Why We Must Focus on Clean, Renewable Energy and Storage, Not “All of the Above,” For Solving Global Climate, Air Pollution, and Energy Security Problems

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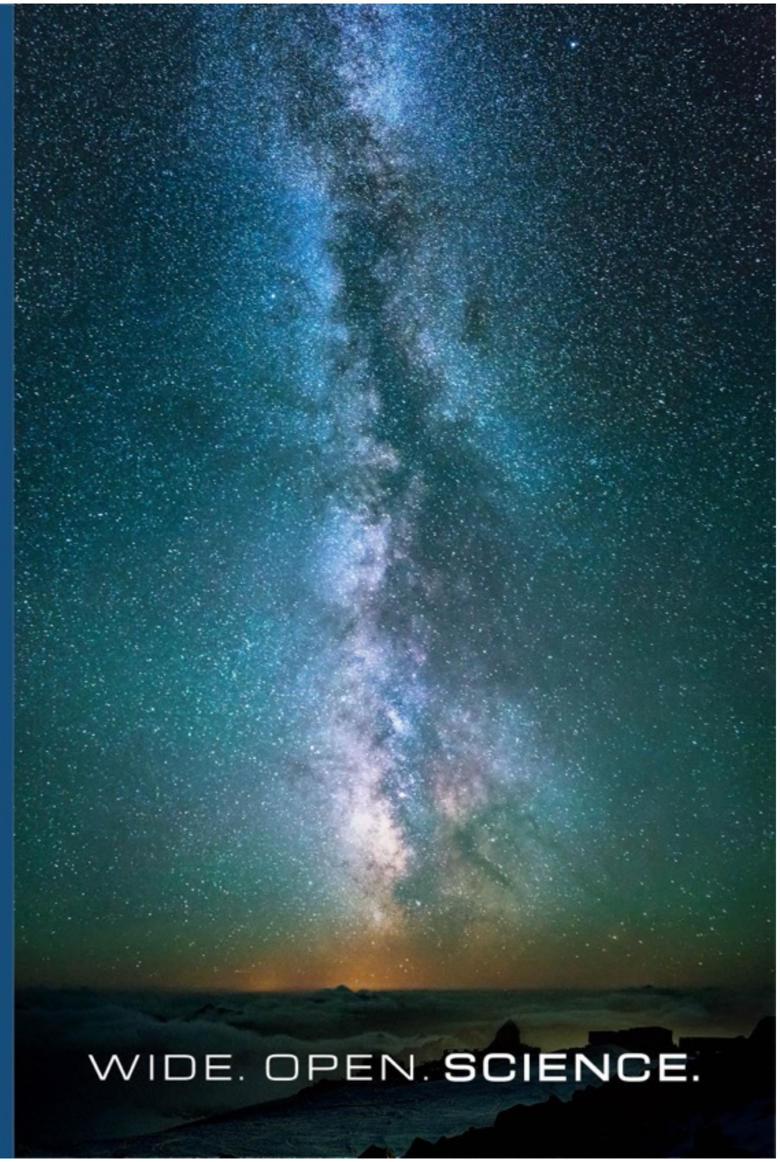


What are the Problems?

Air Pollution: Fossil fuels and bioenergy cause ~7.4 million air pollution deaths/year worldwide, costing ~$30 trillion/year

Global warming: Will cost ~$30 trillion/year by 2050. We must eliminate 80% of emissions by 2030/100% by 2035-2050 to avoid 1.5 C warming

Energy insecurity: Fossil fuels are limited resources. Increasing energy prices over time will result in economic, political, and social instability

Drastic problems require immediate solutions

Wind, Water, Solar (WWS) Solution

Electrify or Provide Direct Heat For All Sectors and Provide the Electricity and Heat with 100% WWS

ELECTRICITY/HEAT	TRANSPORTATION	BUILDINGS	INDUSTRY
Wind	Battery-electric	Heat pumps	Arc furnaces
Solar PV/CSP	H_2 fuel cell	Induction cooktops	Induction furnaces
Geothermal		LED lights	Resistance furnaces
Hydro		Insulation	Dielectric heaters
Tidal/Wave			Electron beam heaters
Solar/Geo Heat			Heat pumps

Jacobson et al., *Energy & Environmental Sciences* (2022)

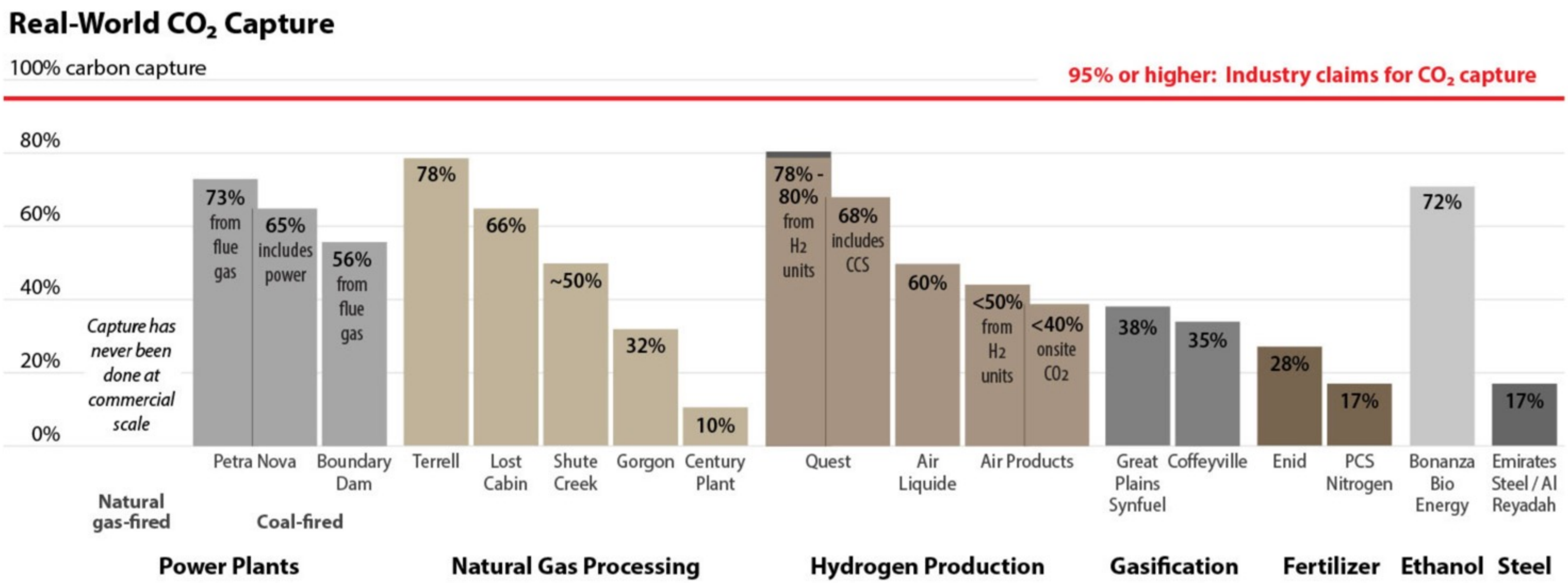
Types of Storage for a 100% WWS System

ELECTRICITY	HEATING/COOLING	OTHER
CSP with storage	Water tank	Non-grid hydrogen
Pumped hydro storage	Ice	Steel
Existing hydroelectric	Underground	Ammonia
Batteries	Borehole	Long-dist. transport
Flywheels	Water Pit	
Compressed air	Aquifer	
Gravitational Storage	Building materials	
Grid hydrogen/fuel cells		

Why Not "All Of The Above?"

Carbon Capture
Direct Air Capture
Blue Hydrogen
Non-Hydrogen-Electro-Fuels
Bioenergy (Biofuels for Transport, Biomass)
New Nuclear (Small or Large)

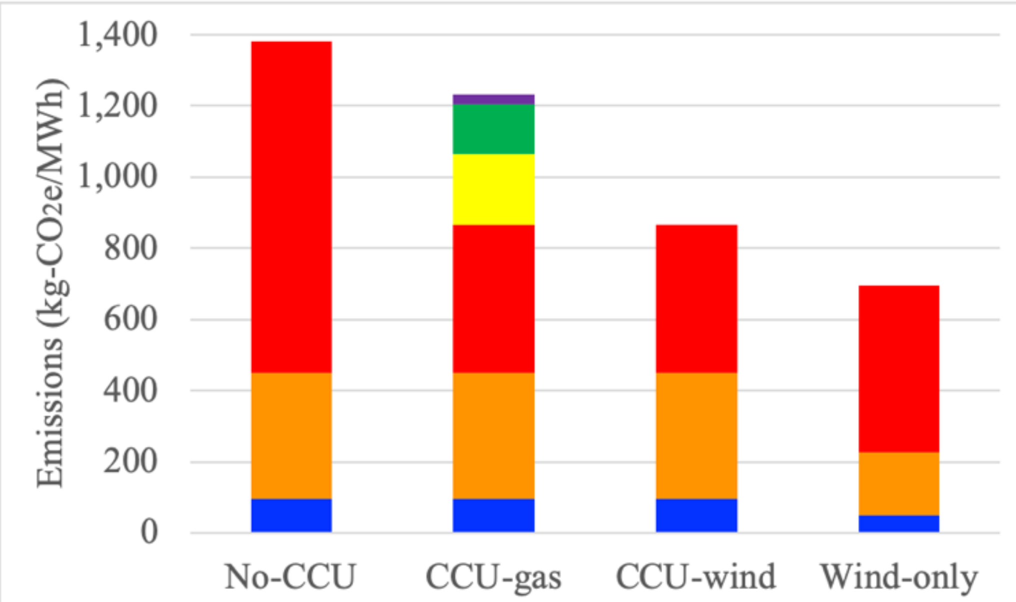
Capture Rates: Industry Claim: 95%; Reality: 10-80%

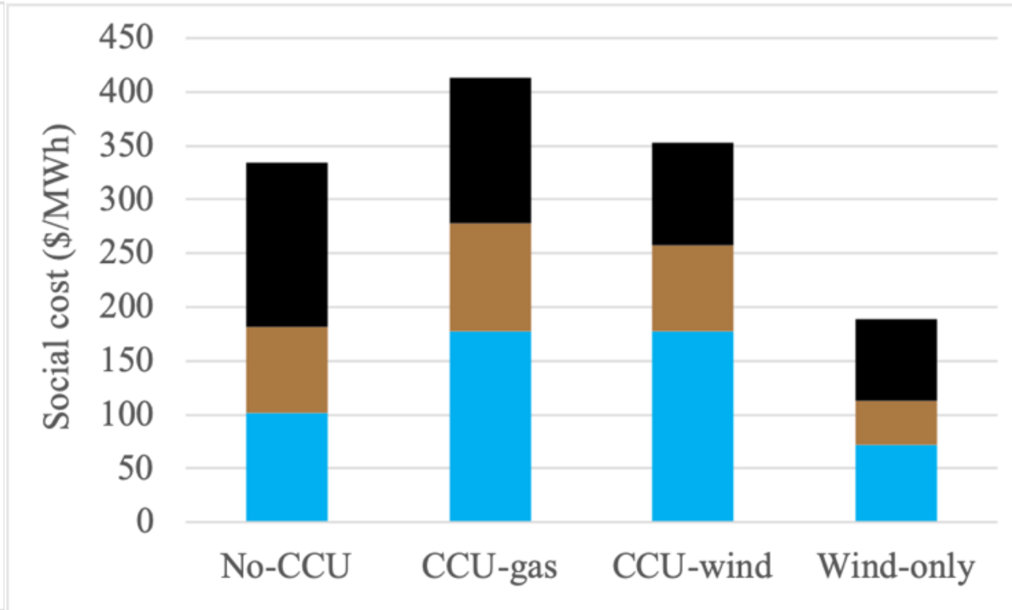


Source: IEEFA analyses based on publicly available data

IEEFA (2023)

Coal With CCU-Petra Nova-CO2e & Social Cost





No-CCU: coal-no CCU; CCU-gas: coal with CCU powered by natural gas; CCU-wind: Coal-CCU powered by wind; Wind-only: replace coal with wind

Blue=upstream coal non-CH_4 CO_2e; Orange=coal upstream CH_4 CO_2e; Red=coal CO_2; Yellow=Gas CO_2; green=Gas CO_2e from CH_4 leaks; Purple=other gas upstream CO_2e; Light blue=electricity+CCU cost; Brown=air pollution cost; **Black**=climate cost

Jacobson, *Energy & Environmental Sciences* (2019)

Summary and Where Does Captured CO_2 Go?

→ Even wind powering coal-CCU increases CO_2 and social cost versus wind replacing coal[1]

73% worldwide is used for enhanced oil recovery (EOR)[2]

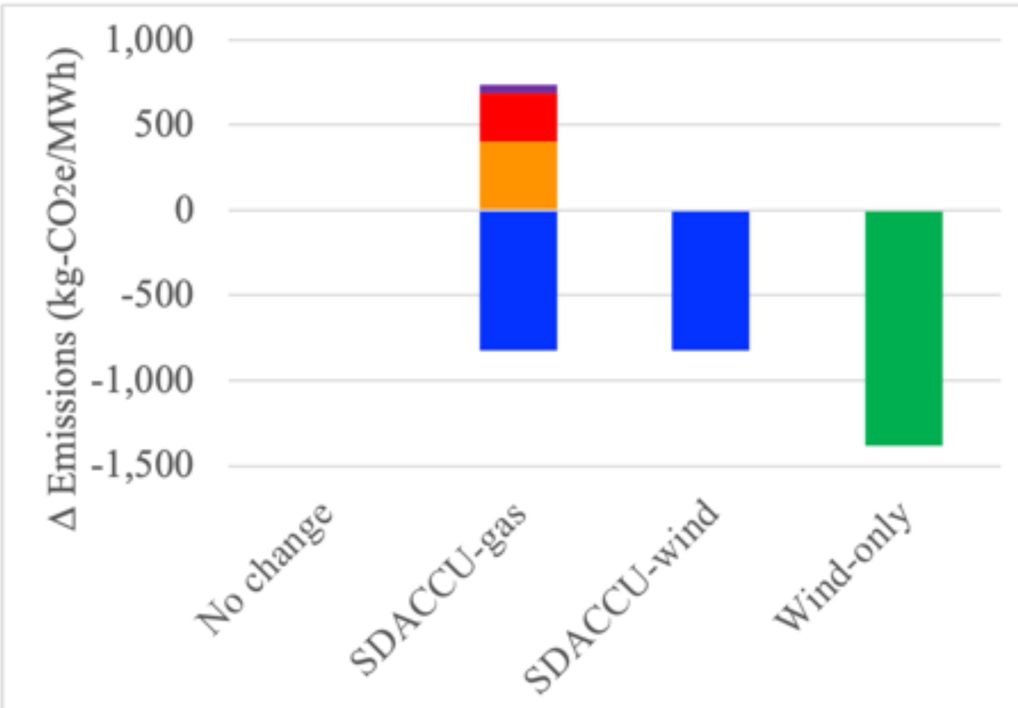
40% of CO_2 used for EOR is lost back to the air[3]

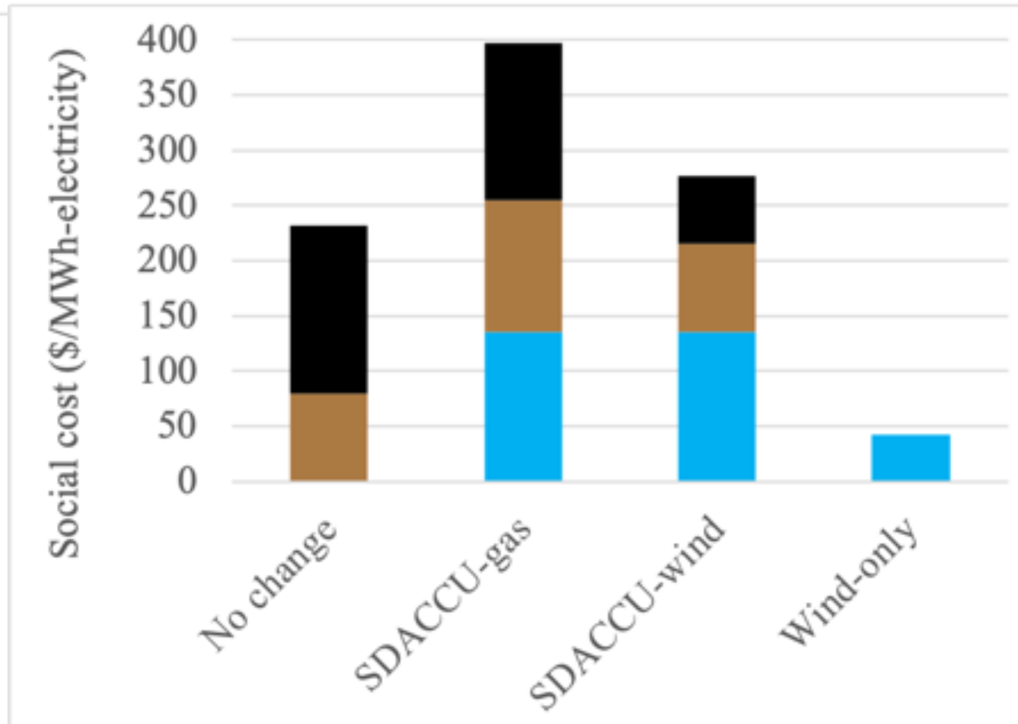
1. Jacobson, *Energy & Environmental Sciences* (2019)

2. IEEFA (2022)

3. Jaramillo et al., *Environmental Science and Technology* (2009)

Change in CO_2e/Social Cost With Direct Air Capture





No change: coal and no SDACCU; SDACCU-gas: coal and SDACCU powered by gas; SDACCU-wind: coal and SDACCU powered by wind; Wind-only: Coal replaced by wind and no SDACCU

Jacobson, *Energy & Environmental Sciences* (2019)

Summary

→ Even wind powering Synthetic Direct Air Carbon Capture and Use (SDACDU) increases CO_2 and social cost (by a factor of >6) versus wind replacing coal

Jacobson, *Energy & Environmental Sciences* (2019)

Ethanol w/CCS+Pipes for FFV vs Wind for BEVs

- Proposal: $5.6 bil to add capture equipment to 34 ethanol refineries and 2,000 mi of CO_2 pipes across five states. CO_2 stored underground. Ethanol for flex-fuel vehicles (FFVs).

- Compare with spending same funds on wind powering battery-electric vehicles (BEVs)

- Compare Ford F-150 FFV with F-150 BEV

Jacobson, *Environmental Science and Technology* (2023)

Battery-Electric Versus Flex-Fuel Vehicle

2023 Ford F-150 4WD Lightning Extended Range BEV

480 Wh/mi on electricity = 578.7 Mi/GJ

Electricity cost: $0.122/kWh

Cost to drive 15,000 miles/yr for 15 years: $13,100

2023 Ford F-150 4WD 8-cyclinder FFV

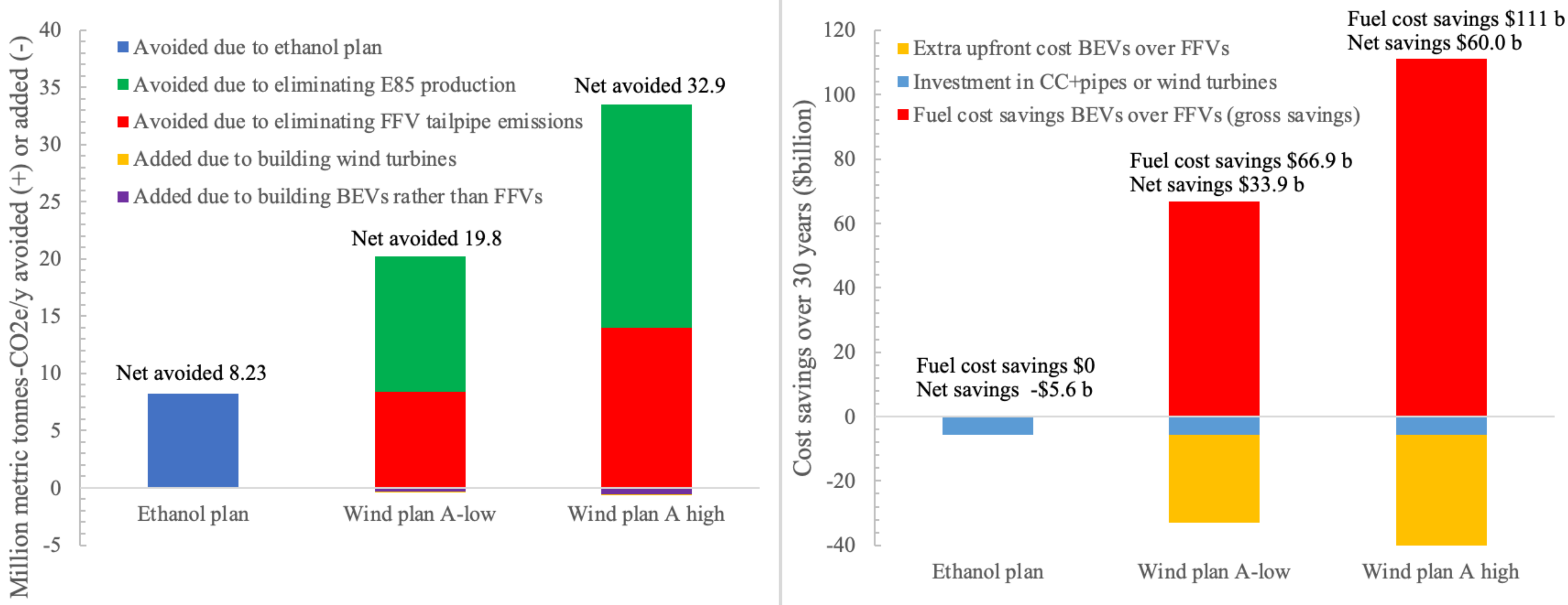
18 mpg on gasoline = 139.1 Mi/GJ

Gasoline cost: $3.86/gallon

Cost to drive 15,000 miles/yr for 15 years: $48,200

→ BEVs use 23.8% the energy and cost 27% the fuel cost to drive the same distance but cost $21,700 more upfront

Wind-BEVs reduce 2.4-4x CO_2; save \$40-66 bil over 30 y Compared With Ethanol for Transport With CCS+Pipes



Jacobson, *Environmental Science and Technology* (2023)

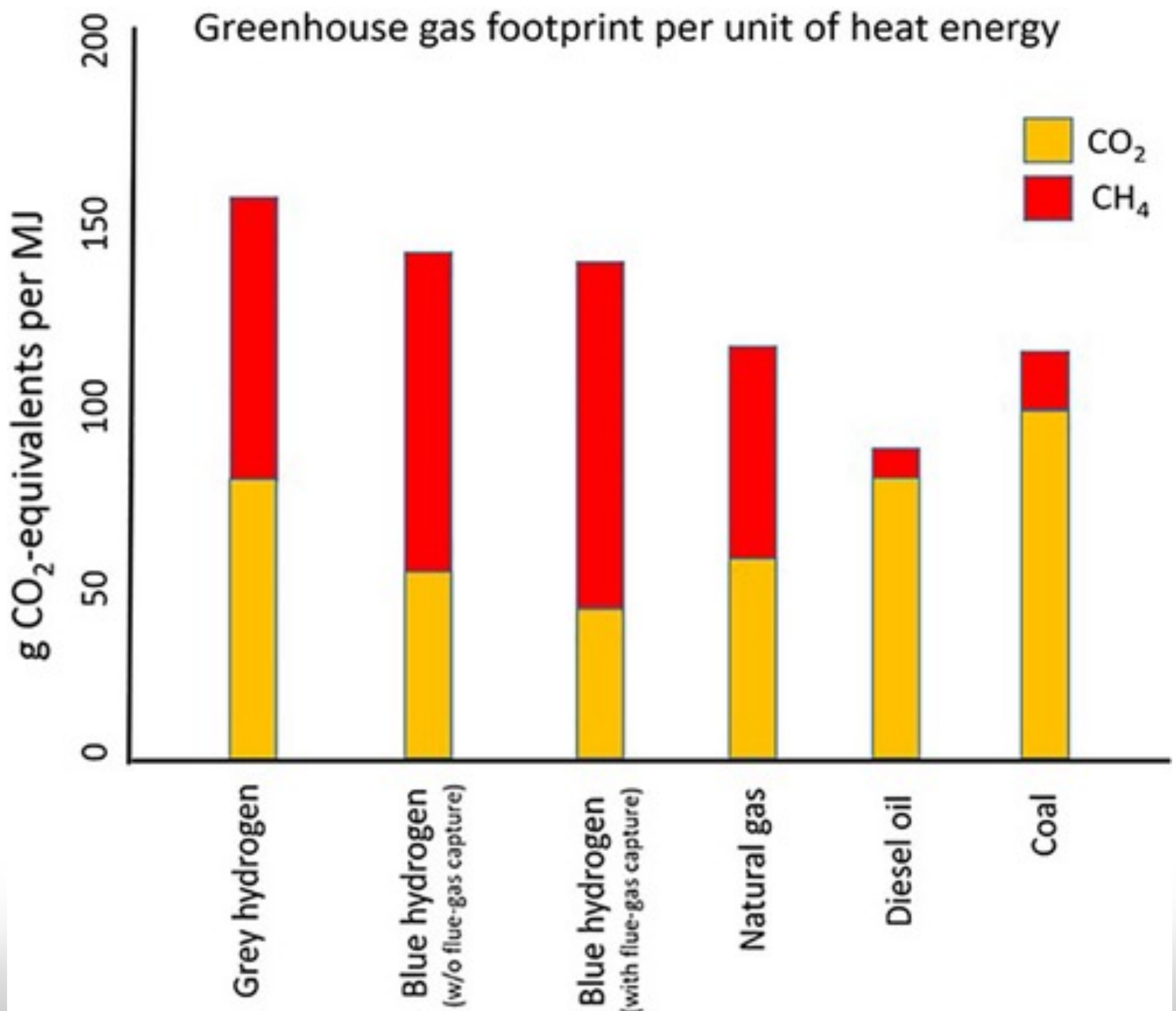
Blue vs. Gray Hydrogen: Assumptions

- Use of steam methane reforming, SMR
- Leakage rate 3.5 (1.54 to 4.3)%
- CO_2 capture rate from pure stream: 85 (78.8-90)%; energy: 65%
- 20-year GWP (100-year also examined)

Howarth and Jacobson, *Energy Science and Engineering* (2021)

Main Result

Blue hydrogen emits more CO_2e than burning fossil (natural) gas for heat



Howarth and Jacobson, *Energy Science and Engineering* (2021)

Issues With Nuclear as Part of the Solution

Takes 10-22 y between plan & operation v 0.5-3 y for new solar/wind

Capital cost 10-16 x and cost per unit energy 5-8 x those of wind/solar

Produces 9-37 times more CO_2e & pollution per unit energy than wind

IPCC 2014: P. 517. "Robust evidence, high agreement" that increased use of nuclear leads to more

(a) Weapons proliferation risk
(b) Meltdown risk
(c) Waste risk
(d) Mining risk

Nuclear Planning-to-Operation Times

	Construction Time (Years)	Plan-to-Operation Time (Years)
Olkiluoto 3 (Finland)	17	22
Hinkley Point (UK)	8-9	18-19
Vogtle 3 and 4 (US)	9.5-10	17-18
Flamanville (France)	17	20
Haiyang 1 and 2 (China)	9	13-14
Taishan 1 and 2 (China)	10-11	12-13
Barakah 1-4 (UAE)	9	12-15
Ringhals 1-4 (Sweden)	6-11	10-18

Conclusion

Carbon capture, direct air capture, blue hydrogen, non-hydrogen electro-fuels, bioenergy, and new nuclear are opportunity costs.

Even when powered by wind-water-solar (WWS), the first five all increase CO_2, air pollution, and social cost and either fossil mining and infrastructure or land use versus using the same WWS to replace a CO_2 source → CCS/U, DAC always increase CO_2.

New nuclear increases cost, time-to-operation, emissions, and catastrophic risk versus new wind/solar

→ We need to focus on what works: WWS, not miracles

Book on 100% WWS ("No Miracles Needed")

https://web.stanford.edu/group/efmh/jacobson/WWSNoMN/NoMiracles.html

Paper on Carbon Capture and Direct Air Capture

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

Paper on Blue versus Gray Hydrogen

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

Paper on Ethanol With Carbon Capture and Pipes

https://web.stanford.edu/group/efmh/jacobson/Articles/Others/23-E85vBEVs.pdf

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