The Clean Energy Revolution is (Finally) Here

Daniel Kammen

Energy and Resources Group (Chair)
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Department of Nuclear Engineering
Director, Renewable and Appropriate Energy Laboratory
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Former Science Envoy, United States Department of State
Resources:

Website: http://rael.berkeley.edu

Twitter: @dan_kammen
RAEL: 50 PhD graduates and counting

Rick Duke, Special Advisor to Pres. Obama on Climate Change

Assoc. Prof Tracey Osborne, Geography, U of Arizona

Asst. Prof Dan Sanchez, Extension, ESPM, UC Berkeley

Prof Charles Kirubi, Environmental Studies, Kenyatta University

Asst Prof Gang He, Dept. Tech. & Society

Stony Brook University

Assoc. Prof. Donna Green, UNSW

Rebekah Shirley, Dir.

Energy Extension, Christian Casillas, U of New Mexico

Asst. Prof Derek Lemoine, Economics, U. of Arizona

Prof. Katie Purvis

Environmental Chemistry, The Claremont Colleges

Prof Tonio Buonosissi, Mechanical Eng., Dir.

Solar Materials Lab, MIT

Assoc. Prof. Joanna Lewis, Georgetown U

Prof Arne Jacobsen

Director, Schatz Energy Lab

Humboldt State U

Prof Tracey Holloway, Atmospheric Science, U Wisc. Founder, Env. Science Women’s Network

Carla Peterman, Commissioner, California Public Commission

Prof Majid Ezzati, Dir.

Global Env. Health Imperial College, London & Harvard School of Public Health

Asst Prof. Deborah Sunter, Mechanical Engineering, Tufts U. & UC Berkeley

Institute of Data Sciences Fellow

Assoc. Prof. Greg Nemet, U. Wisconsin, LaFollette School of Public Affairs & Nelson Institute

http://rael.berkeley.edu
Overview

• The climate crisis is now an (urgent) opportunity

• Infrastructure for the green energy economy

• The power the Just Transition / Green New Deal
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Energy costs (current)
Social Cost of Carbon ($50)
Global total final commercial energy consumption from non-fossil-fuel sources, 1975–2018e (28% of 2018e total)

a. Time profile

b. Components of annual change

2014 APEC Summit

https://iopscience.iop.org/article/10.1088/1748-9326/ab55ab
NDC Commitments to the Paris Accords

Kigali Accords

Needed Innovations

Paris, 2015: 2 degree objective

IPCC, 2018: 1.5 degree objective
Cumulative risks of 3°C warming

Population affected by various risks (millions of people)

- Heatwave exposure: 7,909
- Water stress: 3,920
- Risk to power production: 742
- Crop yield change: 1,817
- Habitat degradation: 1,357

Cumulative risks of 2°C warming

Population affected by various risks (millions of people)

- Heatwave exposure: 5,986
- Water stress: 3,658
- Risk to power production: 385
- Crop yield change: 362
- Habitat degradation: 680

Cumulative risks of 1.5°C warming

Population affected by various risks (millions of people)

- Heatwave exposure: 3,960
- Water stress: 3,340
- Risk to power production: 334
- Crop yield change: 35
- Habitat degradation: 91


**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.

![Graph showing CO2 emissions (Gt per year) from 1990 to 2050.](chart)

- **Historical emissions**
- **600-Gt carbon budget**
  - 2016 peak (best)
  - 2020 peak
  - 2025 peak

- **800-Gt carbon budget**
  - 2020 peak

*Data from The Global Carbon Project.*

Delaying the peak by a decade gives too little time to transform the economy.

Peaking emissions now will give us 25 years to reduce emissions to zero.
The Green Energy Economy

Global energy savings accelerated (haltingly) after 2010

Annual changes in global primary energy intensity, 1981–2018

-5.2% China -3.9% China -2.9% China
-1.3% EU -1.1% EU -1.6% EU
-2.9% US -2.2% US -0.6% US

Average annual change 1981–2010

Average annual change 2001–2015

IEA's 2016 2°C warming CO2 scenario called for 2.6%/y energy intensity drop to 2030

IEA's 2018 2°C warming CO2 scenario calls for 3.2%/y energy intensity drop to 2040

Figure 2 from "Recalibrating climate prospects"

Lovins, Ürge-Vorsatz, Mundaca, Kammen & Glassman

doi:10.1088/1748-9326/ab55ab
Daniel Kammen, Ph.D.
Berkley, California

Dear Dr. Kammen,

Please accept my deepest gratitude for the distinction with which you have represented our country and my Administration as a Science Envoy.

Embodying the spirit of service and the search for shared values that speak to our common interests and humanity, you’ve helped promote the advancement of science, diplomacy, and partnership between nations and strengthen our country’s standing in the world. I want you to know how much I have appreciated your work and the role it has played in our efforts to bring about a future of greater possibility, both here at home and across the globe.

Again, thank you for endeavoring alongside me to demonstrate that there is far more that unites us than that divides us and to bring us closer to a tomorrow that reflects this essential truth. You have my very best wishes for all that lies ahead.

Sincerely,

[Signature]
J.K. Rowling @jk_rowling
I wonder whether there's anyone left in America who doesn't know what an acrostic is.

Daniel M Kammen @dan_kammen
Mr. President, I am resigning as Science Envoy. Your response to Charlottesville enables racism, sexism, & harms our country and planet. pic.twitter.com/eWzDc5Yw6t

Daniel M Kammen @dan_kammen
Mr. President, I am resigning as Science Envoy. Your response to Charlottesville enables racism, sexism, & harms our country and planet.

embassies abroad, we have built significant partnerships in North and East Africa, and in the Middle East, around shared visions of national security, job creation in the U.S. and sustainable energy.

My decision to resign is in response to your attacks on core values of the United States. Your failure to condemn white supremacists and neo-Nazis has domestic and international ramifications. On this issue, I stand with the unequivocal and authoritative statements of Charlottesville Mayor Mike Signer, Virginia Governor Terry McAuliffe, Ohio Governor John Kasich, Senator John McCain, Congresswoman Ileana Ros-Lehtinen, Governor Arnold Schwarzenegger, Presidents George H.W. Bush and George W. Bush, Dr. Cornel West, Linda Sarsour, the Palestinian-American activist and one of the organizers of the Women’s March, and many others.

Particularly troubling to me is how your response to Charlottesville is consistent with a broader pattern of behavior that enables sexism and racism, and disregards the welfare of all Americans, the global community and the planet.

Examples of this destructive pattern have consequences on my duties as Science Envoy. Your decision to abdicate the leadership opportunities and the job creation benefits of the Paris Climate Accord, and to undermine energy and environmental research are not acceptable to me.

Acts and words matter. To continue in my role under your administration would be inconsistent with the principles of the United States Oath of Allegiance to which I adhere.
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California Energy Goals: Aggressive & Evolving

2013: 20%
2020: 33%
2030: 60%

California Senate Bill 100: 100% clean energy by 2045 and 2030 standard now 60% (without nuclear or large hydro)
California Climate Laws

Senate Bill 100:
100% green energy in 2045

Senate Bill 32:
Cap & Trade carbon market

Senate Bill 375:
Vehicle miles must be offset

Solar Mandate:
1 million solar roofs by 2020

EV Mandate:
1 million EVs by 2020
California Energy Efficiency Policy Drives Innovation

Residential New Construction

- All new residential construction in California will be zero net energy by 2020.
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.
Community Groups: blueEnergy, Energy Peace Partners, GRID Alternatives, givepower, SAFE Rivers

Businesses: dissigno, Natel Energy, HumanNeeds, VIRUNGA POWER, Google, KUBE ENERGY, INYENYERI

Nations: China, Malaysia, United States, Colombia, Mexico, Congo, Democratic Republic of Congo, Kenya, Uganda, California

Institutions: AAS, Power Africa, Sustainable Energy for All
RAEL’s "SWITCH" Power System Models to Plan the Clean Energy Transition

WECC (Western North America)

Chile

Mexico - in progress

Kosovo

Nicaragua

East African Power Pool (EAPP):
1. Kenya
2. Planned: Uganda & Tanzania

India & Bangladesh in progress

China

Malaysian Borneo

Mexico - in progress

http://rael.berkeley.edu/edu/project/SWITCH
The SWITCH Modeling Framework

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

\[
\min \text{ NPV} \sum_{i,k=1}^{n,m} TC_k(c_i)
\]

Total Cost \( TC_k = \text{Capital Cost}_i \times \text{Capacity} (c_i) + [\text{Variable Cost}_i \times \text{Capacity} (c_i) \times CF_i \times 8760] \)

\[
\sum_{i=1}^{n} \text{Capacity} (c_i) \times \text{Peak Contribution}_i \geq \text{Annual Peak Demand} \times [1 + \text{Reserve Margin}]
\]

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

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

Total Resource Potential \_i \geq \sum_{k=1}^{m} \text{Capacity} (c_i)
\[
\frac{C_2}{C_1} = \left(\frac{V_2}{V_1}\right)^b
\]
Two-factor learning curves: manufacturing and R&D

Deployment as a function of cost and R&D ... a better fit

\[
\frac{C_2}{C_1} = \left( \frac{V_2}{V_1} \right)^{-b} \left( \frac{[R&D]_2}{[R&D]_1} \right)^{-a}
\]

Well ...
Dispatch in 2050:
Flexibility and variable renewables dominate

- Storage almost exclusively moves solar to the night
- Geothermal only remaining substantial baseload
California Advancing Energy Efficiency

Figure 2: The duck curve shows steep ramping needs and overgeneration risk

Net load - March 31

- Ramp need ~13,000 MW in three hours
- Overgeneration risk
California Advancing Energy Efficiency

New Max. Gen. = 21,740 MW

Min. Gen. = 15 GW
From the SWITCH Model to Implementation

California’s (2020) 2% Peak Demand Storage Requirement

EnerVault Iron-Chromium Technology

1 MW-hr capacity at 250 kW (4 hour duration)

Turlock, CA
The SWITCH Modeling Framework

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

\[
\min_{(c_{i})} \sum_{i=1}^{nm} TC_k (c_i)
\]

Total Cost \( TC_k = \text{Capital Cost}_i * \text{Capacity} (c_i) + [\text{Variable Cost}_i * \text{Capacity} (c_i) * CF_i * 8760] \)

\[
\sum_{i=1}^{n} \text{Capacity} (c_i) * \text{Peak Contribution}_i \geq \text{Annual Peak Demand} * [1 + \text{Reserve Margin}]
\]

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

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

\[
\text{Total Resource Potential}_i \geq \sum_{k=1}^{m} \text{Capacity} (c_i)
\]
Visiting Scholars Participating in RAEL-China Research Partnership

Professor Zechun Hu 2018
Professor Minyou Chen 2018, 2019
Ziming Ma, PhD Student 2018 - 2019
Bo Li, PhD Student 2019
Dongran Liu, PhD Student 2019 - 2020
Guangzhi Yin, PhD Student 2019 - 2020
Xiaoli Zhang, PhD Student 2019 - 2020
China’s Energy Future

**SWITCH China model**

- Capacity expansion deterministic linear program

- Minimizes total cost of the power system:
  - Generation investment and operation
  - Transmission investment and operation
  - New module: CO$_2$ emission cost

Geographic:
- 31 load areas

Temporal:
- 144 hours simulated for each period (516 hours in total)
  - Dispatch simulated simultaneously with investment decisions
Led by Dr Cheng Zheng, CEO, Aspiring Citizens Cleantech (ACC), Chengdu, China & Gordon Bauer & Daniel Kammen (ERG, UC Berkeley)

100% EV taxi fleet in Shenzhen, China (25,000+ vehicles) 24 month fleet conversion
Optimized dispatch (with a simple app): 50% reduced delay time
Optimized dispatch improves charger economics
Optimized charging time: removing shift change constraint reduces charging burden by up to 90%

- Drivers prefer to change shift with full battery charge, creating inefficient charging behavior

- Peak charging occurs during peak demand, leading to lost revenue

Results:

- Enabling drivers to change shift at ~75% SOC reduces charging burden by almost 50%

- If drivers also take advantage of break times to charge, they can reduce charging burden by 90%

Drivers who change shift at 60-80% SOC charge during lunch and earn more money
Electricity for All: Issues, Challenges, and Solutions for Energy-Disadvantaged Communities

Volume 107, Issue 9 | September 2019

- Guest Editors
- Special Issue Papers

Guest Editors:

Claudio Cañizares
Jatin Nathwani
Daniel Kammen

POWER DECISIONS
Plans to double the number of large hydropower dams on the Mekong River mean that migrating fish and sediment will be unable to reach the delta. Solar power, as well as wind and other renewables, can complement or replace dams with less impact — if such schemes are well planned.

Dams upstream of existing projects block less sediment.

Mekong basin region
Rivers and tributaries

Dam sites (megawatts)

<table>
<thead>
<tr>
<th>Built</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;251</td>
</tr>
<tr>
<td></td>
<td>251-1,000</td>
</tr>
<tr>
<td></td>
<td>1,001-2,500</td>
</tr>
<tr>
<td></td>
<td>&gt;2,500</td>
</tr>
</tbody>
</table>

Photovoltaic potential (kilowatt hours per m² per day)

High

Low

A few square kilometers of solar panels can match a dam’s power.

The proposed Sambor dam would stop fish migration and most of its power would be exported.

Nature publications remain subject to regional and intercontinental claims in published maps.

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The power the Just Transition / Green New Deal
Is US residential solar just for the rich?

By Danielle Ota  Apr 21, 2017 11:15 AM BST 0

Solar Is Not

THE WALL STREET JOURNAL

Solar Subsidies Take Money From the Poor to Help the Rich
Sunroof Data

- Millions of oblique images acquired, processed, and refined.
Large Racial disparity in solar – even at same income

Solar Installations by Racial Composition in Identified Tracts

<table>
<thead>
<tr>
<th>Race</th>
<th>Existing Installations</th>
<th>No Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>76%</td>
<td>24%</td>
</tr>
<tr>
<td>Asian</td>
<td>83%</td>
<td>17%</td>
</tr>
<tr>
<td>White</td>
<td>79%</td>
<td>21%</td>
</tr>
</tbody>
</table>
In one year a youth movement on climate went from

From this

To this

Four million people
September 20 – 27: a week of action
Expectations locally to globally
Environmental Justice

- Lack of EV access where the health benefits are highest
- CA Green New Deal: Dedicated seed fund of $3.5 billion/yr for disadvantaged areas
- CA SB50 (housing access at transit hubs): bill failed 2x

Opinion
Why Housing Policy Is Climate Policy

In California, where home prices are pushing people farther from their jobs, rising traffic is creating more pollution.

By Scott Wiener and Daniel Kammen
Senator Wiener is the chairman of the California Senate’s Housing Committee. Dr. Kammen is a professor of energy at the University of California, Berkeley.

March 25, 2019
Displacement Typologies

Lower income (LI) tracts
1. Not losing LI households
2. At risk of gentrification and displacement
3. Ongoing Gentrification/Displacement

Moderate to high income (MHI) tracts
1. Advanced gentrification
2. Not losing LI households
3. At risk of exclusion
4. Ongoing Exclusion/Displacement
5. Advanced exclusion

http://www.urbandisplacement.org/map/sf
EcoBlock Vision: A Multi-Customer Microgrid Solution

Electrical system combines DER

- Communal rooftop solar PV
- Communal energy storage system (flywheel and/or battery)
- Intelligent loads and electric demand response
- Shared Electric vehicle (EV) charging
- Smart controls in a direct-current (DC) microgrid infrastructure

behind a single interconnection with PG&E
EcoBlock Vision: Different possible topologies for AC and DC power sharing

1. Central DC for EVs + power to grid AC
2. Islanded DC/AC microgrid
3. Fully islanded DC microgrid
4. Fully islanded DC microgrid (plus convenience AC)

Project Team selected Option 2 as most appropriate for the first Pilot EcoBlock.

Different topologies may fit different situations.
Electricity

• System Architecture
  ➢ ~200 kW PV DC microgrid based on utility backbone with single inverter connection to the grid
  ➢ Charging stations for shared EVs – or Individual charging stations
  ➢ 10 x 25 kWh/10 kW flywheel storage
• Estimated ~250 to 300 MWh/year PV production.
Kibera Town Women’s Center, Nairobi: Microgrid franchise model leverages community energy

- Largest slum in Africa
- Minimal infrastructure
- Unmet energy demand
- Leverage Women’s resource center (600 users/day)
- Women’s resource center opens 2017
- Community training center
- Hub of franchise model for community micro-grid
The Green Energy Economy

RENWABLE BONDS

With solar and wind booming, the chemical industry dabbles with forgoing petroleum as its feedstock

By Robert R. Service

U.S. deployment of renewable energy

Total electrical generation capacity (gigawatts)


Onshore wind power
Utility-scale solar panels

U.S. cost of renewable energy

Cost per energy ($/megawatt hour)


Onshore wind power
Utility-scale solar panels
The Green Energy Economy

Better living through renewables
Industrial chemists make most molecules by breaking down and refining hydrocarbons in oil and natural gas into smaller compounds. Researchers now want to use renewable electricity to energize simple starting materials such as water and carbon dioxide (CO₂) and stitch the pieces together into the same compounds.

Steam cracking
Today, ethylene, which forms the basis of many plastics, is made by steam cracking. Typically, a feedstock of ethane and steam go into a furnace at up to 850°C. The heat tears a pair of hydrogen (H₂) atoms from ethane to make ethylene, which is then separated out in compression and distillation chambers.

Electrosynthesis
This newer, low-temperature approach uses electricity—ideally from solar and wind power—and a metal catalyst to split apart water and CO₂ molecules, generating H₂ and carbon monoxide. Electricity and catalysts then recombine those pieces to make ethylene gas and liquid ethanol.

Low temperature (80 C+)  High temperature (400 C+)
Thank you

- Twitter: @dan_kammen
- http://rael.berkeley.edu