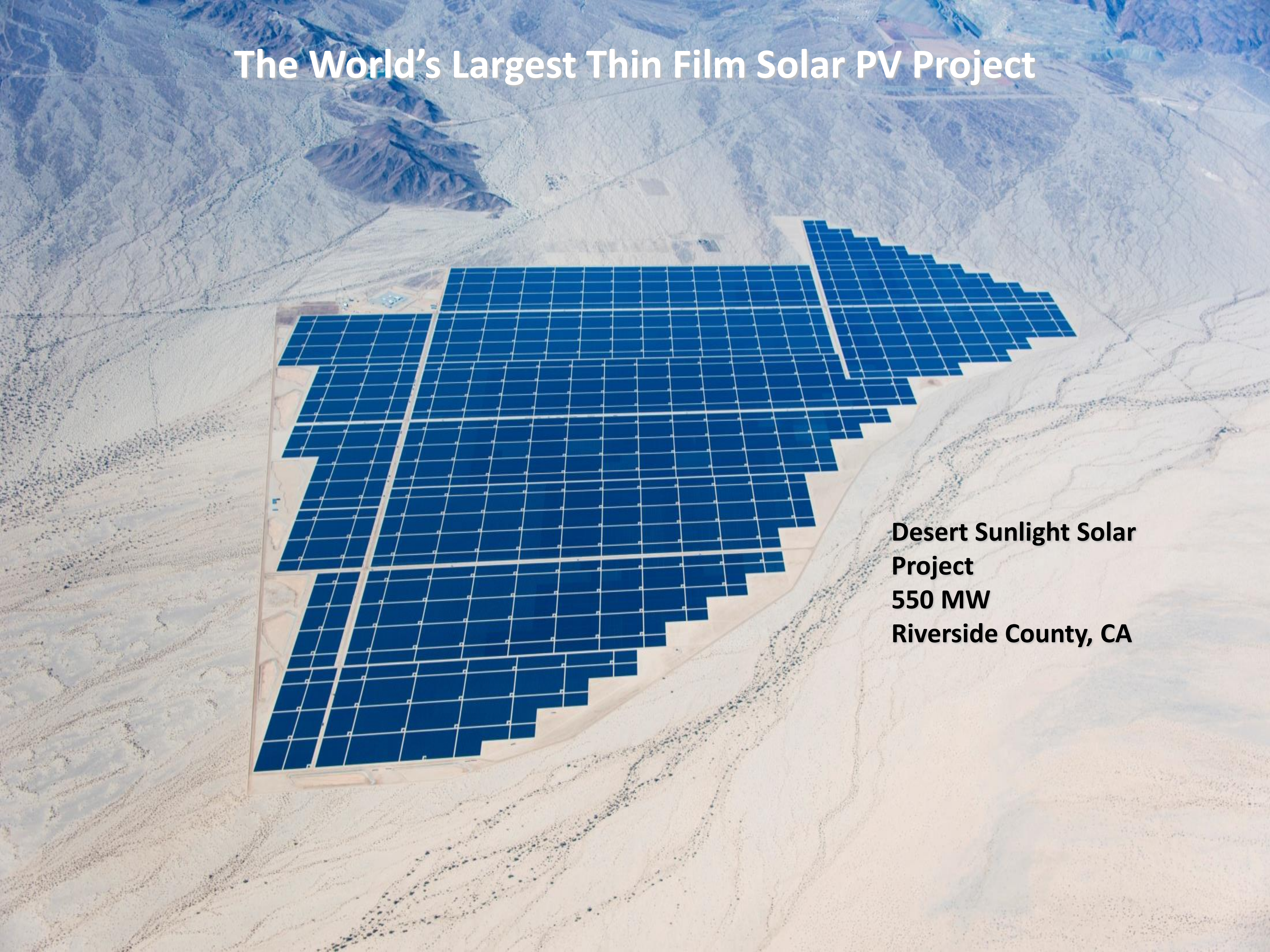
CA Peak Power: Testimony by Goldstein and Rosenfeld (Dec. 1974)



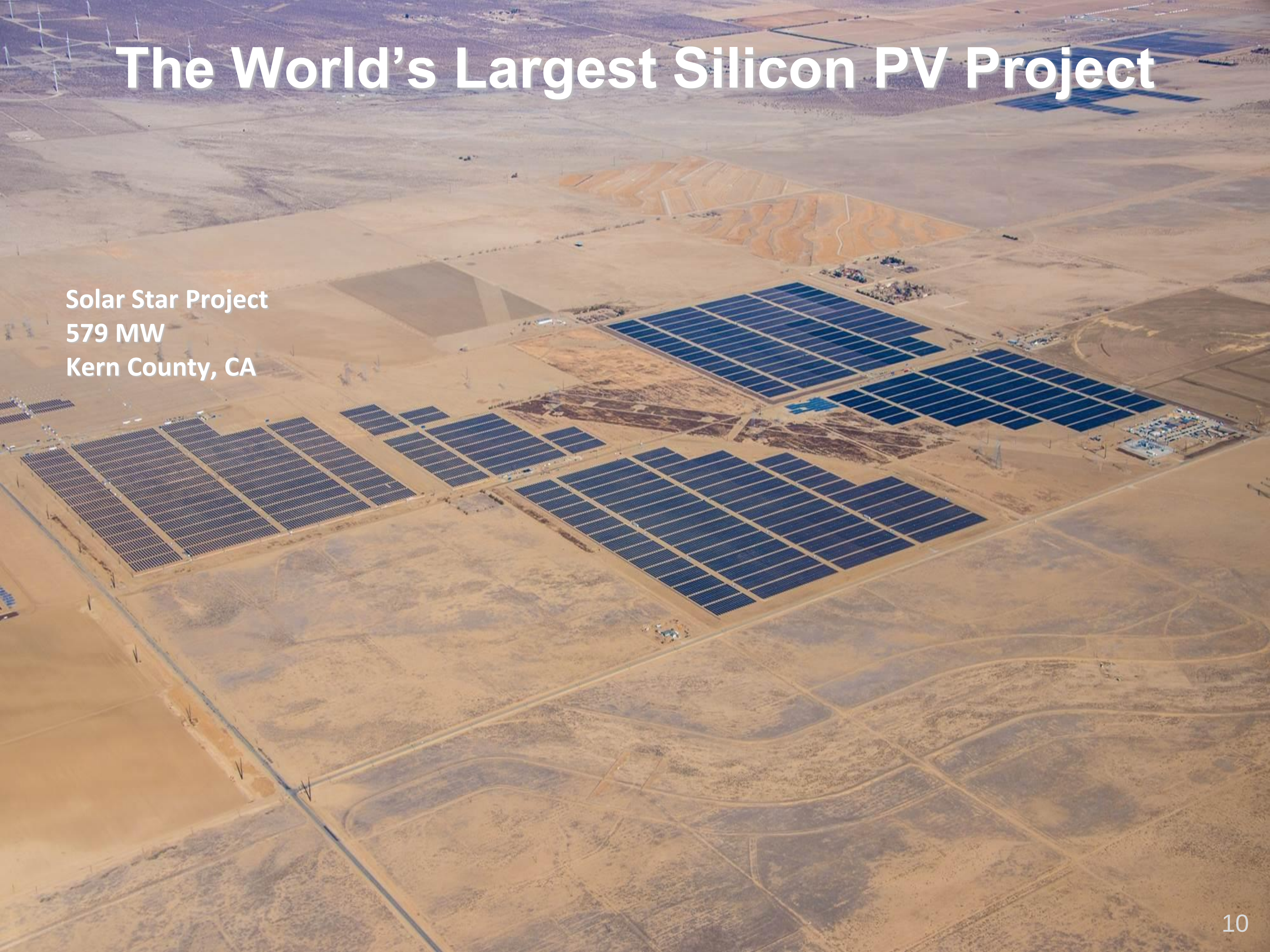
We can actually be confident because …



The World’s Largest Thin Film Solar PV Project



The World's Largest Silicon PV Project



Solar Star Project
579 MW
Kern County, CA

The World’s Largest Iron-Chromium Flow Battery

EnerVault Iron-Chromium Technology
1 MW-hr capacity at 250 kW (4 hour duration)
Turlock, CA

Fastest production car ever: 0–60 in 2.5* sec.

The fine print: At $144,000 the Model S P100D with Ludicrous mode is the third fastest accelerating production car ever produced, with a 0-60 mph time of 2.5* seconds. However, both the LaFerrari and the Porsche 918 Spyder were limited $1 million dollar cars and cannot be bought new. Those cars are small two seaters with very little luggage space, the pure electric, all-wheel drive Model S P100D has four doors, seats 5.

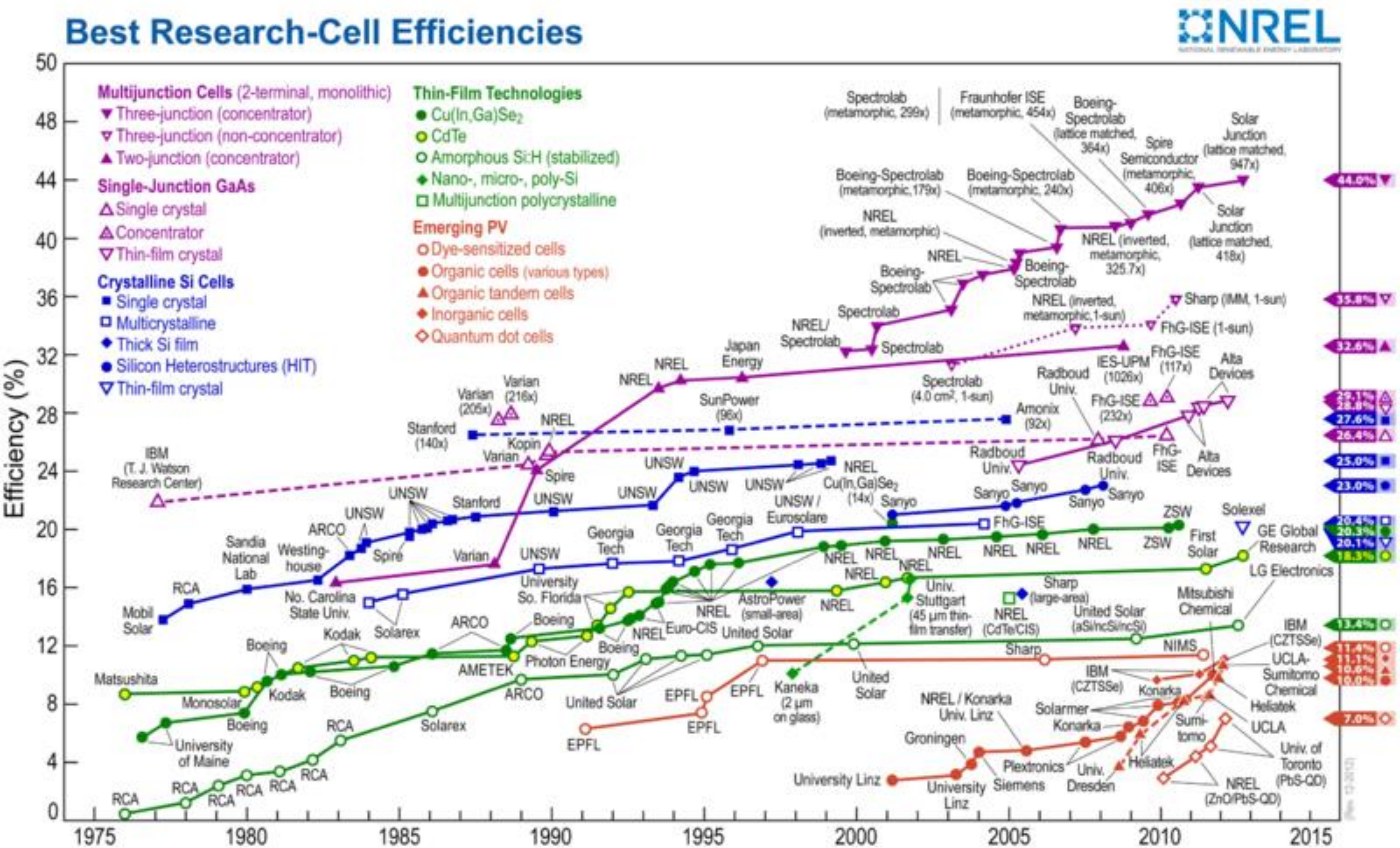
UNDER2° REGIONS REPRESENT

1.2 BILLION PEOPLE

AND

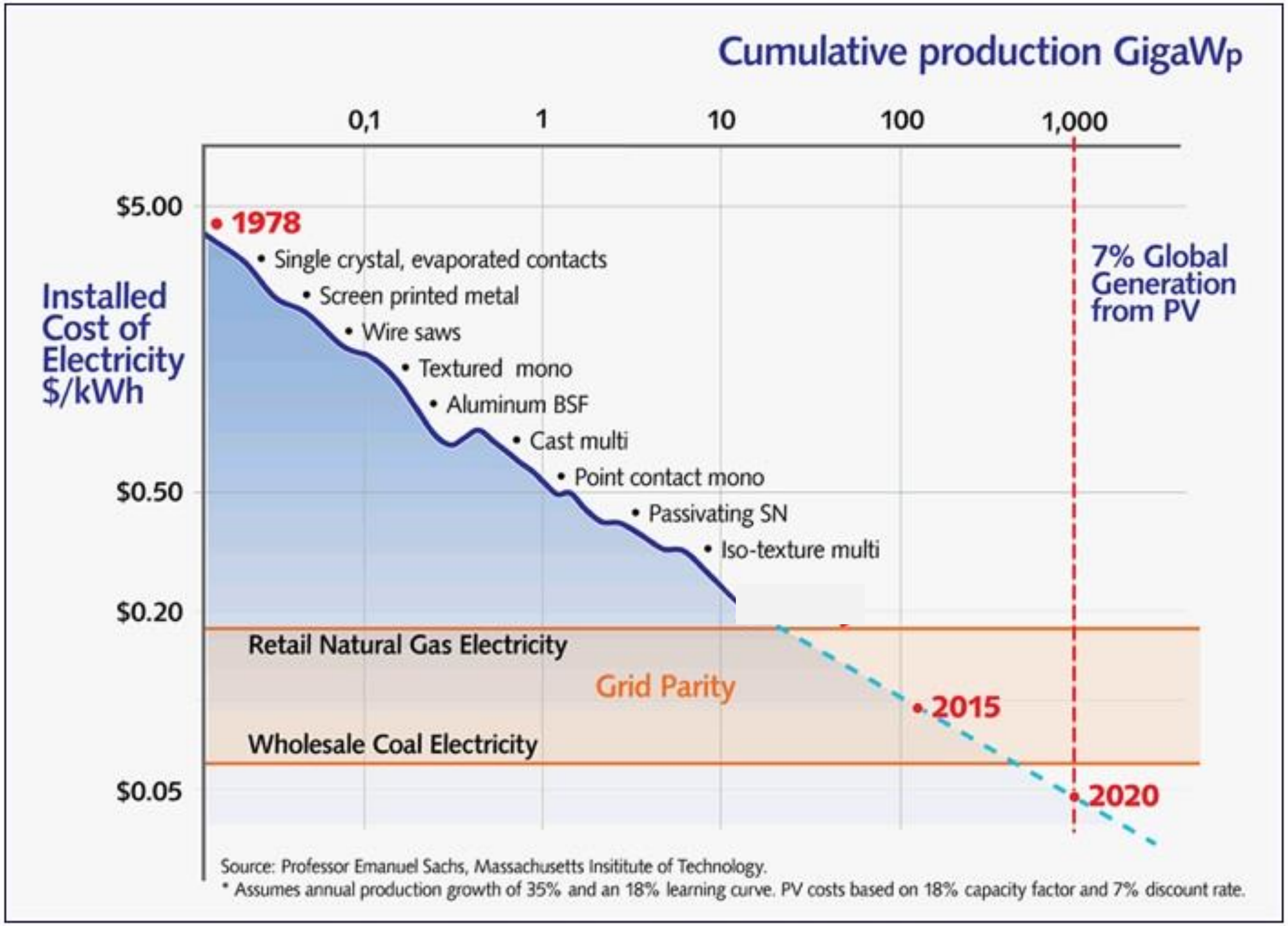
$28.8 TRILLION IN GDP

That's 39% of the global economy



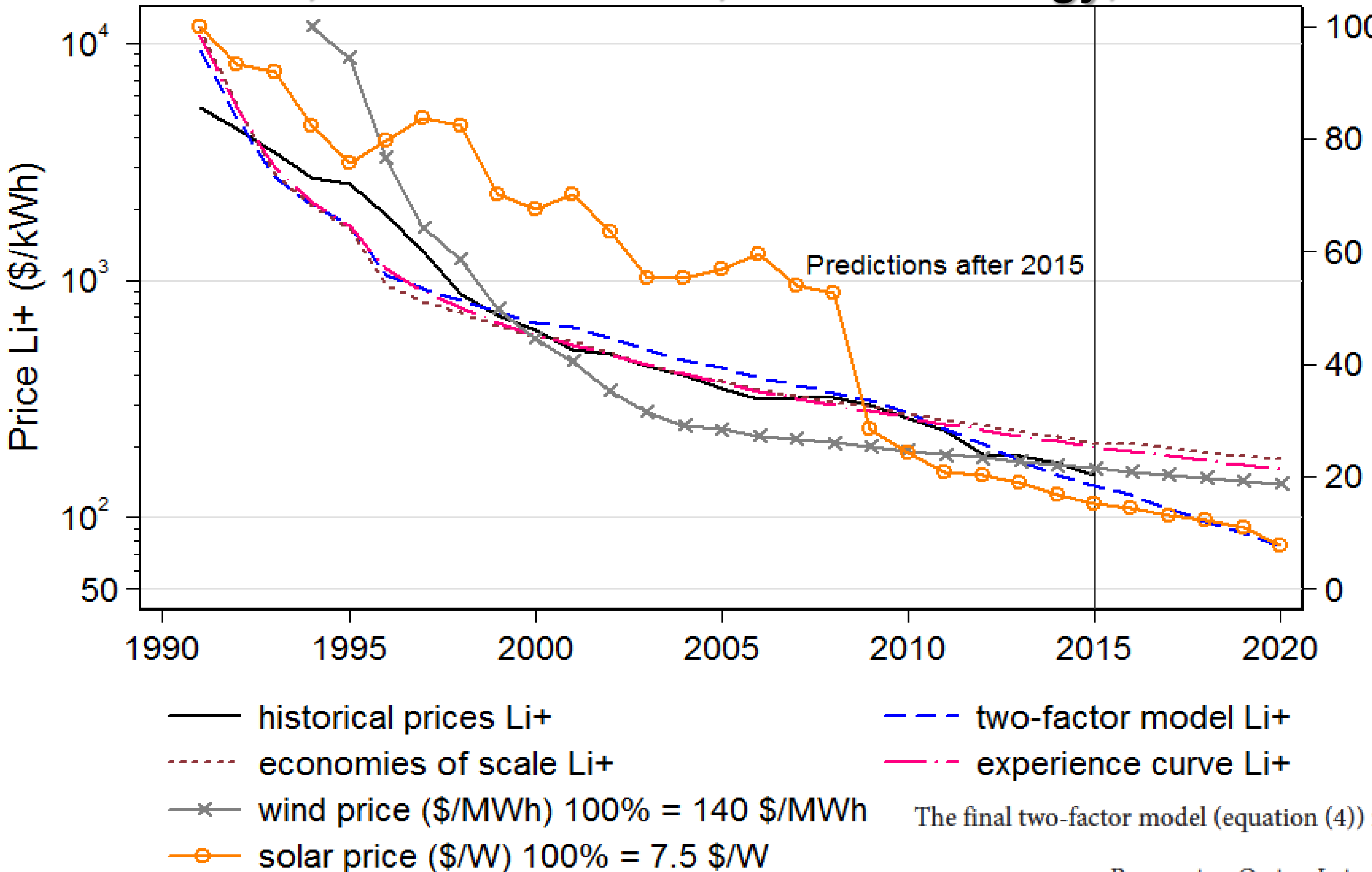
Best Research-Cell Efficiencies
NREL
Efficiency (%)
50
48
44
40
36
32
28
24
20
16
12
8
4
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
Multijunction Cells (2-terminal, monolithic)
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Silicon Heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells (various types)
Organic tandem cells
Inorganic cells
Quantum dot cells
Spectrolab (metamorphic, 299x)
Fraunhofer ISE (metamorphic, 454x)
Boeing-Spectrolab (lattice matched, 364x)
Spire Semiconductor (metamorphic, 406x)
Solar Junction (lattice matched, 947x)
Boeing-Spectrolab (metamorphic,179x)
Boeing-Spectrolab (metamorphic, 240x)
NREL (inverted, metamorphic)
Solar Junction (lattice matched, 418x)
NREL (inverted, metamorphic, 325.7x)
Sharp (IMM, 1-sun)
NREL (inverted, metamorphic,1-sun)
FhG-ISE (1-sun)
Spectrolab (4.0 cm², 1-sun)
IES-UPM (1026x)
FhG-ISE (117x)
FhG-ISE (232x)
Alta Devices
Radboud Univ.
Amonix (92x)
SunPower (96x)
Japan Energy
NREL/ Spectrolab
Stanford (140x)
Varian (205x)
Varian (216x)
Kopin
Spire
IBM (T. J. Watson Research Center)
UNSW
Cu(In,Ga)Se2 (14x)
UNSW / Eurosolare
Georgia Tech
Sanyo
FhG-ISE
Solexel
ZSW
First Solar
GE Global Research
LG Electronics
Mitsubishi Chemical
IBM (CZTSSe)
UCLA-Sumitomo Chemical
Heliatek
UCLA
Univ. of Toronto (PbS-QD)
NREL (ZnO/PbS-QD)
Mobil Solar
RCA
Sandia National Lab
Westing-house
ARCO
No. Carolina State Univ.
Solarex
University So. Florida
AstroPower (small-area)
Univ. Stuttgart (45 µm thin-film transfer)
Sharp (large-area)
NREL (CdTe/CIS)
United Solar (aSi/ncSi/ncSi)
Matsushita
Monosolar
Kodak
Boeing
University of Maine
AMETEK
Photon Energy
Euro-CIS
United Solar
Kaneka (2 µm on glass)
EPFL
NIMS
Konarka
Solarmer
Sumi-tomo
NREL / Konarka Univ. Linz
Groningen
Plextronics
Univ. Dresden
Siemens
University Linz
44.0%
35.8%
32.6%
29.1%
28.8%
27.6%
26.4%
25.0%
23.0%
20.4%
20.3%
20.1%
18.3%
13.4%
11.4%
11.1%
10.6%
10.0%
7.0%

Solar cost decreases 10% per year



Storage ExhibitsSame Trend as Wind and Solar

Kittner, Lill & Kammen, Nature Energy, 2017

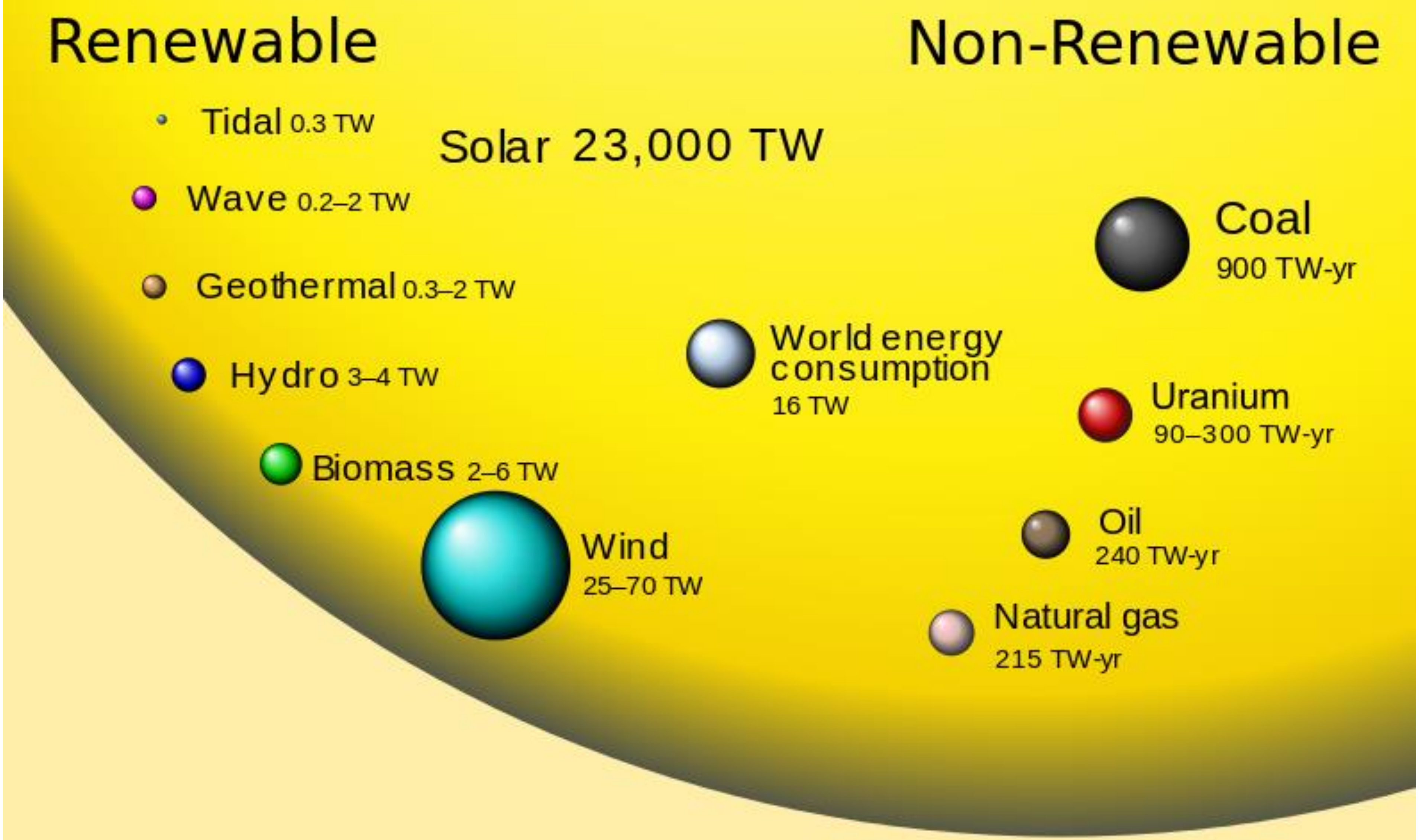


The final two-factor model (equation (4)) is as follows:

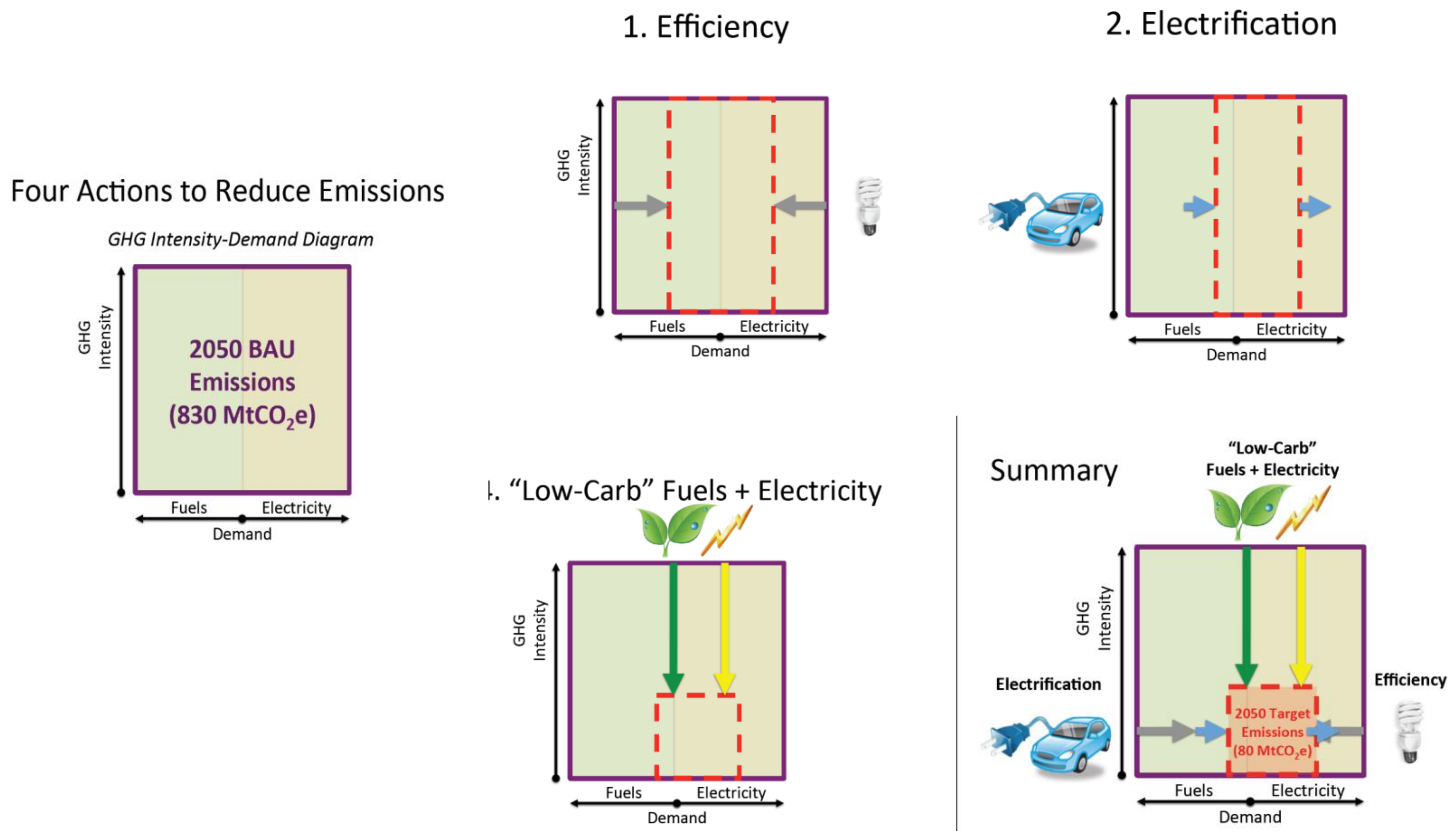
$$P_i = \gamma_0 + \gamma_1 Q_i + \gamma_2 I_i + \epsilon_i$$

$$\text{Forecasted price} = \left(\frac{10^{\gamma_0}}{Q_i^{-\gamma_1}}\right)(10^{\gamma_2})^{I_i}$$

Energy Sources and Consumption

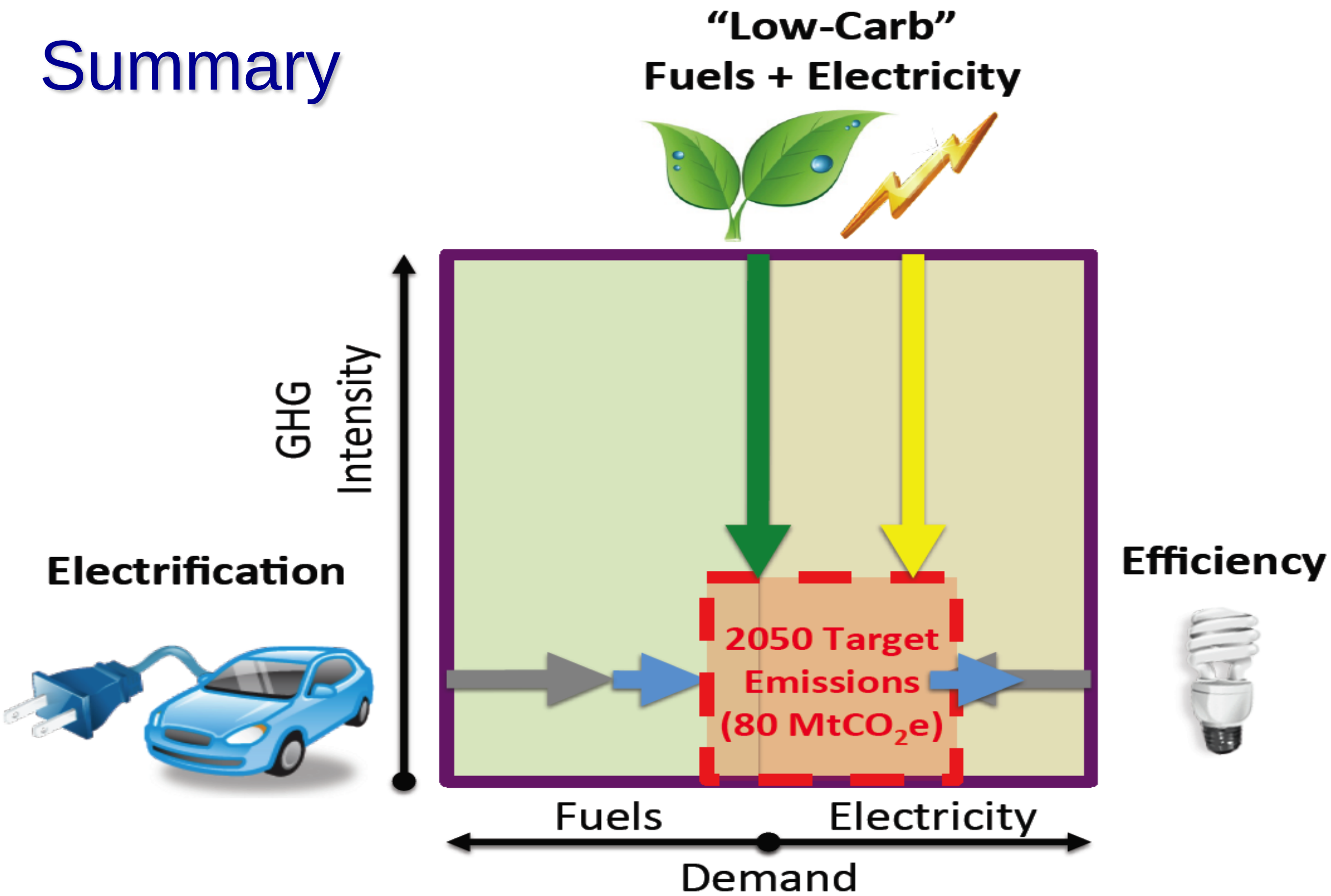


A pathway to sustainability



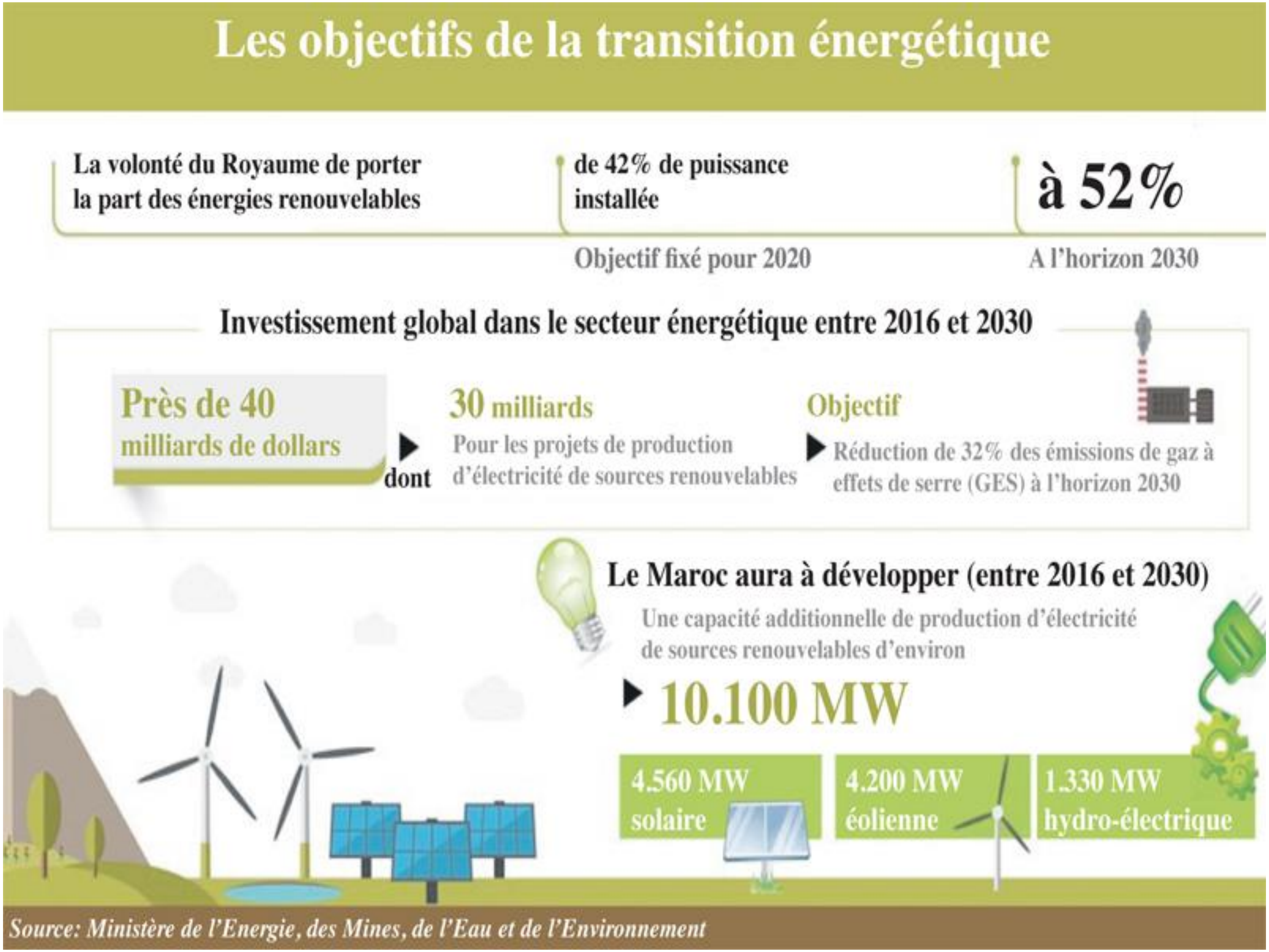
http://rael.berkeley.edu

Summary

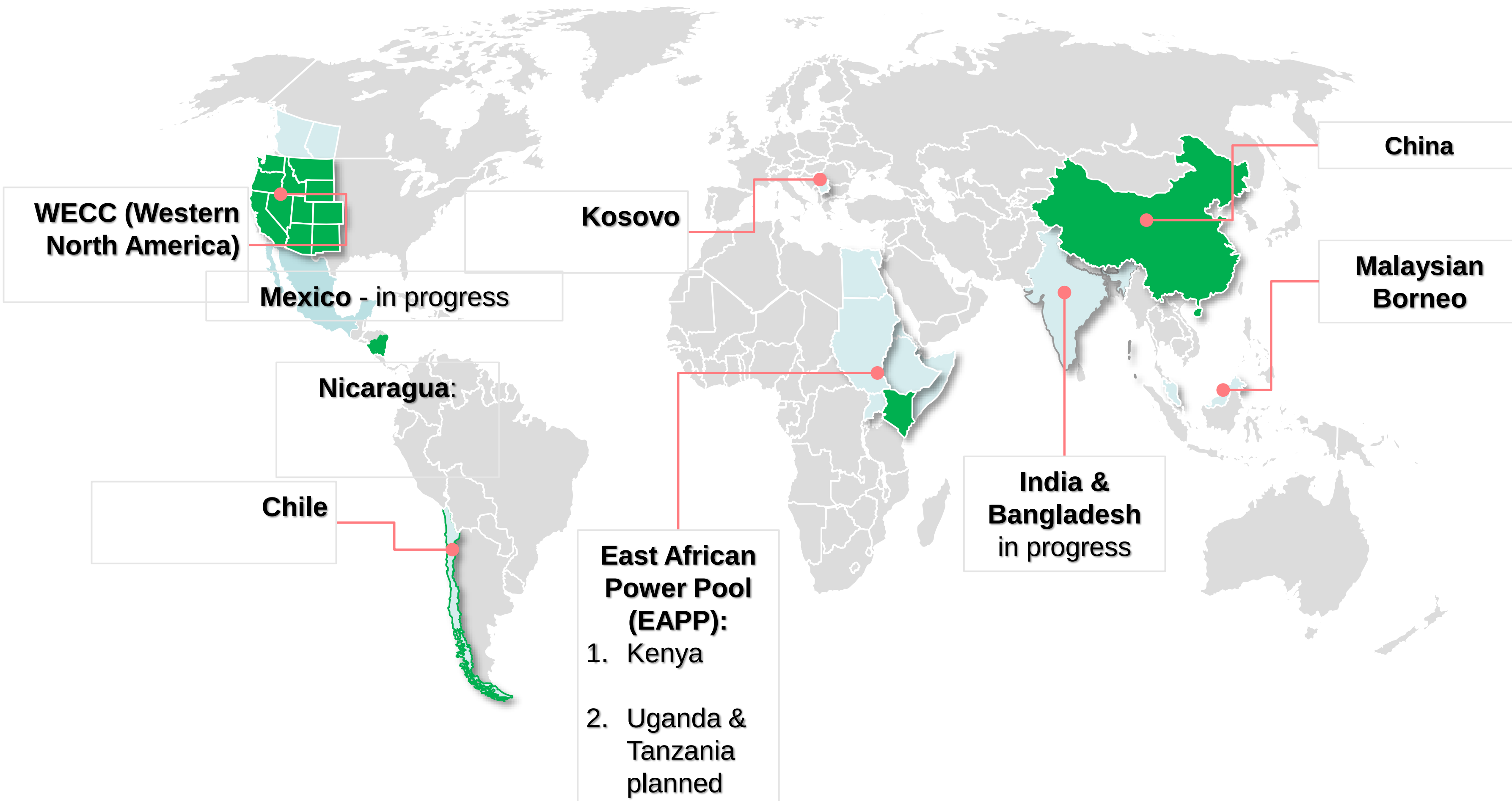


"Low-Carb"
Fuels + Electricity
GHG
Intensity
Electrification
2050 Target
Emissions
(80 $MtCO_2e$)
Efficiency
Fuels
Electricity
Demand

Morocco


Les objectifs de la transition énergétique
La volonté du Royaume de porter la part des énergies renouvelables
de 42% de puissance installée
Objectif fixé pour 2020
à 52%
A l'horizon 2030
Investissement global dans le secteur énergétique entre 2016 et 2030
Près de 40 milliards de dollars
dont
30 milliards
Pour les projets de production d'électricité de sources renouvelables
Objectif
Réduction de 32% des émissions de gaz à effets de serre (GES) à l'horizon 2030
Le Maroc aura à développer (entre 2016 et 2030)
Une capacité additionnelle de production d'électricité de sources renouvelables d'environ
10.100 MW
4.560 MW solaire
4.200 MW éolienne
1.330 MW hydro-électrique
Source: Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement

RAEL's "SWITCH" Power System Models to Plan the Clean Energy Transition



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

SWITCH Model Description Analytics

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

$$\underset{(c_i)}{min.} NPV \sum_{i,k=1}^{n,m} TC_k\ (c_i)$$

$$Total\ Cost\ TC_k = Capital\ Cost_i * Capacity\ (c_i) + [Variable\ Cost_i * Capacity\ (c_i) *\ CF_i *\ 8760]$$

$$\sum_{i=1}^{n} Capacity\ (c_i) * Peak\ Contribution_i \quad \geq Annual\ Peak\ Demand * [1 + Reserve\ Margin]$$

$$\sum_{i=1}^{n} [Capacity\ (c_i) *\ CF_i *\ 8760]\ \geq\ Annual\ Load$$

$$Annual\ Load *\ Spill\ Factor\ \geq \sum_{i=1}^{n}\ [Capacity\ (c_i) *\ \ CF_i *\ 8760]$$

$$Total\ Resource\ Potental_i\ \geq \sum_{k=1}^{m}\ Capacity\ (c_i)$$

Environmental Science & Technology

Policy Analysis

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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*[,‡,§,∥]

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[‡]Renewable and Appropriate Energy Laboratory, [§]Energy and Resources Group, and [∥]Goldman School of Public Policy, University of California, Berkeley, California 94720, United States

[⊥]Energy and Environmental Economics, Inc. (E3), San Francisco, California 94104, United States

[#]China National Institute of Standardization, Beijing 100191, P.R. China

Supporting Information

ABSTRACT: We present an integrated model, SWITCH-China, of the Chinese power sector with which to analyze the economic and technological implications of a medium to long-term decarbonization scenario while accounting for very-short-term renewable variability. On the basis of the model and assumptions used, we find that the announced 2030 carbon peak can be achieved with a carbon price of ~\$40/tCO_2. Current trends in renewable energy price reductions alone are insufficient to replace coal; however, an 80% carbon emission reduction by 2050 is achievable in the Intergovernmental Panel on Climate Change Target Scenario with an optimal electricity mix in 2050 including nuclear (14%), wind (23%), solar (27%), hydro (6%), gas (1%), coal (3%), and carbon capture and sequestration coal energy (26%). The co-benefits of carbon-price strategy would offset 22% to 42% of the increased electricity costs if the true cost of coal and the social cost of carbon are incorporated. In such a scenario, aggressive attention to research and both technological and financial innovation mechanisms are crucial to enabling the transition at a reasonable cost, along with strong carbon policies.

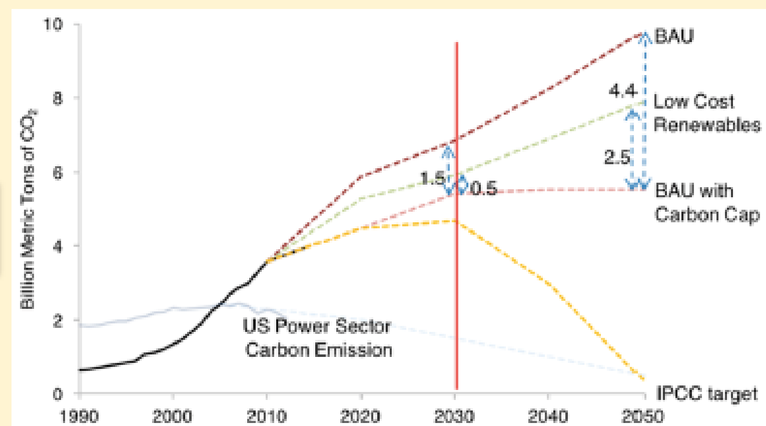
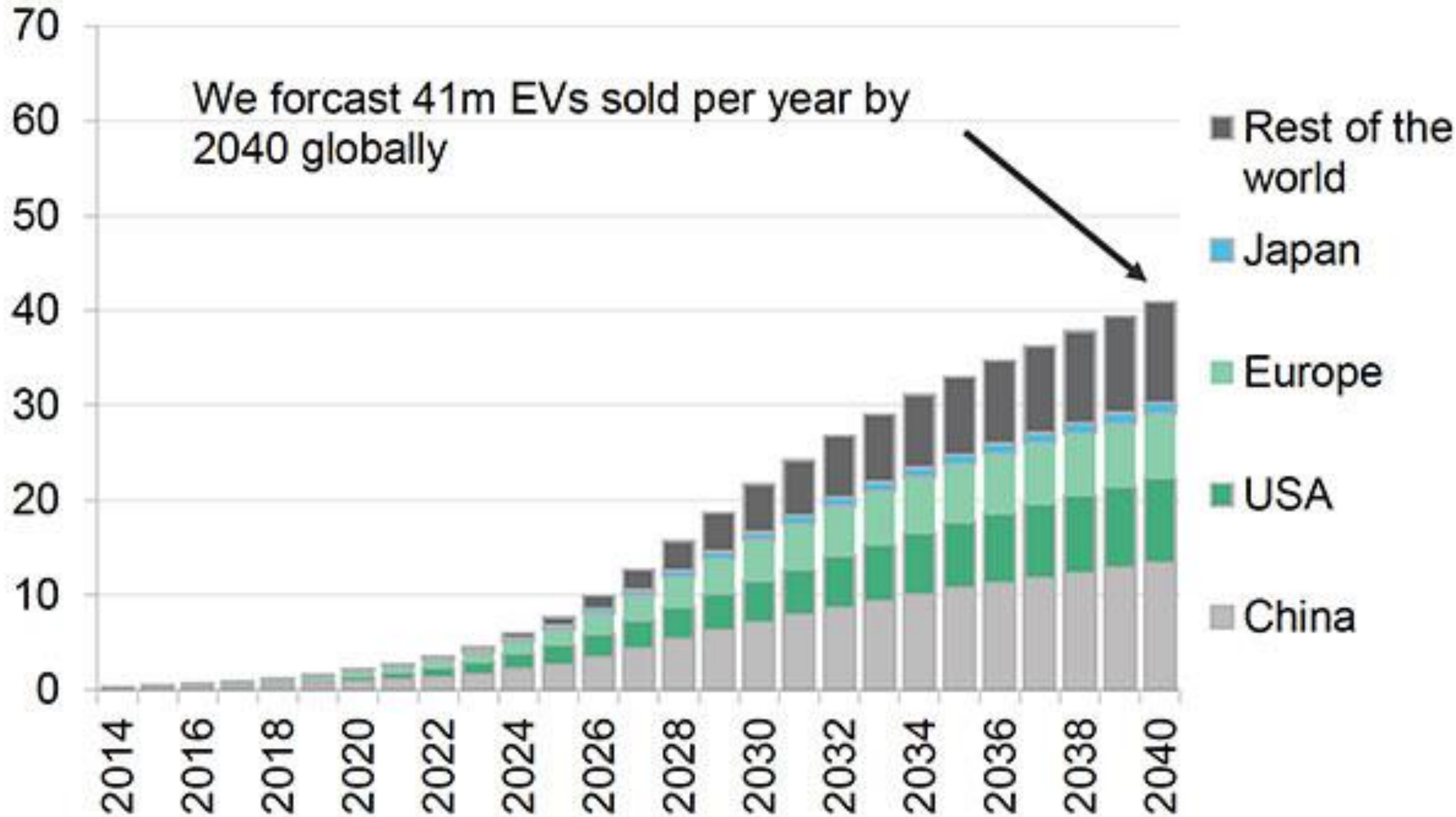


Figure 11: BNEF global EV sales forecast by geography, 2015–2040 (m vehicles per year)



Source: Bloomberg New Energy Finance, Marklines

Partnerships (examples):

State Key Laboratory of Power Transmission Equipment and System Security and New Technology
Chongqing University
重庆大学输配电装备及系统安全与新技术国家重点实验室

June 2, 2016: Saeed Mohammed Al Tayer
CEO of Dubai Electricity and Water Authority (DEWA)

BloombergMarkets | Saudi Arabia Gets Cheapest Bids for Solar Power in Auction

Saudi Arabia Gets Cheapest Bids for Solar Power in Auction

By **Anthony Dipaola**

October 3, 2017, 6:19 AM PDT *Updated on* October 3, 2017, 2:00 PM PDT

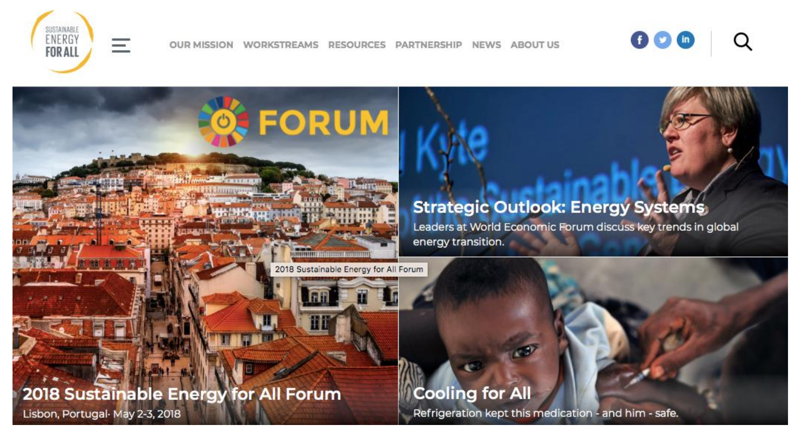
From **Climate Changed**

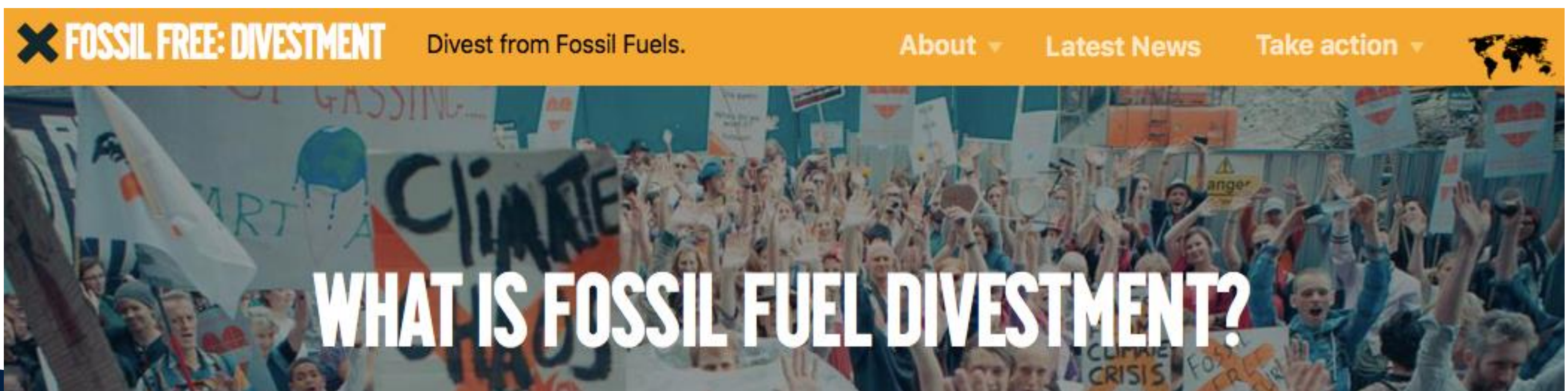
→ Masdar, EDF offer to supply power for 1.7 cents/Kilowatt hour

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

Impossible without secure mobile money

Don't forget behavior change (evolution)





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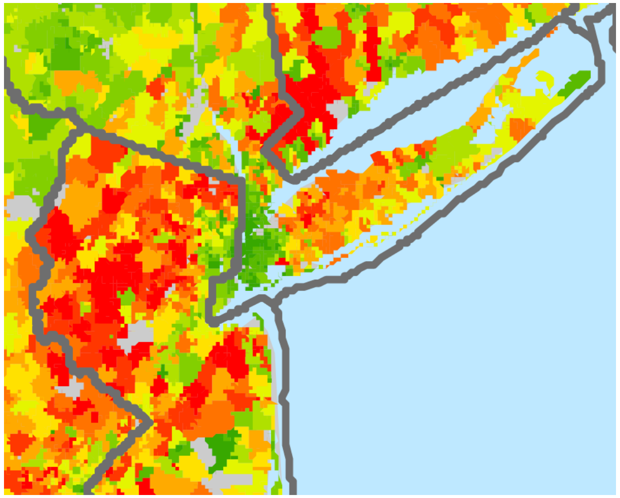
Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density

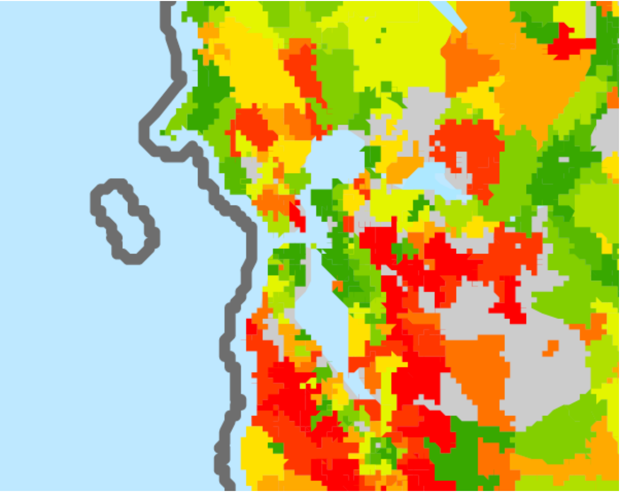
Christopher Jones*,† and Daniel M. Kammen*,†,‡,§

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

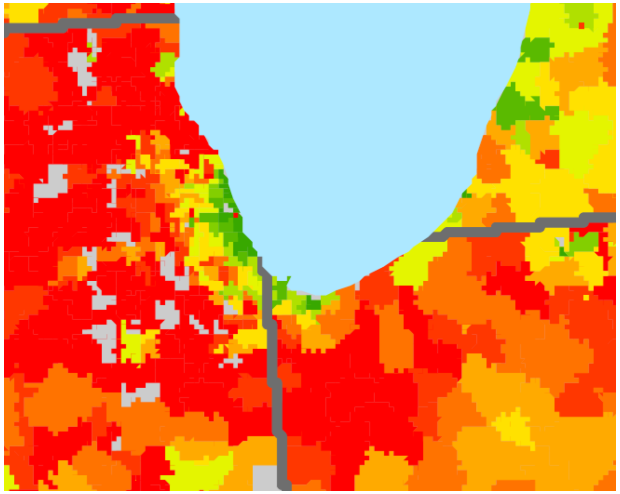
http://coolclimate.berkeley.edu/maps



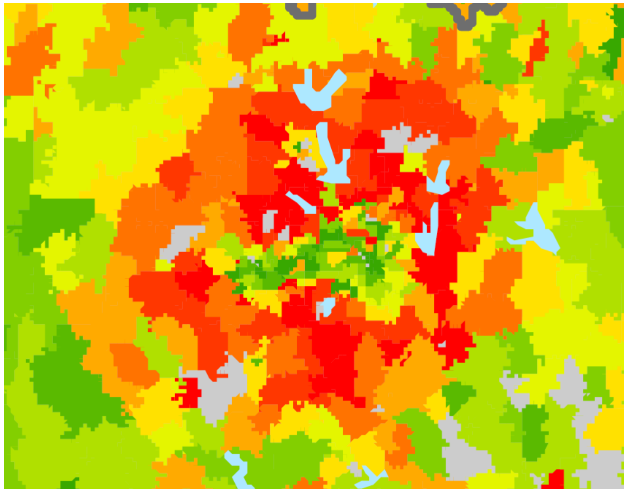
New York



San Francisco
Bay Area



Chicago



Dallas

Jones and Kammen, 2014

http://coolclimate.berkeley.edu/maps

Resources:

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