Confronting Climate Gridlock

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About the speaker

- Associate Professor of Civil and Environmental Engineering at Rice
  - At Rice since 2006
  - A&WMA member
- National Science Foundation CAREER award
- 50+ peer-reviewed publications, 70+ op-eds
- Website: cohan.rice.edu
Available in hardcover, Kindle, Nook, and audio book

Amazon Hot New Releases

New Releases in Environmental Policy

#1
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Adam M. Sowards
Hardcover
$56.00

#2
Ever Green: Saving Big Forests to Save the Planet
John W. Reid
Hardcover
$27.99

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Daniel S. Cohen
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#4
Is Science Enough?: Forty Critical Questions About Climate Justice (Myths Made in America)
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Katharine Hayhoe
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Eugene Linden

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Supercharge Me: Net Zero Faster
Eric Lonergan

#8
Is Science Enough?: Forty Critical Questions About Climate Justice
Aviva Chomsky

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To Govern the Globe: World Orders and...
Alfred W. McCoy

#10
Fire and Flood: The True History of Our Epic...
Eugene Linden

Amazon: https://www.amazon.com/Confronting-Climate-Gridlock-Diplomacy-Technology/dp/030025167X/
Other options: https://yalebooks.yale.edu/book/9780300251678/confronting-climate-gridlock/
Three keys to confronting gridlock: Diplomacy, Technology, and Policy

Book draws from >100 interviews with diplomats, scholars, innovators, etc.
How the Keys Interact to Unlock Climate Gridlock

- Technology
  - Enables more ambitious policy
  - "Regulation breeds innovation"
  - Provides clout and credibility
  - Impels and leverages action
  - Fosters collaboration
- Diplomacy
  - Enables others to do more
- Policy

"Regulation breeds innovation"
Temperatures are nearing Paris Agreement limits

http://berkeleyearth.org/global-temperature-report-for-2021/
Global fossil CO$_2$ emissions: 34.8 ± 2 GtCO$_2$ in 2020, 53% over 1990
Projection for 2021: 36.4 ± 2 GtCO$_2$, 4.9% [4.1%–5.7%] higher than 2020

The 2021 projection is based on preliminary data and modelling.
Source: Friedlingstein et al 2021; Global Carbon Project 2021
Global fossil CO$_2$ emissions are projected to increase by 4.9% [4.1%–5.7%] in 2021. The 2021 projections are based on preliminary data and modelling.

Second-largest emitter, but 14% and falling

Source: Friedlingstein et al 2021; Global Carbon Project 2021
Fossil CO₂ Emissions per capita

Annual Fossil CO₂ Emissions: per capita (selected countries)

U.S. has declined but leads all major nations

- USA 14.2 tonnes/person in 2020
- Russia 10.8
- Japan 8.1
- China 7.4
- EU27 5.8
- World 4.5
- India 1.8

Source: Friedlingstein et al 2021; Global Carbon Project 2021
Worst-case scenarios avoided, but not on track for 1.5-2°C
Net-zero in U.S. isn’t enough

C-ROADS Base case

C-ROADS with U.S. nearing net-zero

Need to decarbonize energy affordably, reliably, and fast, in ways that make it achievable globally

C-ROADS: Climate Interactive [https://c-roads.climateinteractive.org/]
Still, U.S. is crucial

- Most emissions historically and per-capita
- Largest economy and consumer market
- Leads in technology development
- Leading driver and barrier to diplomacy
- Need to make clean energy cheap here so it can be deployed elsewhere
  - Learning by doing drives down cost and improves performance
The Technology Key
Energy transitions historically have been slow

Past energy transitions took 50+ years. Can we decarbonize the economy by 2050?

https://www.eia.gov/todayinenergy/detail.php?id=26912
Baseline projections expect fossil fuels to remain dominant

U.S. EIA, Annual Energy Outlook 2022
Some technology transitions have been incredibly fast

Outlooks are often wrong! E.g., overpredicted coal…

Image from Zeke Hausfather, @hausfath
... And underpredicted renewables
Even optimists failed to foresee cost declines in solar

Solar Costs Are Decades Ahead of Forecasts

Cost Forecasts
Source + Year Made

Actual Costs

Ramez Naam - rameznaam.com

Slides from Ramez Naam: https://rameznaam.com/2020/05/14/solars-future-is-insanely-cheap-2020/
Learning curves: Costs tend to fall ~18% per doubling in deployment

Solar prices on a log scale (each tick mark is a doubling)

Each tick mark is a doubling in global cumulative solar

Slides from Ramez Naam: https://rameznaam.com/2020/05/14/solars-future-is-insanely-cheap-2020/
Learning curves for the Model T

Figure 1. The price of the Ford Model T from 1909-1923[2].

Slides from Ramez Naam: https://rameznaam.com/2020/05/14/solars-future-is-insanely-cheap-2020/
Steps toward decarbonization

United States Mid-Century Strategy for Deep Decarbonization (White House, Nov. 2016)
Pillars of clean energy

Roles for the pillars of clean energy:

- **Efficiency**: Shrinks all boxes
- **Clean electricity**: Cleans up area below the electric frontier
- **Electrification**: Moves up the electric frontier
- **Other clean fuels**: Decarbonizes above frontier
- **Carbon sinks**: Offset the emissions that remain

NREL Electrification Futures Study
Decarbonizing Electricity: Options

All renewables and nuclear have far lower life cycle emissions than any fossil fuel.
Wind and solar are least cost

## Levelized Cost of Energy Comparison—Unsubsidized Analysis

Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Existing</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV—Rooftop Residential</td>
<td>$147</td>
<td>$221</td>
</tr>
<tr>
<td>Solar PV—Rooftop C&amp;I</td>
<td>$67</td>
<td>$180</td>
</tr>
<tr>
<td>Solar PV—Community</td>
<td>$59</td>
<td>$91</td>
</tr>
<tr>
<td>Solar PV—Crystalline Utility Scale</td>
<td>$30</td>
<td>$41</td>
</tr>
<tr>
<td>Solar PV—Thin Film Utility Scale</td>
<td>$28</td>
<td>$37</td>
</tr>
<tr>
<td>Solar Thermal Tower with Storage</td>
<td>$126</td>
<td>$156</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$56</td>
<td>$93</td>
</tr>
<tr>
<td>Wind</td>
<td>$25</td>
<td>$50</td>
</tr>
<tr>
<td>Gas Peaking</td>
<td>$151</td>
<td>$196</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$131</td>
<td>$204</td>
</tr>
<tr>
<td>Coal</td>
<td>$152</td>
<td>$204</td>
</tr>
<tr>
<td>Gas Combined Cycle</td>
<td>$129</td>
<td>$204</td>
</tr>
</tbody>
</table>

Sources: Lazard estimates.

Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 90% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled “Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital” for cost of capital sensitivities. These results are not intended to represent any particular geography. Please see page titled “Solar PV versus Gas Peaking and Wind versus CCGT—Global Markets” for regional sensitivities to selected technologies.

1. Unless otherwise indicated herein, the low case represents a single-axis tracking system and the high case represents a fixed-tilt system.
2. The fuel cost assumption for Lazard’s global, unsubsidized analysis for gas-fired generation resources is $3.45/MMBTU.
3. The fuel cost assumption for Lazard’s global, unsubsidized analysis for gas-fired generation resources is in the range of $2.50 – $3.60/MMBTU.
4. Unless otherwise indicated, the analysis herein does not reflect decommissioning costs, ongoing maintenance-related capital expenditures or the potential economic impacts of federal loan guarantees or other subsidies.
5. Represents the midpoint of the marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper- and lower-quartile estimates derived from Lazard’s research. Please see page titled “Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation” for additional details.
6. High and incorporates 90% carbon capture and storage. Does not include cost of transportation and storage.
7. Represents the LCCO of the observed high case gas combined cycle inputs using a 20% blend of “Blue” hydrogen, i.e., hydrogen produced from a steam-methane reformer using natural gas as a feedstock, and sequestering the resulting CO2 in a nearby saline aquifer. No plant modifications are assumed beyond a 2% adjustment to the plant’s heat rate. The corresponding fuel cost is $5.20/MMBTU, assuming $1.39/kg for Blue hydrogen.
8. Represents the LCCO of the observed high case gas combined cycle inputs using a 20% blend of “Green” hydrogen, i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern. No plant modifications are assumed beyond a 2% adjustment to the plant’s heat rate. The corresponding fuel cost is $10.05/MMBTU, assuming $4.15/kg for Green hydrogen.

**Lazard 2021, Unsubsidized levelized cost of electricity**
Wind costs have fallen 72%, and solar 90% since 2009

Lazard 2021, Unsubsidized levelized cost of electricity
Wind and solar costs down, nuclear and coal up since 2009

Levelized Cost of Energy Comparison—Historical Utility-Scale Generation Comparison

Lazard’s unsubsidized LCOE analysis indicates significant historical cost declines for utility-scale renewable energy generation technologies driven by, among other factors, decreasing capital costs, improving technologies and increased competition.

Selected Historical Mean Unsubsidized LCOE Values

<table>
<thead>
<tr>
<th>Technology</th>
<th>2009 LCOE ($/MWh)</th>
<th>2020 LCOE ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>$359</td>
<td>$179</td>
</tr>
<tr>
<td>Coal</td>
<td>$275</td>
<td>$272</td>
</tr>
<tr>
<td>Wind</td>
<td>$248</td>
<td>$76</td>
</tr>
<tr>
<td>Solar PV</td>
<td>$135</td>
<td>$82</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>$123</td>
<td>$71</td>
</tr>
<tr>
<td>Gas Peaker</td>
<td>$111</td>
<td>$68</td>
</tr>
<tr>
<td>Solar Peaker</td>
<td>$100</td>
<td>$59</td>
</tr>
<tr>
<td>Gas-Crystalline</td>
<td>$91</td>
<td>$47</td>
</tr>
<tr>
<td>Geothermal</td>
<td>$80</td>
<td>$42</td>
</tr>
<tr>
<td>Combined Cycle</td>
<td>$79</td>
<td>$40</td>
</tr>
<tr>
<td>Coal Peaker</td>
<td>$74</td>
<td>$37</td>
</tr>
</tbody>
</table>

Lithium-ion battery costs

Battery pack price (real 2020 $/kWh)

Note: Pack price across passenger EVs, e-buses, commercial EVs and stationary storage. In EVs, the pack consists of cells, module housing, battery management system (BMS), wiring, pack housing and thermal management system. For stationary storage, we consider the equivalent to be the battery rack.

2014: Renewables, nuclear, and carbon capture pathways all seemed plausible

Figure 29. 2050 Electric Generation by Resource Type

Nuclear scenario modeled to be least cost in 2014
2020: Solar and wind lead in all net-zero pathways

Solar and wind generated electricity have dominant roles in all net-zero pathways

- Share of electricity from carbon-free sources roughly doubles from ~37% today to 70-85% by 2030 and reaches 98-100% by 2050.
- Wind + solar grows >4x by 2030 to supply ~½ of U.S. electricity in all cases except E+RE-; in that case, growth is constrained, but still triples by 2030 to supply ⅓ of electricity.
- By 2050, wind and solar supply ~85-90% of generation in E+, E-, and E-B+. In E+RE-, 44%; in E+RE+, 98%.
Land Use for Solar, Wind, and Biomass in net-zero scenarios

Total land area/visual footprint in 2050 for solar, wind, and biomass across scenarios is 0.25 to 1.1 million km².

Note: In these maps, the sum of land areas of colored states is roughly the same as the area nationally of the indicated uses.

Equivalent land area for
- Solar farms
- Wind farms
- Biomass farms*
- Direct air capture

Note: Directly impacted land area for wind farms (equipment footprint) is indicated by . For solar and biomass, directly impacted areas are 92% and 100% of shaded area shown.

* On lands converted from food production.

Emerging option: Enhanced geothermal

Google Taps Fervo Energy To Develop Enhanced Geothermal Systems in Nevada

CLIMATE CHANGE

What it will take to unleash the potential of geothermal power

Four new pilot plants funded by the US infrastructure bill could help expand the range of the “forgotten renewable.”

Deep Energy and Eavor forms partnership to deploy closed-loop geothermal technology

Criterion Energy Partners secures strategic investment for geothermal project
Electrification: Shifting the electric frontier

Roles for the pillars of clean energy:
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NREL Electrification Futures Study
How homes are heated in U.S.

Mostly electricity in the South (~60% electric in Texas)

Mostly natural gas in the Midwest

Mostly natural gas in the West

Mostly natural gas and fuel oil in the Northeast

Figure 4. Natural gas is the most-used heating fuel in heated homes in three of four Census regions. Main space heating fuel by Census region.

EIA 2015 Residential Energy Consumption Survey
Transition to electric heat pumps in most net-zero strategies

Space heating

Water heating

Policies can create virtuous cycle of technology learning curves

• ↑Production ▼↓Cost ▲ ↑Production ▲ ....

• “Technology push” policies: RD&D lowers cost of a technology (↓Cost)

• “Market pull” policies: Create demand for a product (↑Production)
  – Procurement: e.g., Government fleet
  – Incentives: e.g., electric car tax credits
  – Mandates: e.g., California new home solar
  – Emissions taxes
Take-home messages

• Decarbonizing the U.S. is necessary but not sufficient for decarbonization globally
• Efficiency, clean electricity, and electrification are pillars of clean energy
• Solar, wind, EVs, and heat pumps likely to lead the way
• Need to create virtuous cycles of learning by doing to drive technologies forward