How Green is Blue Hydrogen?

Study Finds Hydrogen Produced with CCS Produces High Emissions

September 7, 2021
WEBINAR LOGISTICS

Join audio:
- Choose Mic & Speakers to use VoIP
- Choose Telephone and dial using the information provided

Use the orange arrow to open and close your control panel

Submit questions and comments via the Questions panel

This webinar is being recorded. We will email you a webinar recording within 48 hours. CEG’s webinars are archived at www.cleanegroup.org/webinars
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
Why Not Carbon Capture?
### Coal Plant With CCU Powered by Natural Gas

<table>
<thead>
<tr>
<th>Units: kg-(\text{CO}_2\text{e}/\text{MWh})</th>
<th>20 yr</th>
<th>100 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Upstream (\text{CO}_2) and leaked (\text{CH}_4) from coal</td>
<td>450</td>
<td>237</td>
</tr>
<tr>
<td>b) (\text{CO}_2) from stack</td>
<td>931</td>
<td>931</td>
</tr>
<tr>
<td>c) (\text{CO}_2) captured from stack by equipment</td>
<td>516</td>
<td>516</td>
</tr>
<tr>
<td><strong>Percent of stack (\text{CO}_2) captured (c/b)</strong></td>
<td><strong>55%</strong></td>
<td><strong>55%</strong></td>
</tr>
<tr>
<td>CO(_2)e emitted by natural gas mining+combustion</td>
<td>367</td>
<td>283</td>
</tr>
<tr>
<td>e) Captured CO(_2)e not returned to air by natgas (c-d)</td>
<td>149</td>
<td>233</td>
</tr>
<tr>
<td><strong>Percent CO(_2)e reduction realized e/(a+b)</strong></td>
<td><strong>10.8%</strong></td>
<td><strong>20%</strong></td>
</tr>
</tbody>
</table>

CCU attached to coal plant reduces only 11-20\% of CO\(_2\)e it is expected to over 20-100 y
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\(_2\)e; Orange=coal upstream CH\(_4\) CO\(_2\)e; Red=coal CO\(_2\); Yellow=nat gas CO\(_2\); green=Natgas CO\(_2\)e from CH\(_4\) leaks; Purple=other natgas upstream CO\(_2\)e; 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$_2$e 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$_2$e 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

<table>
<thead>
<tr>
<th>Units: kg-CO$_2$e/MWh</th>
<th>20 yr</th>
<th>100 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) CO$_2$ removed from air</td>
<td>825</td>
<td>825</td>
</tr>
<tr>
<td>b) CO$_2$e from natural gas upstream returned to air</td>
<td>334</td>
<td>165</td>
</tr>
<tr>
<td>c) CO$_2$ from natural gas combustion returned to air</td>
<td>404</td>
<td>404</td>
</tr>
<tr>
<td>d) Net CO$_2$e reduced due to natural gas (a-b-c)</td>
<td>87</td>
<td>256</td>
</tr>
<tr>
<td>Percent of removed CO$_2$e that stays removed (d/a)</td>
<td>11%</td>
<td>31%</td>
</tr>
</tbody>
</table>

Natural gas-powered DAC reduces a net of only 11-31% of CO$_2$e that is captured over 20-100 years.
1\textsuperscript{st} case: no change; 2\textsuperscript{nd}: Use SDACCU powered by natural gas; 3\textsuperscript{rd}: Use SDACCU powered by wind; 4\textsuperscript{th}: replace coal with wind

Blue=removal CO\textsubscript{2}; Orange=natgas turbine CO\textsubscript{2}; Red=natgas upstream CH\textsubscript{4} CO\textsubscript{2}e; Orange=natgas upstream non-CH\textsubscript{4} CO\textsubscript{2}e; Green=CO\textsubscript{2}e 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 obtained with hydrogen fuel cell, requiring more equipment
- $\text{ATR always results in 38-100}\%$ more methane leaks and upstream pollution
- $\text{CO}_2$ from ATR can be captured more efficiently, but more $\text{CO}_2$ produced

Howarth and Jacobson (2021)
Base Case Results

Greenhouse gas footprint per unit of heat energy

- Grey hydrogen
- Blue hydrogen (w/o flue gas capture)
- Blue hydrogen (w/ flue gas capture)
- Natural gas
- Diesel oil
- Coal

$gCO_2$-equivalents per MJ
Blue H₂ Similar Emissions to Grey H₂

• Grey hydrogen (H₂ from steam reforming with no carbon capture): 153 g-CO₂eq/MJ

• Blue hydrogen (H₂ 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-CO₂eq/MJ and requires natural gas mining + storing CO₂

• Green hydrogen (H₂ 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

Twitter: @mzjacobson
UPCOMING WEBINAR

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

*Tuesday, September 14, 1-2pm ET*

Read more and register at: [www.cleanegroup.org/webinars](http://www.cleanegroup.org/webinars)