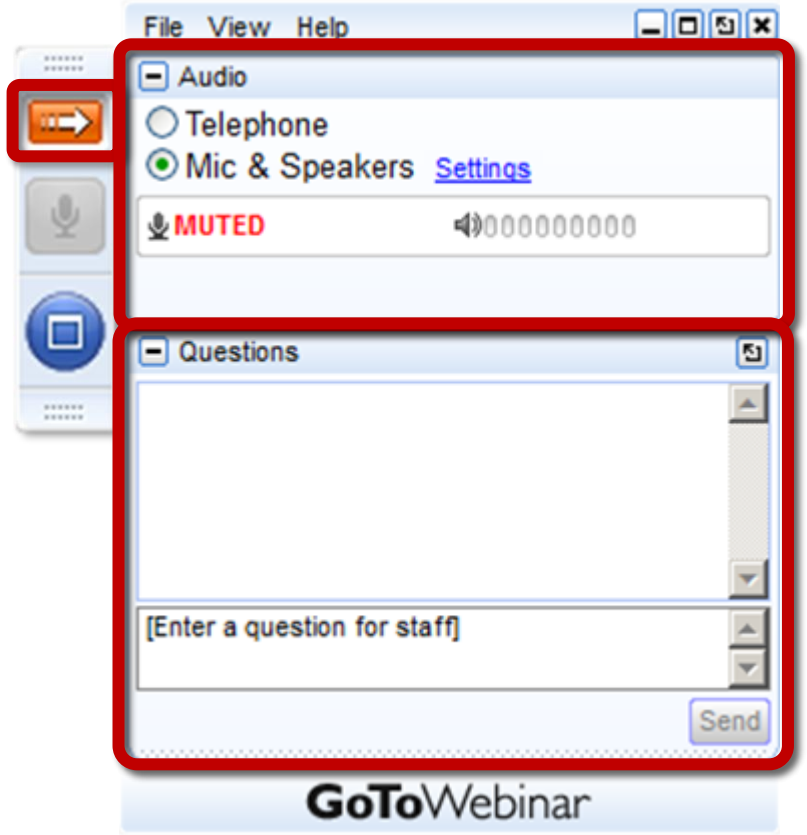
How Green is Blue Hydrogen?

Study Finds Hydrogen Produced with CCS Produces High Emissions

CleanEnergy Group

September 7, 2021

WEBINAR LOGISTICS



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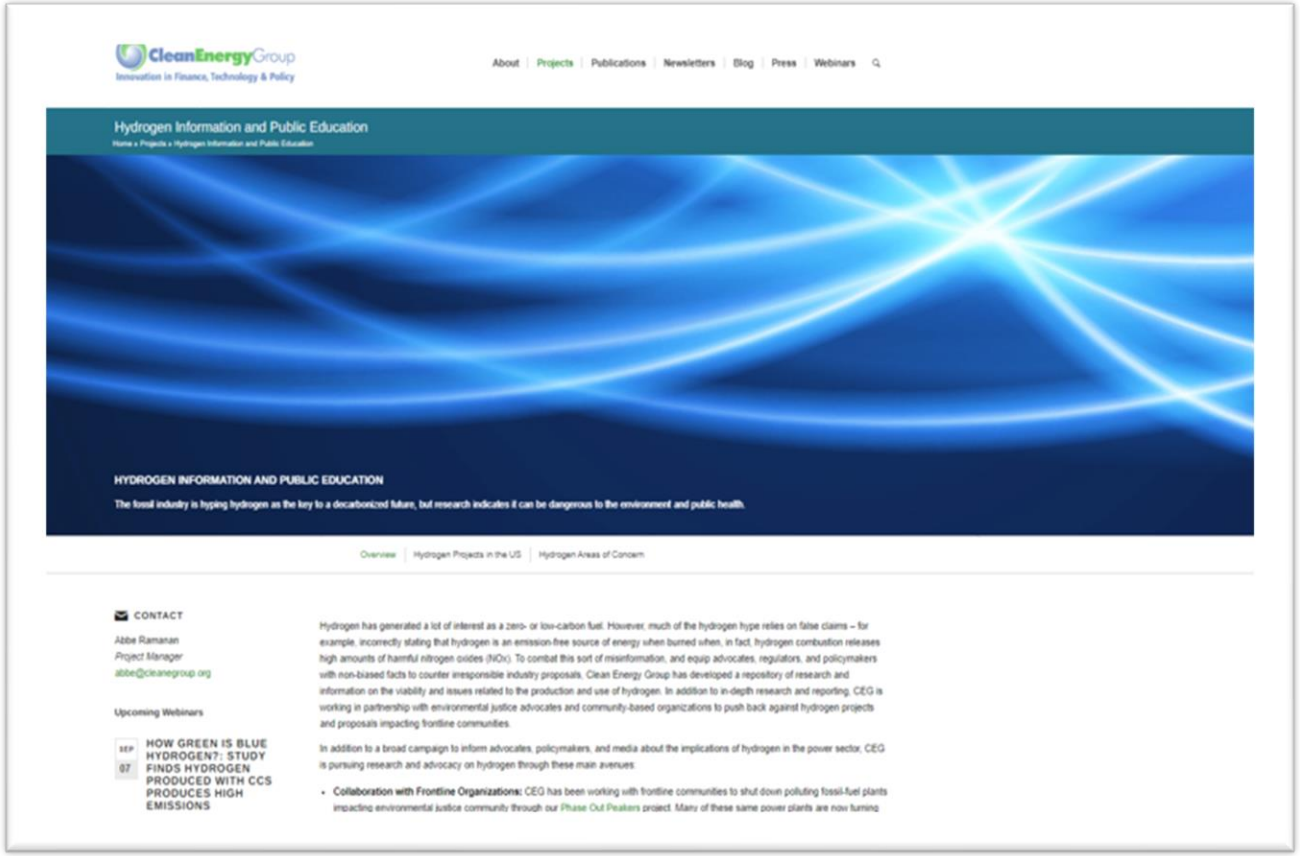
HYDROGEN INFORMATION AND PUBLIC EDUCATION (HIPE)

- Newly launched webpage with links to resources
- Continuously updated list of hydrogen projects in the U.S.
- Developing independent guidance for policymakers, regulators, and advocates in communities facing hydrogen project proposals
- Pursuing research on:
  - NOx emissions
  - Water usage in green hydrogen production
  - Renewables use



www.cleanegroup.org/ceg-projects/hydrogen

WEBINAR SPEAKERS

Abbe Ramanan
Project Manager,
Clean Energy Group
(moderator)

Mark Jacobson
Professor of Civil and Environmental Engineering and Director of the Atmosphere/Energy Program, Stanford University

How Green is Blue Hydrogen

Mark Z. Jacobson
Stanford University

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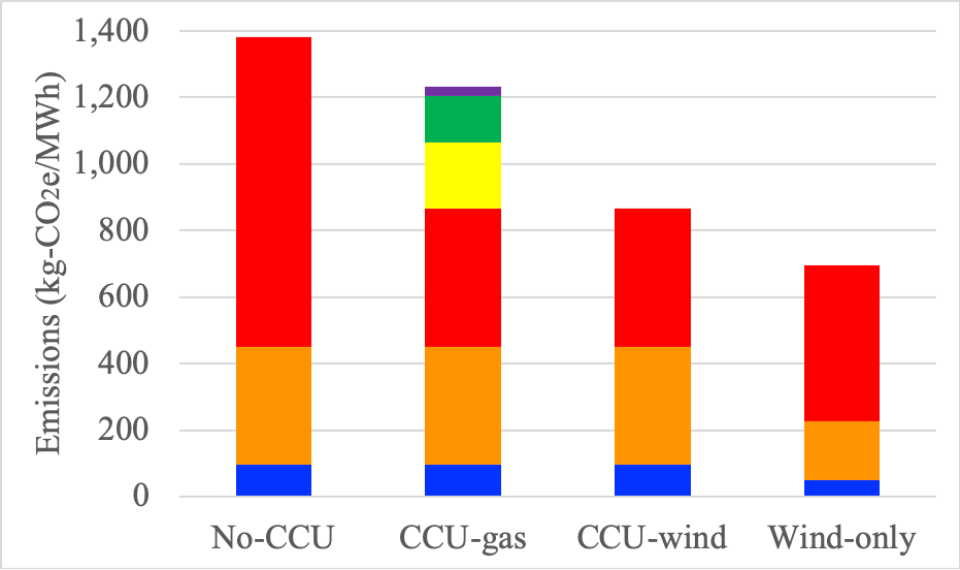
Why Not Carbon Capture?

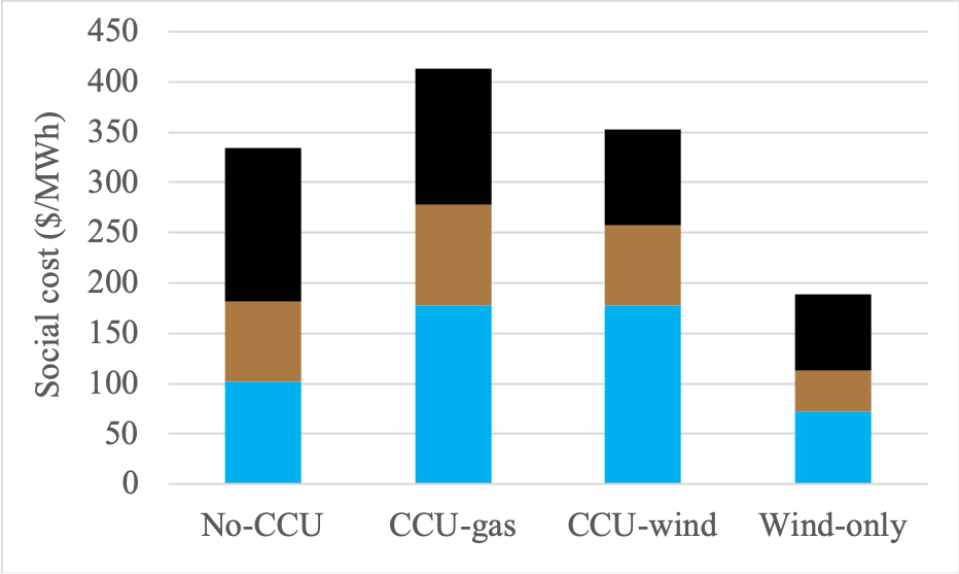
Coal Plant With CCU Powered by Natural Gas

Units: kg-CO_2e/MWh	20 yr	100 yr
a) Upstream CO_2 and leaked CH_4 from coal	450	237
b) CO_2 from stack	931	931
c) CO_2 captured from stack by equipment	516	516
Percent of stack CO_2 captured (c/b)	**55%**	**55%**
CO_2e emitted by natural gas mining+combustion	367	283
e) Captured CO_2e not returned to air by natgas (c-d)	149	233
Percent CO_2e reduction realized e/(a+b)	**10.8%**	**20%**

CCU attached to coal plant reduces only 11-20% of CO_2e it is expected to over 20-100 y

Change in CO_2e and Social Cost in 3 CCU Cases





1st case coal-No-CCU; 2nd: Coal-CCU powered by natural gas;

3rd : Coal-CCU powered by wind; 4th: replace coal with wind

Blue=upstream coal non-CH_4 CO_2e; Orange=coal upstream CH_4 CO_2e; Red=coal CO_2; Yellow=nat gas CO_2;

green=Natgas CO_2e from CH_4 leaks; Purple=other natgas upstream CO_2e;

Light blue=elec+CCU cost; Brown=air pol cost; Black=climate cost

Summary of CCS/U

- Using natural gas to run coal-CCU reduces CO_2e only 11.8-20% over 20-100 years while increasing air pollution and mining 25% and incurring a CCU equipment cost
- Using wind to run coal-CCU reduces CO_2e only 34-44% while keeping air pollution and mining the same, while incurring equip cost
- Using same wind to replace coal reduces CO_2 emissions, air pollution emissions, and mining 49.7% and has no CCU equipment cost

Why Not Synthetic Direct Air Carbon Capture and Storage?

Opportunity Cost of SDACCS

- WWS energy technologies do the same thing as SDACCS
  - Prevent carbon from getting into air rather than remove it

But WWS also eliminates or reduces

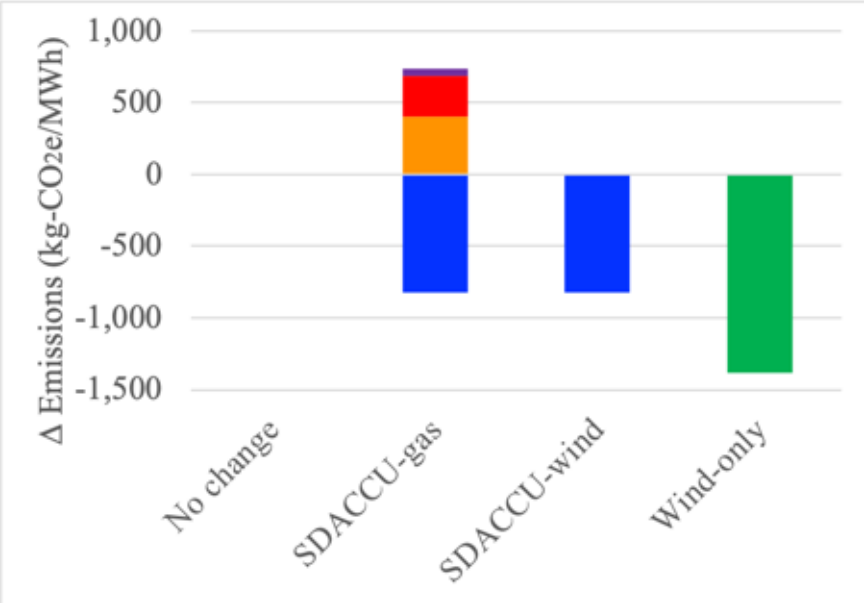
a) non-CO_2 air pollutants from fossil combustion
b) upstream fuel mining and pollution
c) pipeline, refinery, gas station, etc. infrastructure
d) oil spills, oil fires, gas leaks, gas explosions
e) International conflicts over energy
f) Blackout risk by decentralizing power

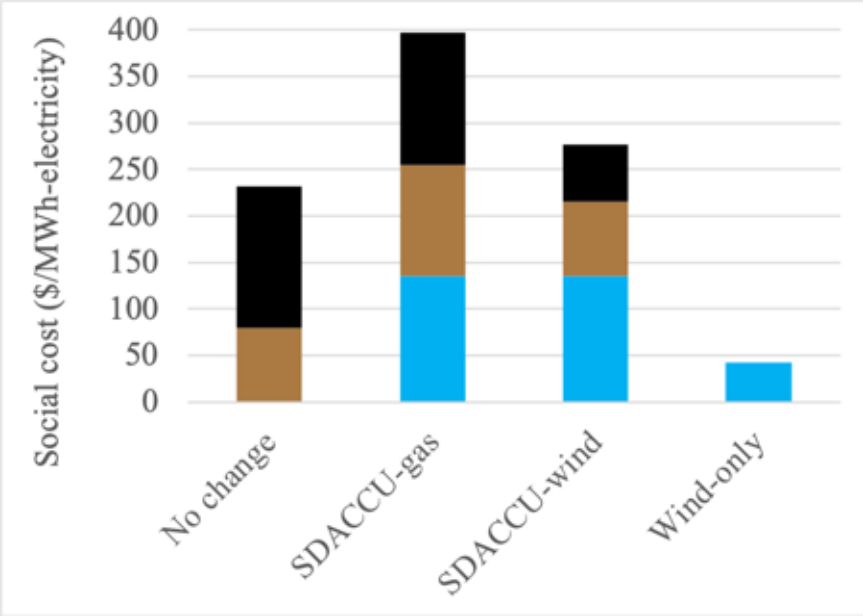
Direct Air Capture Powered by Natural Gas

Units: kg-CO_2e/MWh	20 yr	100 yr
a) CO_2 removed from air	825	825
b) CO_2e from natural gas upstream returned to air	334	165
c) CO_2 from natural gas combustion returned to air	404	404
d) Net CO_2e reduced due to natural gas (a-b-c)	87	256
Percent of removed CO_2e that stays removed (d/a)	11%	31%

→Natural gas-powered DAC reduces a net of only 11-31% of CO2e that is captured over 20-100 years.

Change in CO_2e and Social Cost in 3 DAC Cases





1st case: no change; 2nd: Use SDACCU powered by natural gas;

3rd : Use SDACCU powered by wind; 4th: replace coal with wind

Blue=removal CO_2; Orange=nnatgas turbine CO_2; Red=natgas upstream CH_4 CO_2e; Orange=natgas upstream non-CH_4 CO_2e; Green=CO_2e reduction due to replacing coal plant with wind;

Light blue=equip cost; Brown=airpol cost; Black=climate cost over 20 y.

Blue vs. Gray Hydrogen: Main Assumptions

- Use of steam methane reforming, SMR (vs. autothermal reforming, ATR)
- Leakage rate 3.5 (1.54 to 4.3)%
- Carbon dioxide capture rate for pure stream from SMR: 85 (78.8-90)%; flue gas: 65%
- 20-year GWP (80-year also examined)

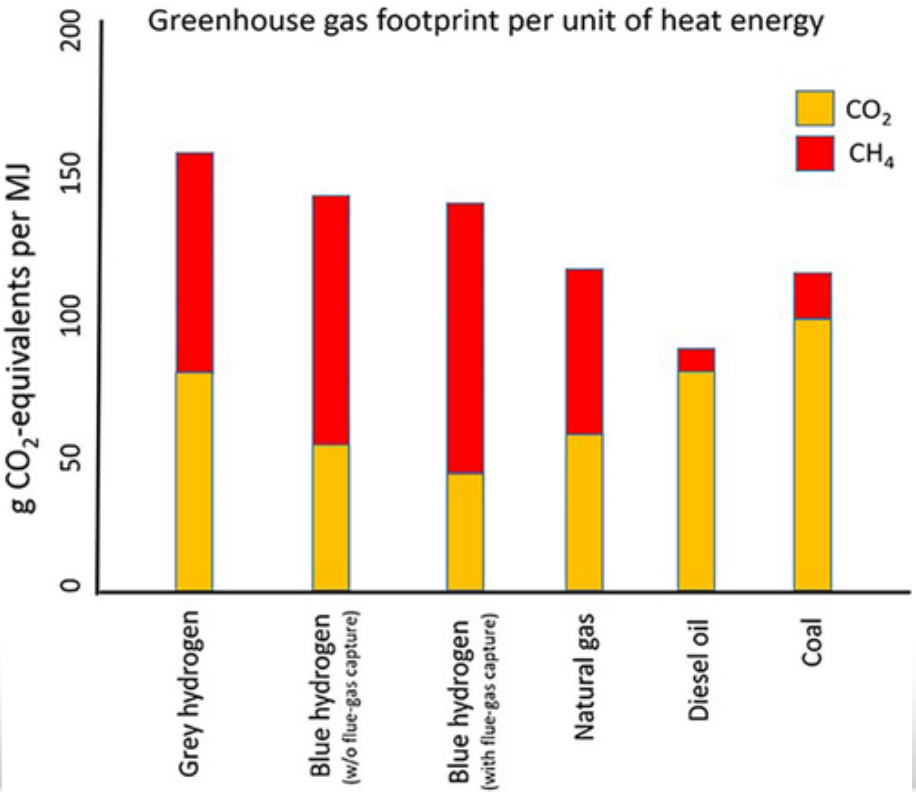
Howarth and Jacobson (2021)

ATR Vs. SMR

- ATR produces 2 hydrogen molecules per methane; SMR produces 4
- ATR can get 2.9 by reacting waste carbon monoxide with steam, which requires more equipment and energy
- ATR requires pure oxygen to be separated from air, requiring more equipment and energy
- To reduce carbon dioxide capture needs, energy for heat and oxygen separation can be obtain with hydrogen fuel cell, requiring more equipment
- -> ATR always results in 38-100% more methane leaks and upstream pollution
- CO_2 from ATR can be captured more efficiently, but more CO_2 produced

Howarth and Jacobson (2021)

Base Case Results



Blue H_2 Similar Emissions to Grey H_2

- Grey hydrogen (H_2 from steam reforming with no carbon capture): 153 g-CO2eq/MJ
- Blue hydrogen (H_2 from steam reforming with carbon capture) with mining, heat, and capture equipment powered by fossil fuels: 135-139 g-CO2eq/MJ
- Burning natural gas for heat: 111 g-CO2eq/MJ
- Blue hydrogen powered by renewables still emits 52 g-CO_2eq/MJ and requires natural gas mining + storing CO_2
- Green hydrogen (H_2 by electrolysis): 0 g-CO2eq/MJ and no natural gas mining or air pollution

Howarth and Jacobson (2021)

Book on 100% WWS

https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook.html

Paper on Carbon Capture and Direct Air Capture

https://web.stanford.edu/group/efmh/jacobson/Articles/Others/19-CCS-DAC.pdf

Paper: How Green is Blue Hydrogen

https://onlinelibrary.wiley.com/doi/full/10.1002/ese3.956

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How SMART-E Loans Can Make Residential Energy Upgrades More Accessible

Tuesday, September 14, 1-2pm ET

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