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Center on Global Energy Policy

Low-C Hydrogen in a net-zero economy: Emissions, Arithmetic, Models, and Policy

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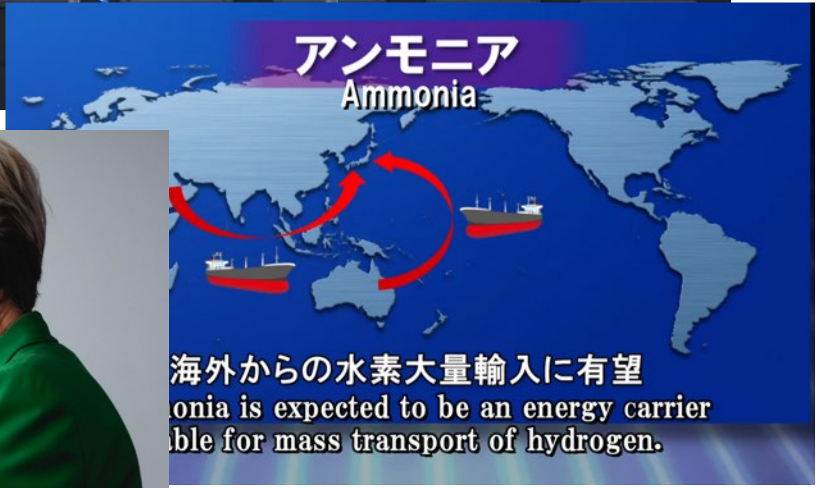
H_2 is Hot

World's Largest Green Hydrogen Project in Saudi Arabia



DOE: Hydrogen Earthshot

Hard to separate hype, help and opportunity

Hydrogen: the Swiss Army knife of deep decarbonization

Heavy Industry

- Replacing/decarbonizing current hydrogen production (70 Mt/y + 477 Mt/y CO_2)
- Industrial heat (cement, iron & steel, chemicals, refining, glass, ceramics, paper)

Transportation Sector

- Direct use as a fuel (heavy duty trucking; port operation)
- Feedstock to synthetic fuels (ammonia, synthetic jet fuel & methanol)

Power Sector

- Alternative power storage (like a long-duration battery) with stationary fuel cells
- Get value from power congestion & curtailment

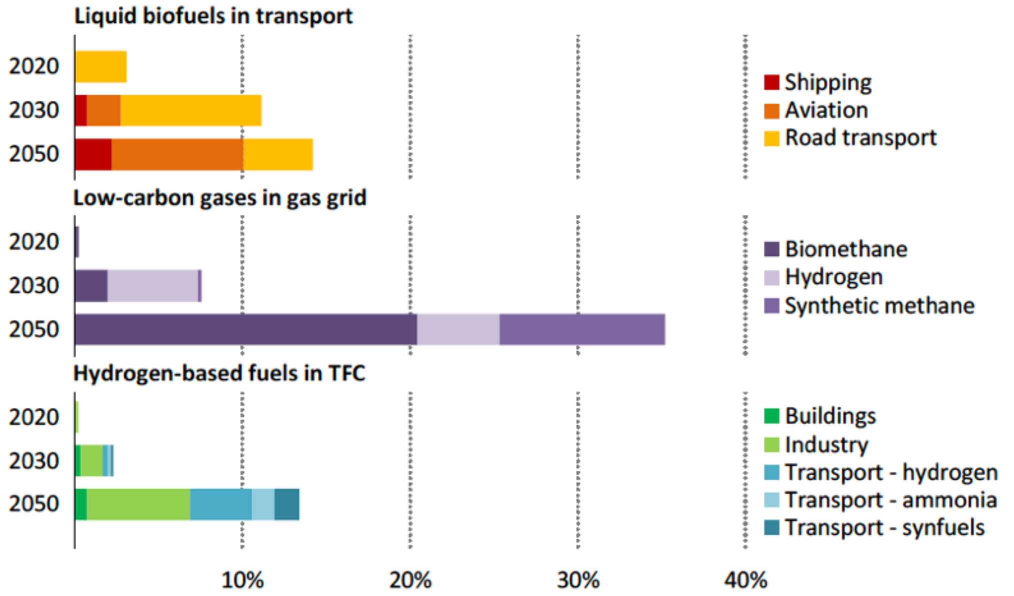
Multi-sectoral Applications

- Near-term and long-term replacement for natural gas (heat and power)
- Feedstock to a circular carbon economy (fuels, plastics, chemicals)
- CO_2 removal (biomass+CCS to hydrogen; energy for CO_2 removal systems)

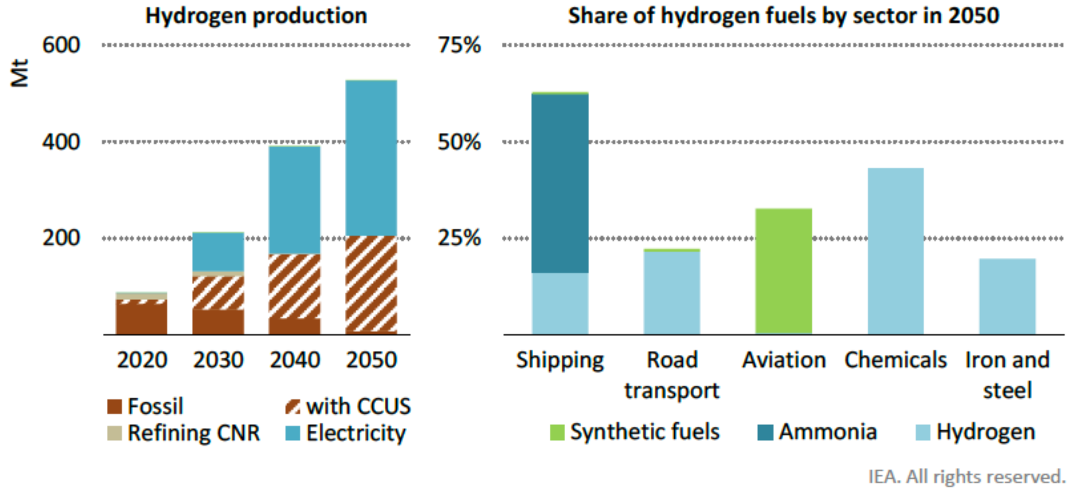
Hydrogen is a big part of a net-zero economy

Key applications: Industry, shipping, aviation, trucks, heat
Mix of blue & green

Global supply of low-C fuels

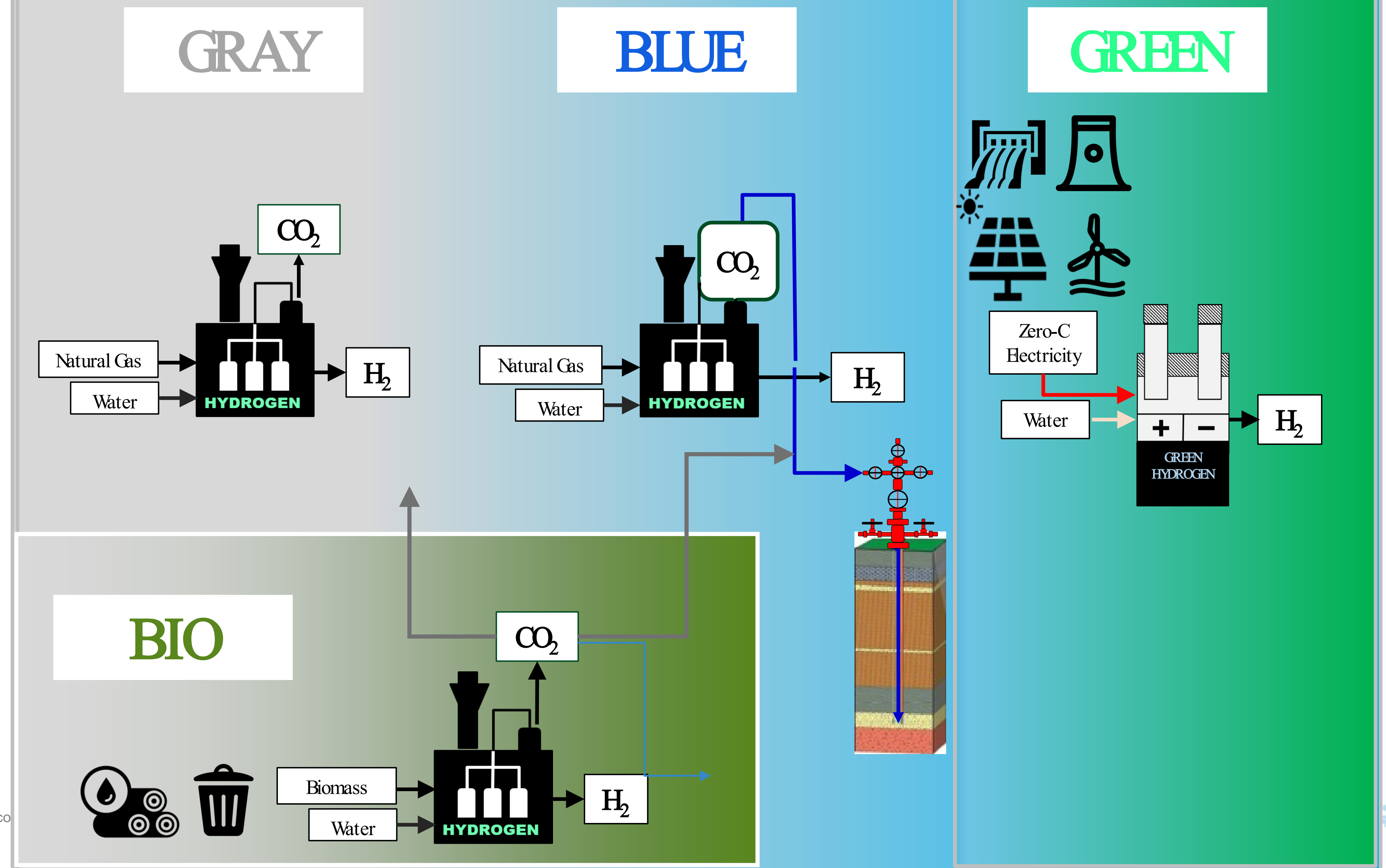


Global H2 production by fuel & use by sector

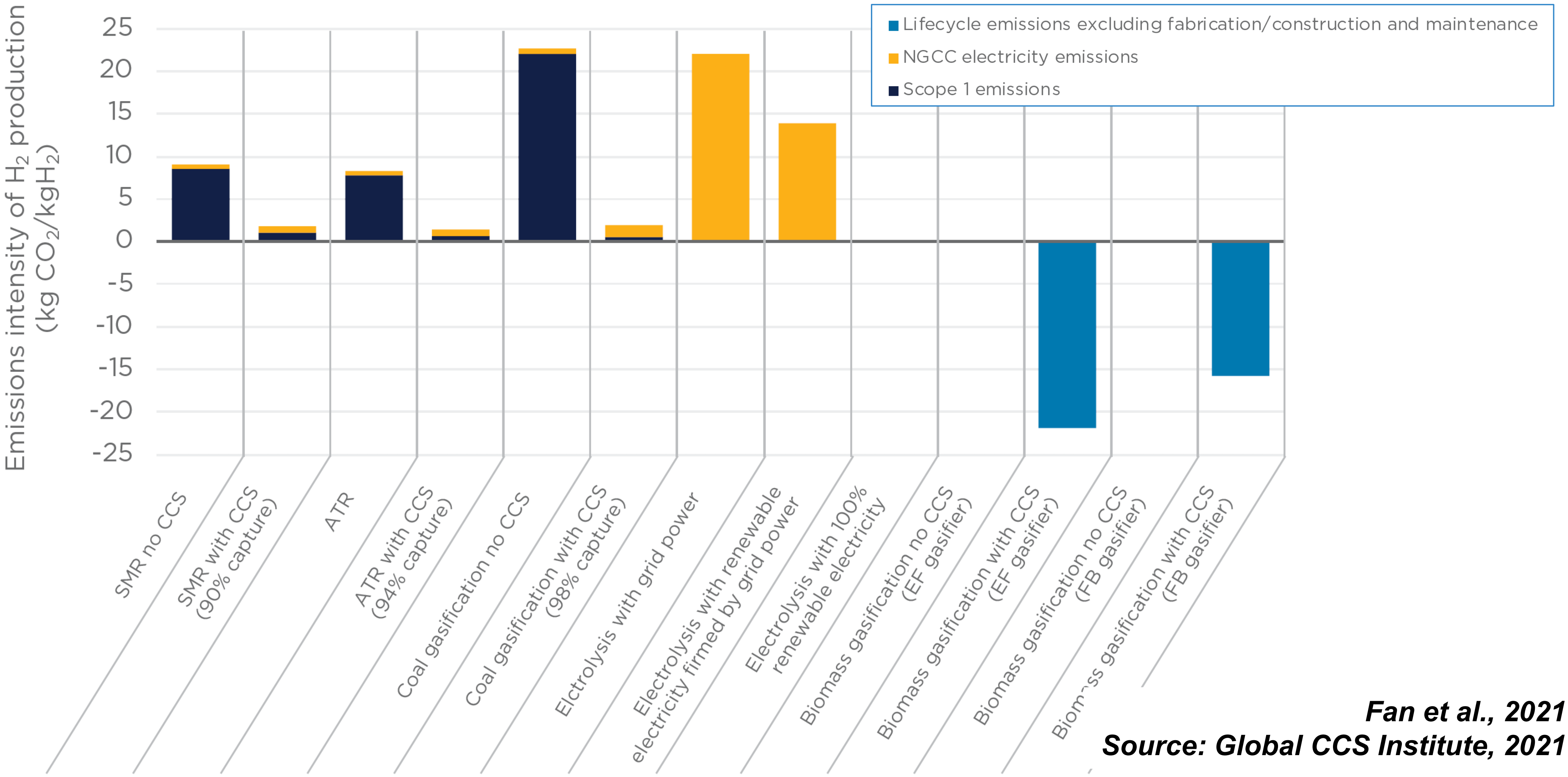


IEA, Net-zero 2050 (2021)

How hydrogen is made



Fair question: What's the true footprint of H_2 production & use?



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Fan et al., 2021

Source: Global CCS Institute, 2021

H_2 Production 2020

Total production:120Mtpa

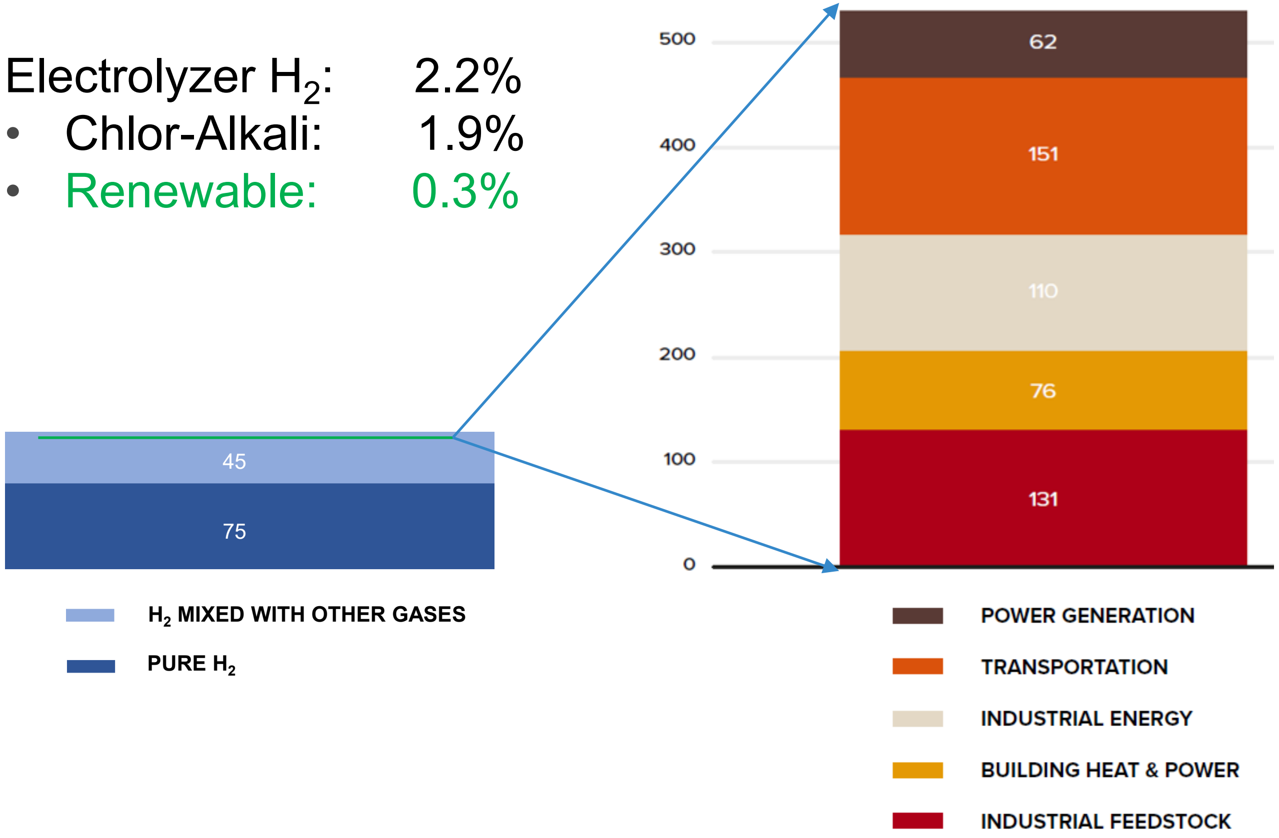
Fossil origin H_2: 97.8%
- Without CCS: 97.5%
- With CCS: 0.4%

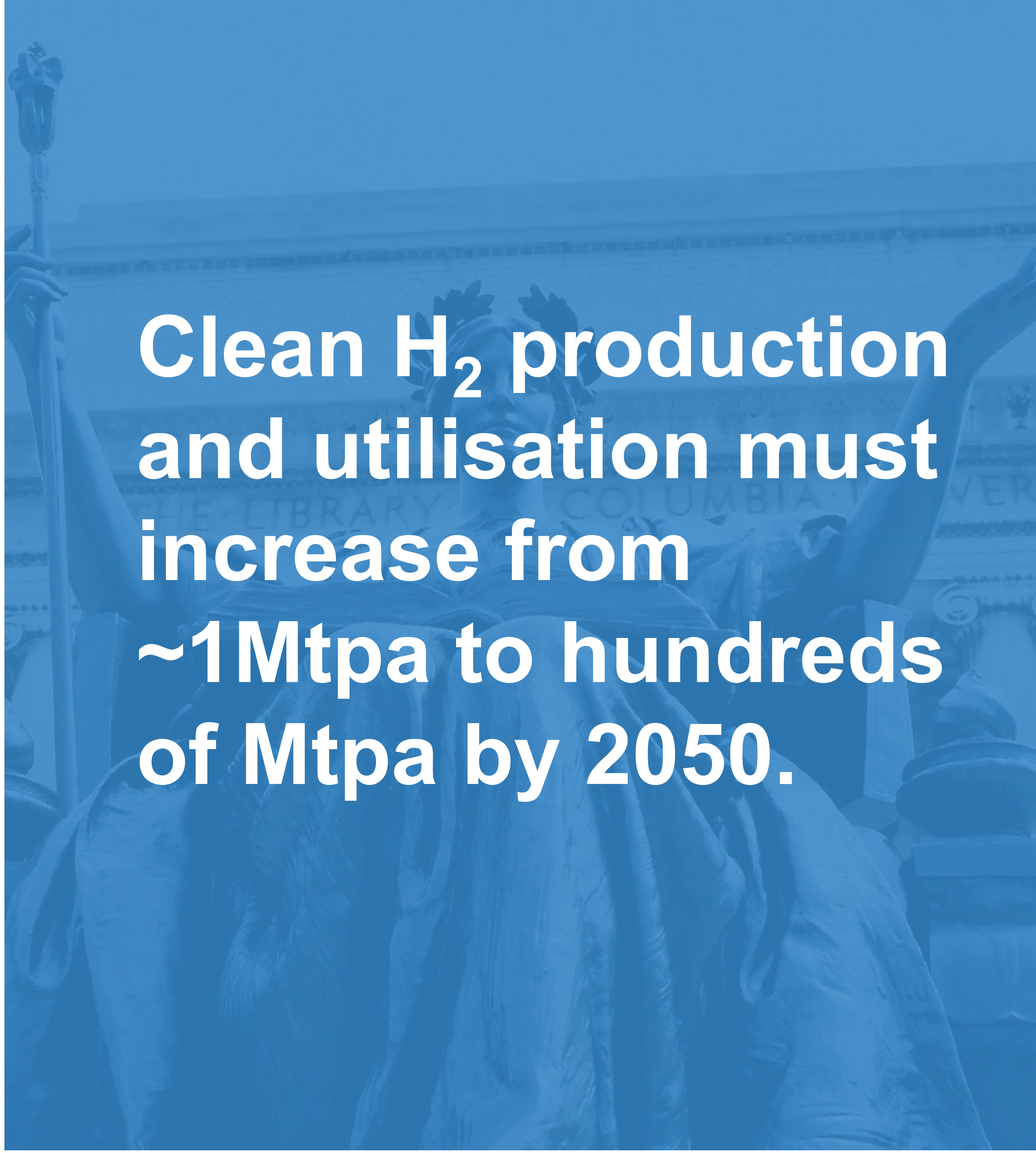
Electrolyzer H_2: 2.2%
- Chlor-Alkali: 1.9%
- Renewable: 0.3%

H_2 Production 2050

Total production:530Mtpa

Clean H_2: 100%





Clean H_2 production and utilisation must increase from ~1Mtpa to hundreds of Mtpa by 2050.

Key challenges

Cost

- **Green**: \$3-8/kg (55% electricity, 30% electrolyzer, 15% BOP)
- **Blue**: \$1.2-1.8/kg (for D, price of gas & decarb fraction)

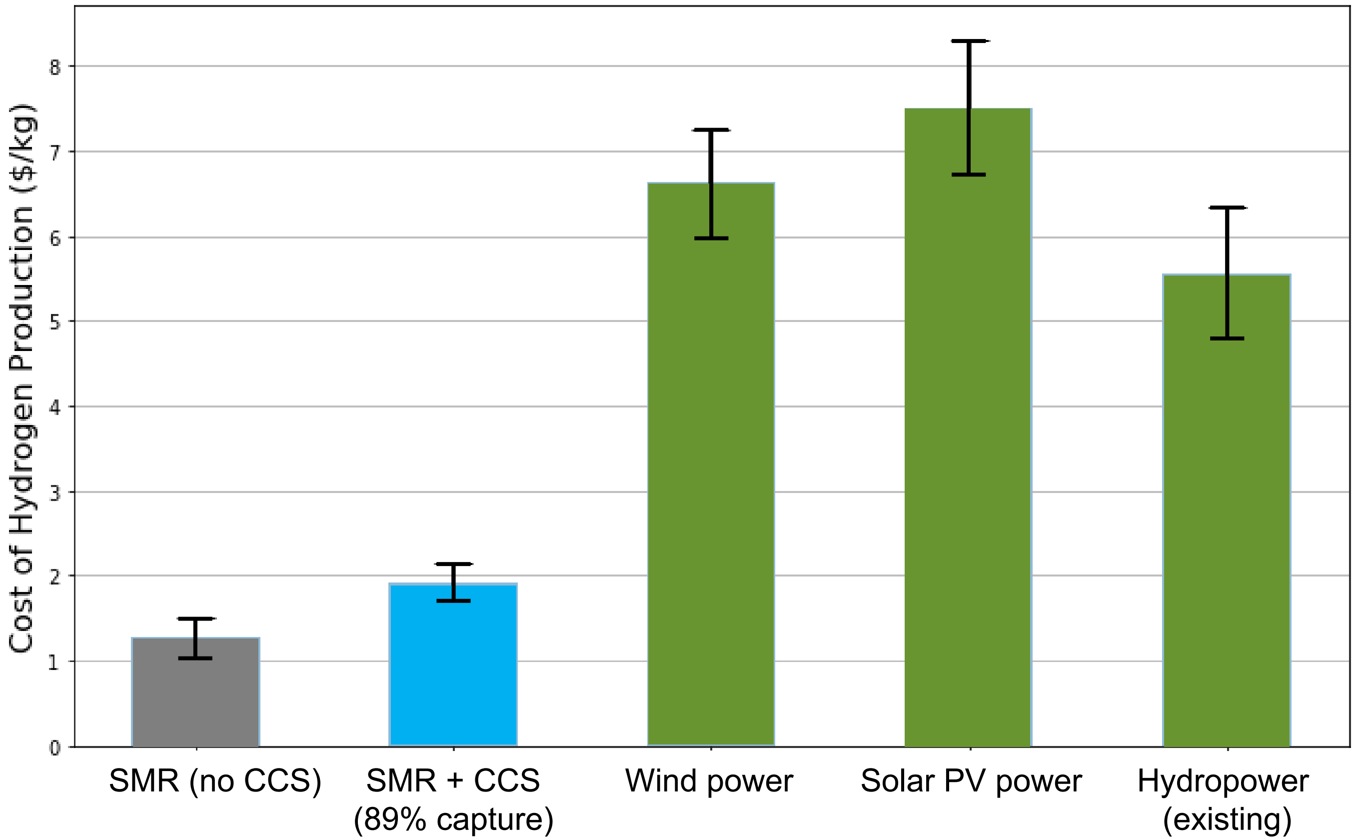
Technology limits

- Manufacturing: bespoke production (China, Germany, Korea, Norway, Japan trying to change)
- Pipeline tolerances: 7-20% in most existing natgas pipeline networks
- Safety: Invisible – sensors & controls, home safety, etc.

Infrastructure (EWIIW)

- **Green**: Massive build of transmission & zero-C electricity supply (26,000 TWh = 530 Mtpa)
- **Blue**: CO_2 pipelines, fueling infrastructure, pore volume access; upstream CH_4; **acceptance**

Costs of U.S. hydrogen production (\$/kg)

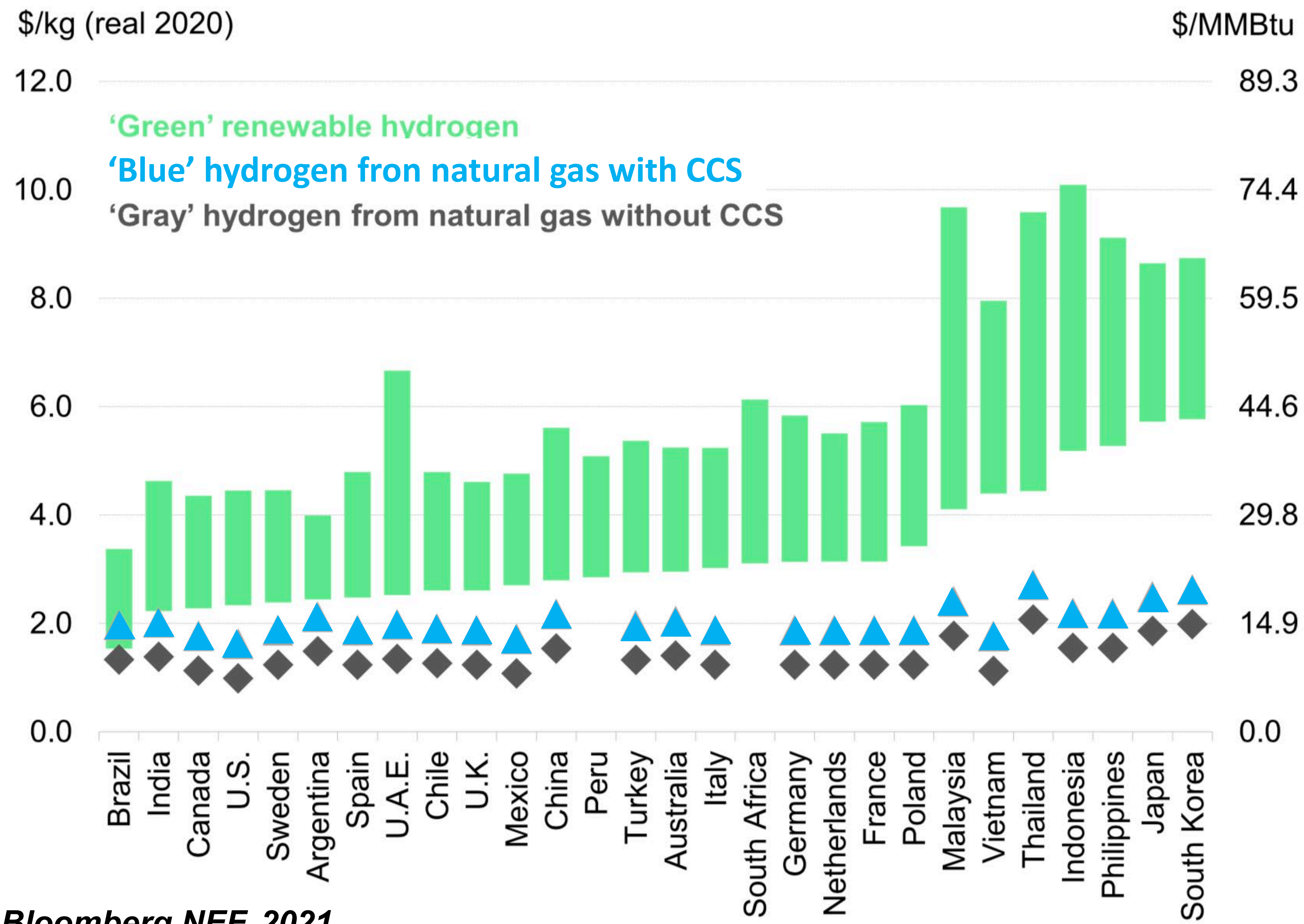


Cost of electricity	Capacity Factor	Cost of H_2 (\$/kg)*
\$30/MWh	90%	\$2
\$. 5/MWh	20%	\$2

* For \$1000/kW electrolyzers

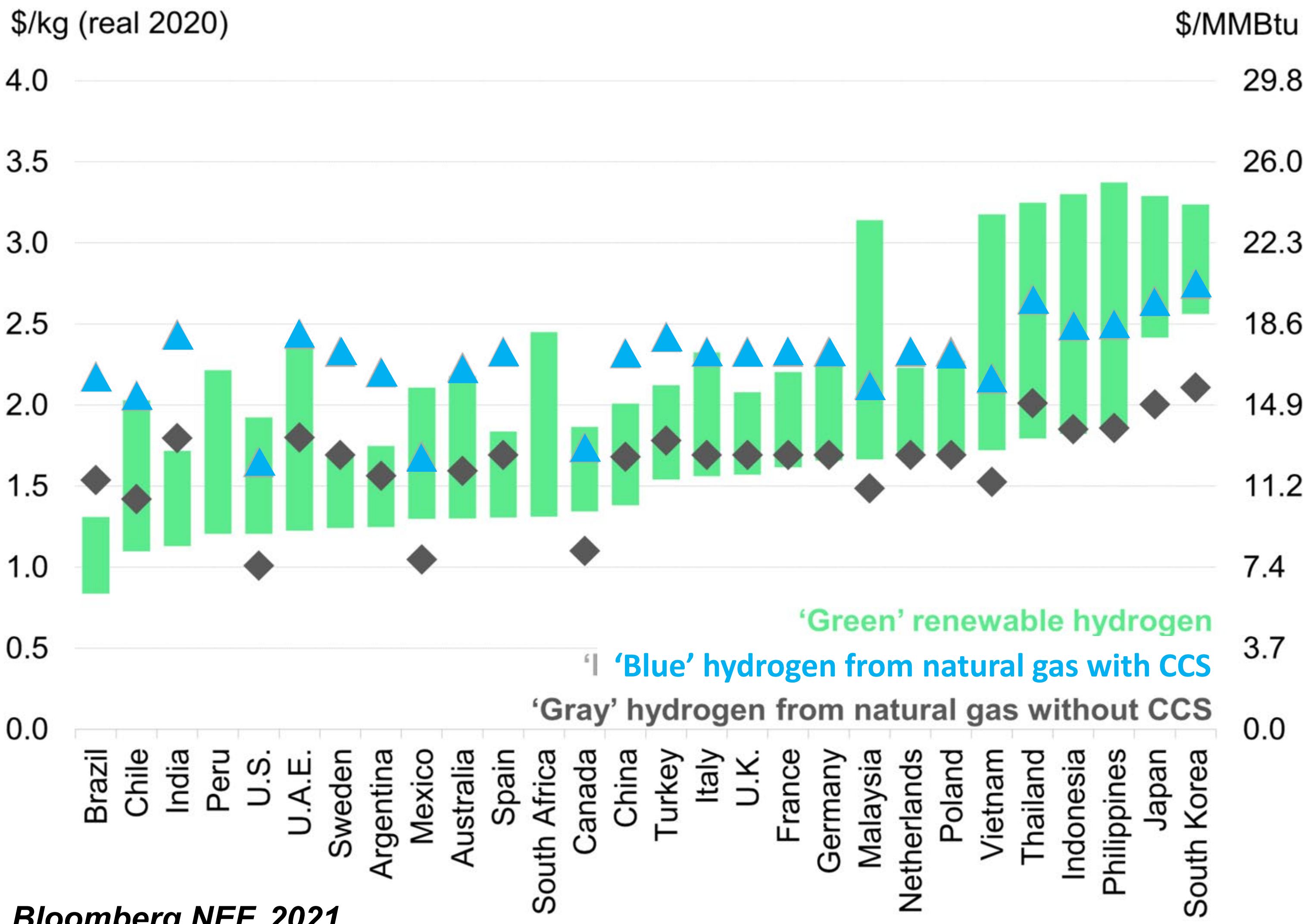
Friedmann et al., 2019

Today, blue beats green most everywhere



Bloomberg NEF, 2021

Tomorrow (2030*), green looks more promising



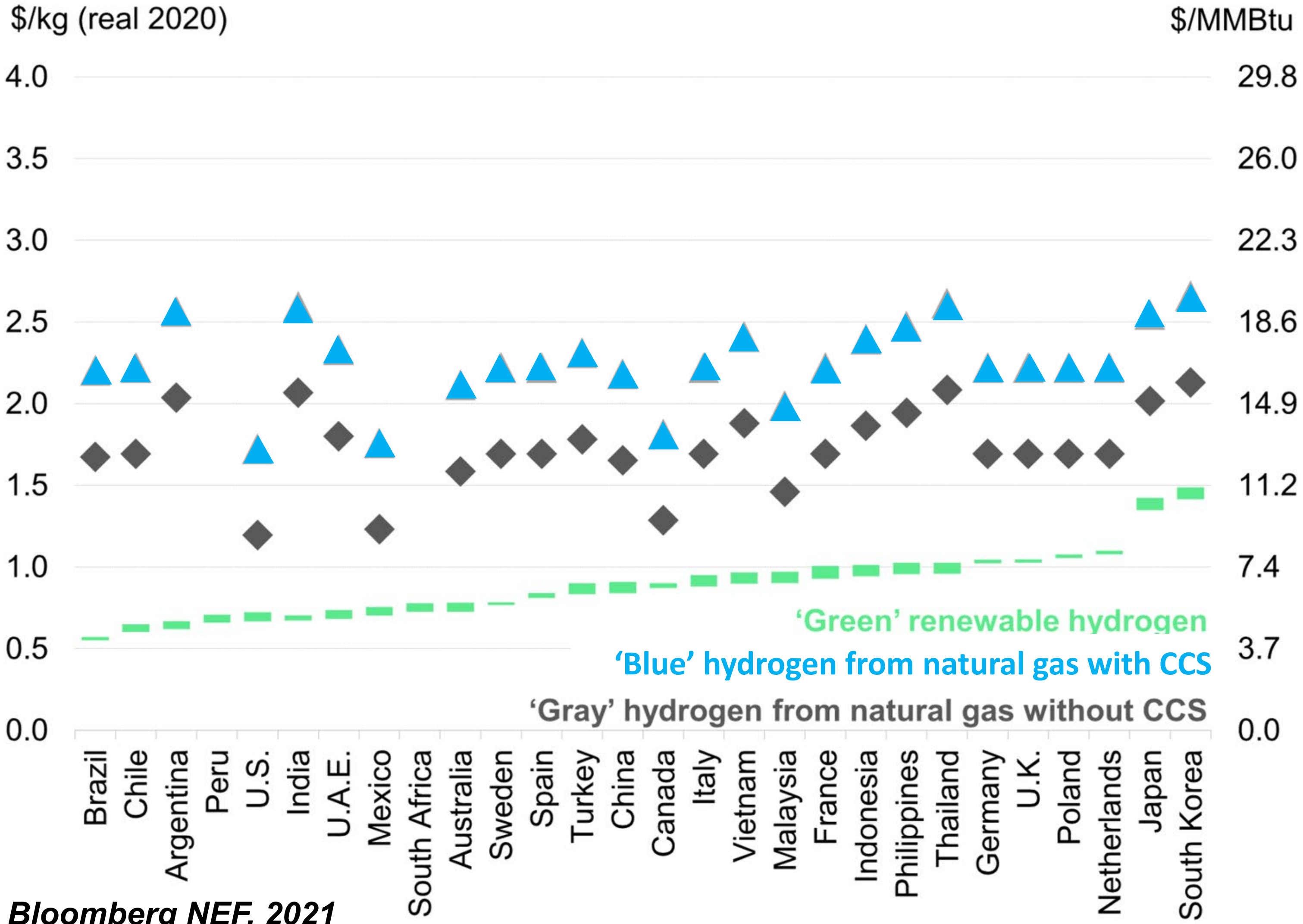
Bloomberg NEF, 2021

* Big grain of salt on this date 2035-2040 more likely for same outcome

Sensitive to learning rates for renewables, electrolyzers

Infrastructure limits & deployment rates both important

Eventually (2050), green should beat blue most markets



Bloomberg NEF, 2021

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Facility	H_2 Production (tonnes/day)	H_2 Production Process	Operational Commencement
Blue hydrogen			
Enid Fertiliser	200 (in syngas)	Methane reformation	1982
Great Plains Synfuel	1,300 (in syngas)	Coal gasification	2000
Air Products	500	Methane reformation	2013
Coffeyville	200	Petroleum coke gasification	2013
Quest	900	Methane reformation	2015
Alberta Carbon Trunk Line - Sturgeon	240	Asphaltene residue gasification	2020
Alberta Carbon Trunk Line - Agrium	800	Methane reformation	2020
Sinopec Qilu	100 (estimated)	Coal/Coke gasification	2021 (planned)
Green hydrogen			
Trondheim	0.3	Solar (!)	2017
Fukushima	2.4 (10 MW)	Solar	2020
NEOM	650	Wind + Solar	2025 (planned)

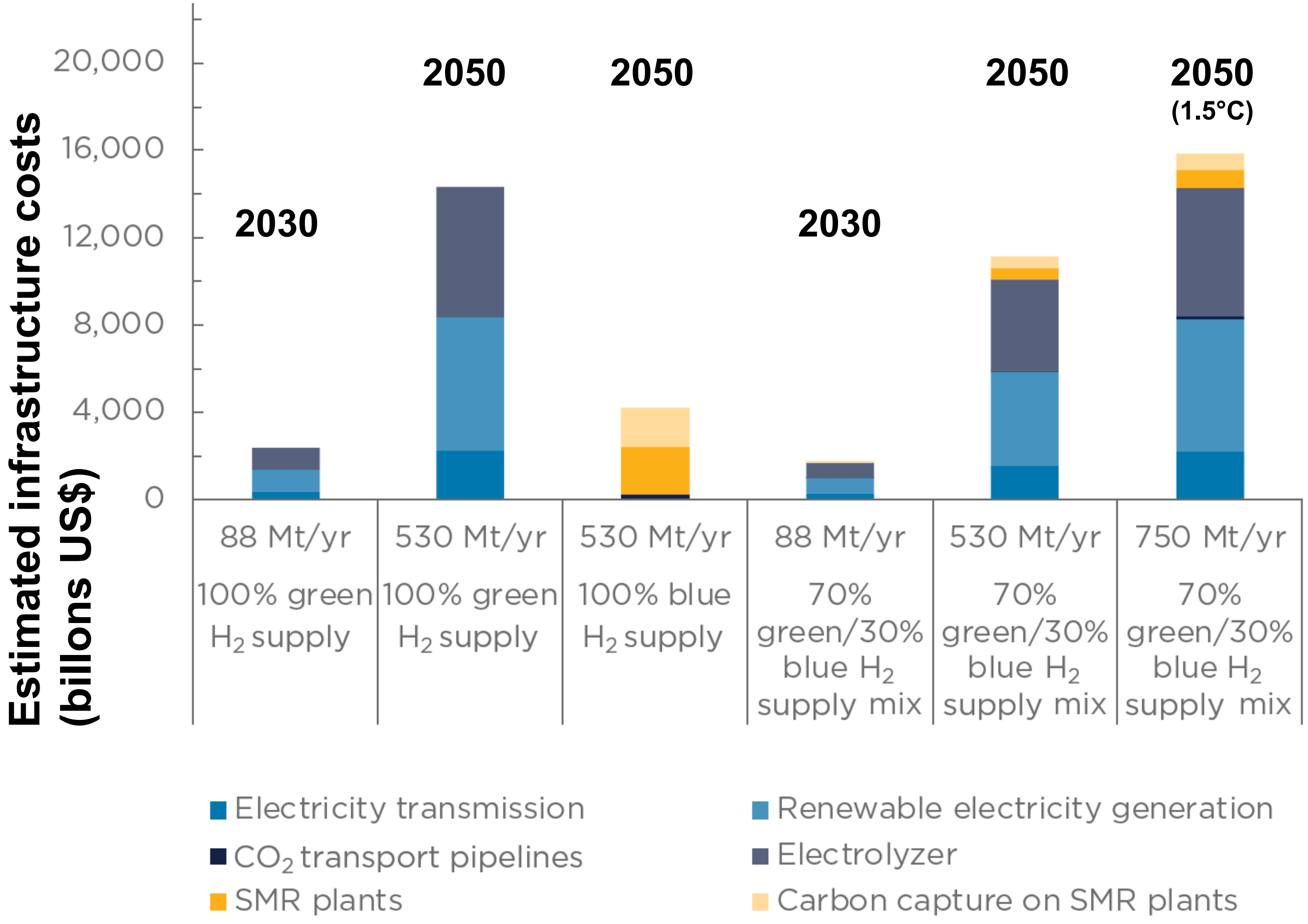
Friedmann et al., 2020

Infrastructure limits will delay deployment & add to system costs

- Transmission lines
- Power build-out
- Electrolyzer costs

Mix of blue & green H_2 delivers lower cost + greater volumes

Global hydrogen demand (2030 & 2050; IEA scenarios)



Source: Fan et al., 2021

Key challenges

Sector	2020	2030	2050
Bioenergy			
Share of modern biofuels in modern bioenergy (excluding conversion losses)	20%	45%	48%
Advanced liquid biofuels (mboe/d)	0.1	2.7	6.2
Share of biomethane in total gas networks	<1%	2%	20%
CO_2 captured and stored from biofuels production (Mt CO_2)	1	150	625
Hydrogen			
Production (Mt H_2)	87	212	528
of which: low-carbon (Mt H_2)	9	150	520
Electrolyser capacity (GW)	<1	850	3 585
Electricity demand for hydrogen-related production (TWh)	1	3 850	14 500
CO_2 captured from hydrogen production (Mt CO_2)	135	680	1 800
Number of export terminals at ports for hydrogen and ammonia trade	0	60	150

Note: mboe/d = million barrels of oil equivalent per day; Mt = million tonnes; H_2 = hydrogen.

IEA, Net-zero 2050 (2021)

Upstream emissions receiving greater attention

Howarth & Jacobsen (2021) + NY Times story = controversy

Upstream emissions today

- **EPA: 1.1-1.7%**
- **EDF: 2.0-2.3%**
- **Flaring regions: closer to 3%**

What's possible

- Monitoring technology getting good
- Able to seal & repair leaks
- Industry voluntary standard:
  - 0.2% (best)
  - BAU (too common)
- Biden admin: proposing new regs.

How green is blue hydrogen?

Robert W. Howarth[1] | Mark Z. Jacobson[2]

For Many, Hydrogen Is the Fuel of the Future. New Research Raises Doubts.

By Hiroko Tabuchi

A few new and helpful analyses

Pembina Inst. (2021)

includes upstream emissions (~10% LCA if not managed)

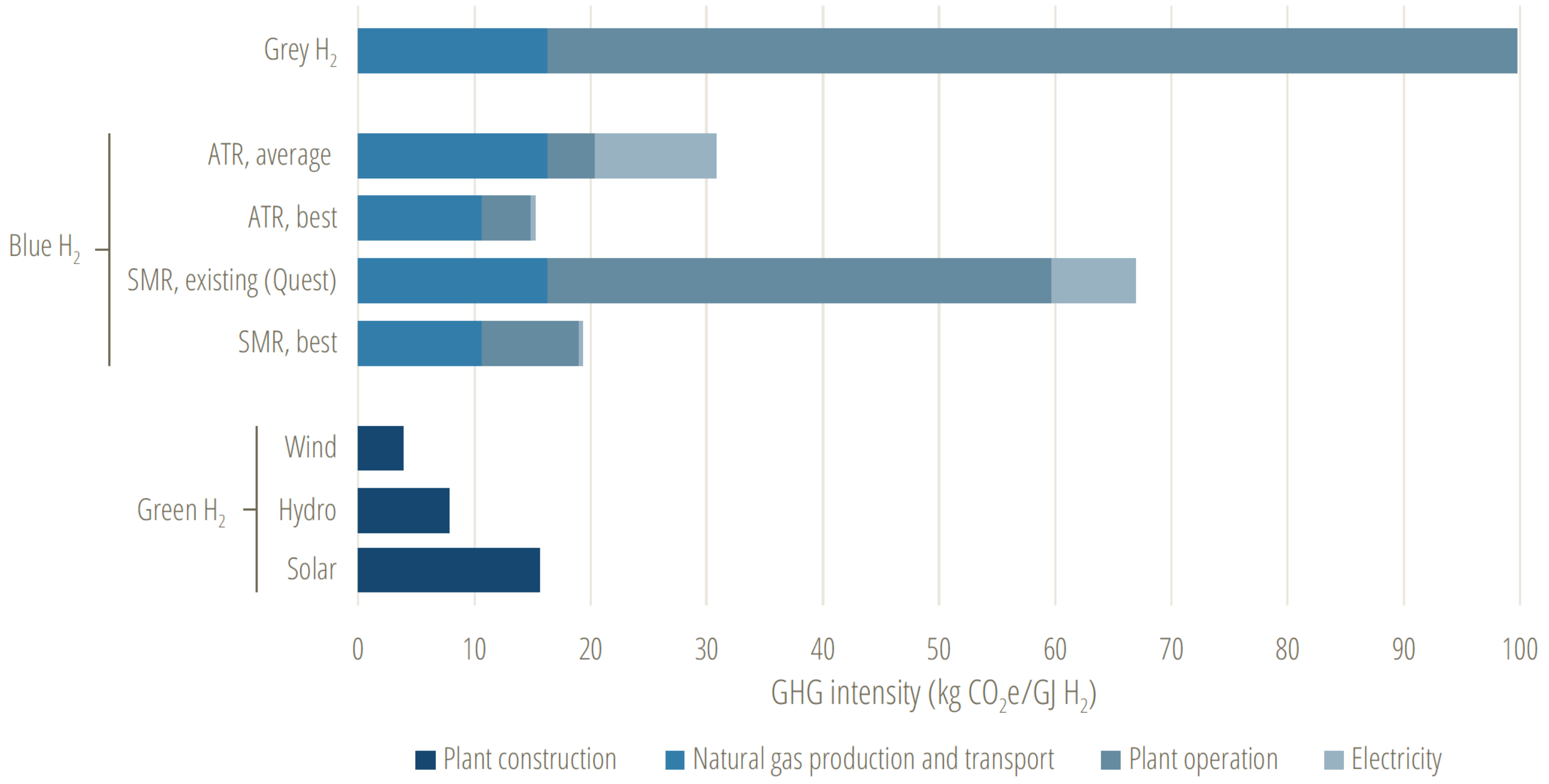
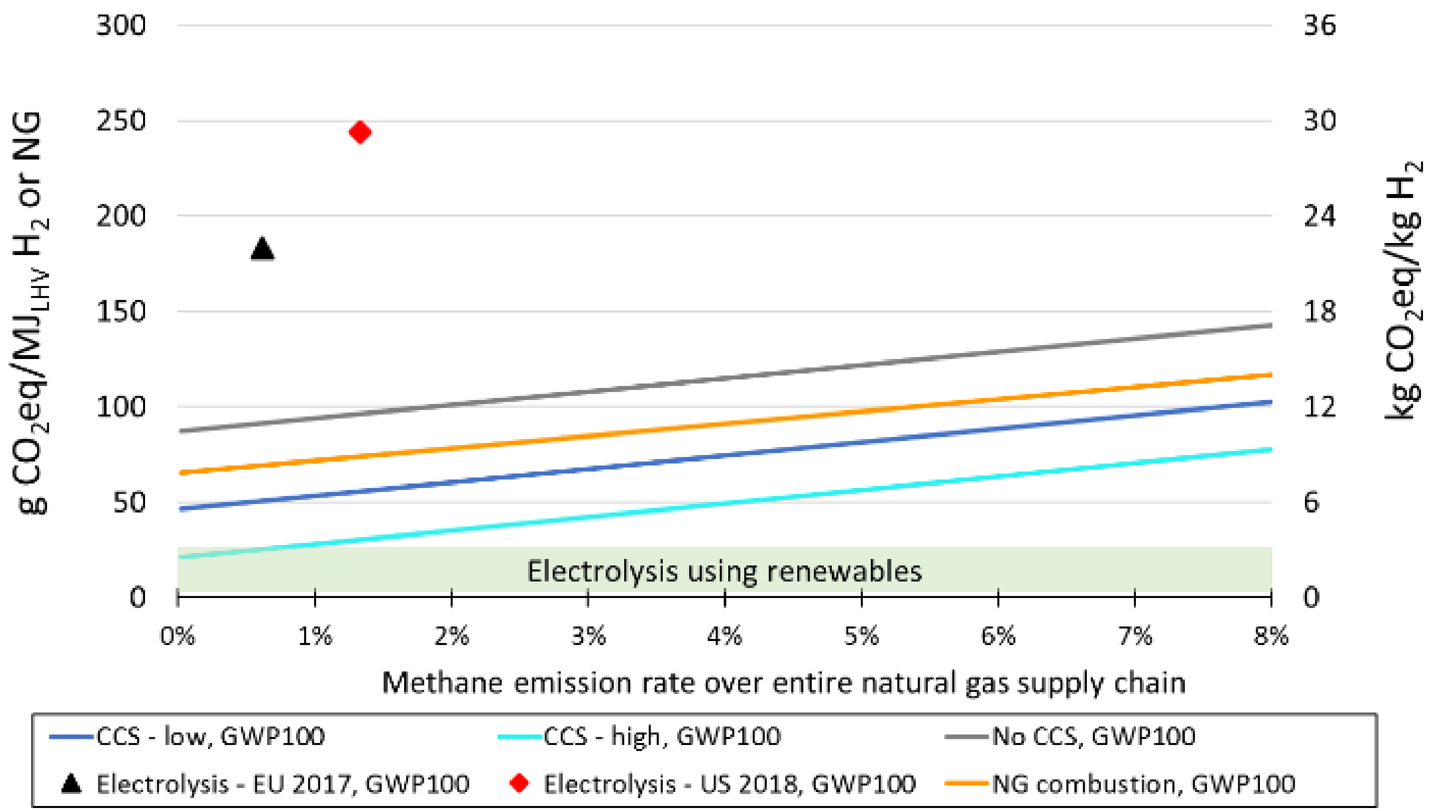


Figure 3. Life cycle carbon intensity of hydrogen production

Conclusions: Blue H_2 could reduce 85%
Blue H_2 best = solar best



A few new and helpful analyses

Bauer et al. (2021)

Conclusion: high capture Blue H_2 could contribute to a net-zero world with very low upstream emissions

These numbers matter!

Policy & political dynamic is non-linear & changing quickly

CALIFORNIA ENVIRONMENTAL JUSTICE ALLIANCE

Hydrogen Policy Landscape: US

Hydrogen PTC – ranked against standard SMR

- $3/kg for 95% less; $1/kg for 95-85%; $0.75 for 75-85%
- Not possible to achieve the 95% standard!!

CCS & 45Q

- Could be as high as $85/ton CO_2 – cannot be stacked with H_2 PTC
- "Denial of double benefit" provision could make it difficult

Some Power Sector Bits

- Clean Energy Payment Program (CEPP) – H_2 footprint assumptions & baseline will affect payments
- 9 states have clean electricity standards – not clear how H_2 might qualify for rate recovery

Hydrogen Hubs, Innovation & Infrastructure

- $8B for 4 hydrogen hubs
- Hydrogen earth shot
- Ports, fueling stations, CO_2 and H_2 pipelines, new transmission lines

Hydrogen Policy Landscape: Other nations

UK
- Blue & green H_2 part of national strategy
- Hubs + contract for differences

Canada
- Blue & green H_2 part of national strategy
- Infrastructure, clean fuel standard, $170/t C tax

EU
- Blue & green H_2 part of EU strategy
- Infrastructure, incentives, grants

Middle East
- KSA: Blue & green H_2 part of national strategy
- UAE: Blue & green H_2 part of national strategy
- Qatar: Blue H_2 part of national strategy

Japan
- Low-C green premium (blue & green)
- Focus on fuel cells, electrolyzers, shipping

China
- Green H_2 part of national strategy (also grey)
- Focus on fuel cells & electrolyzers

India
- Announcement of new industrial H2 program (steel and refining/chemicals focus)

Chile
- Green H_2 part of national strategy

Australia
- Blue & green H_2 part of national strategy

A few parting thoughts

Arithmetic matters!!

US policy is being shaped without numeracy

- We may shut out virtuous blue & green options
- Will slow deployment
- Will limit US trade, export, and climate priorities

Other nations are taking an “all of the above” approach

We will see more baseless assessments and aggressive messaging

- Many groups have a business model rewarding shrill & innumerate claims
- More scientists and advocates comfortable with ad hominem attacks

Critical & important role for groups like NETL & GTI

Thank You

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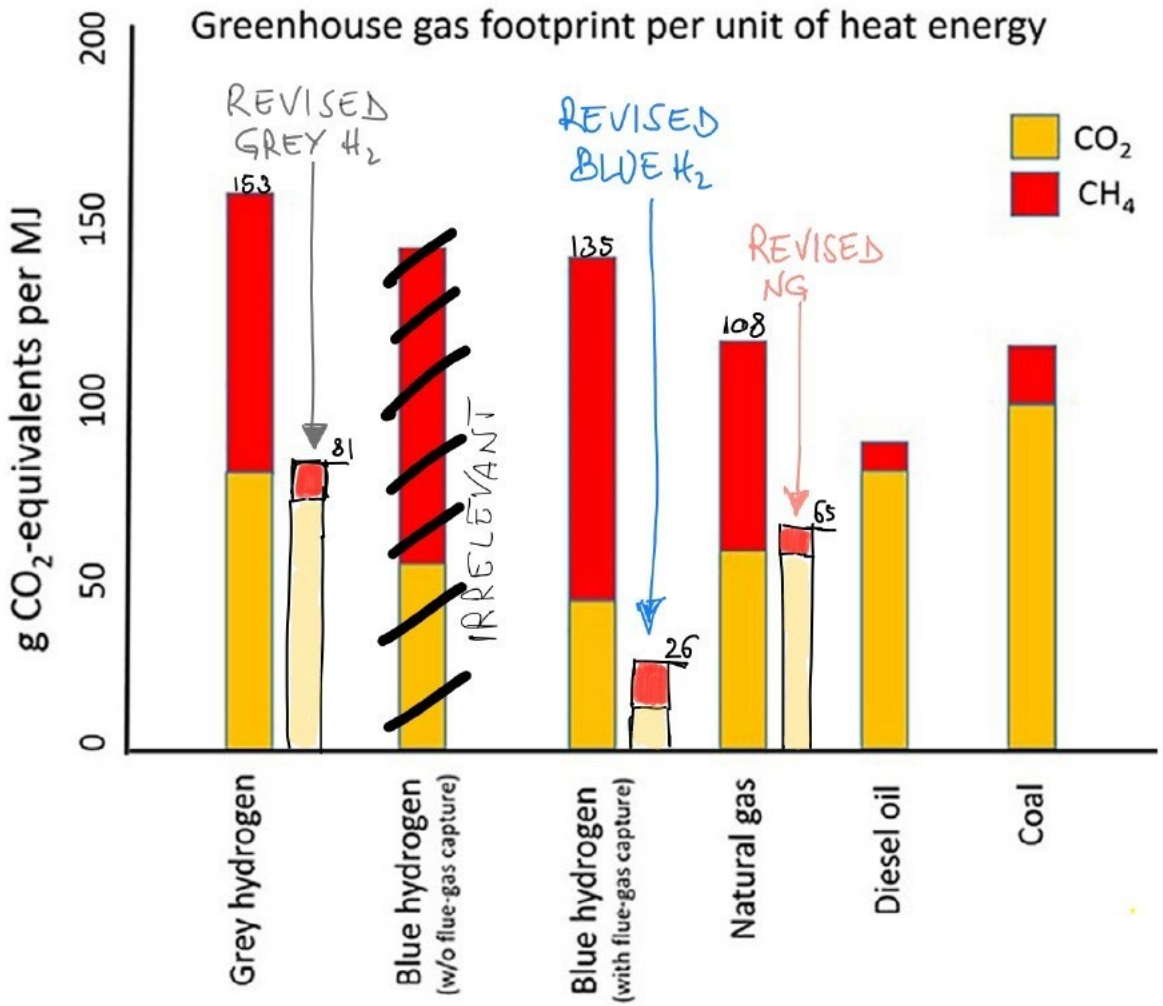
Assumptions

Howarth & Jacobsen (2021)

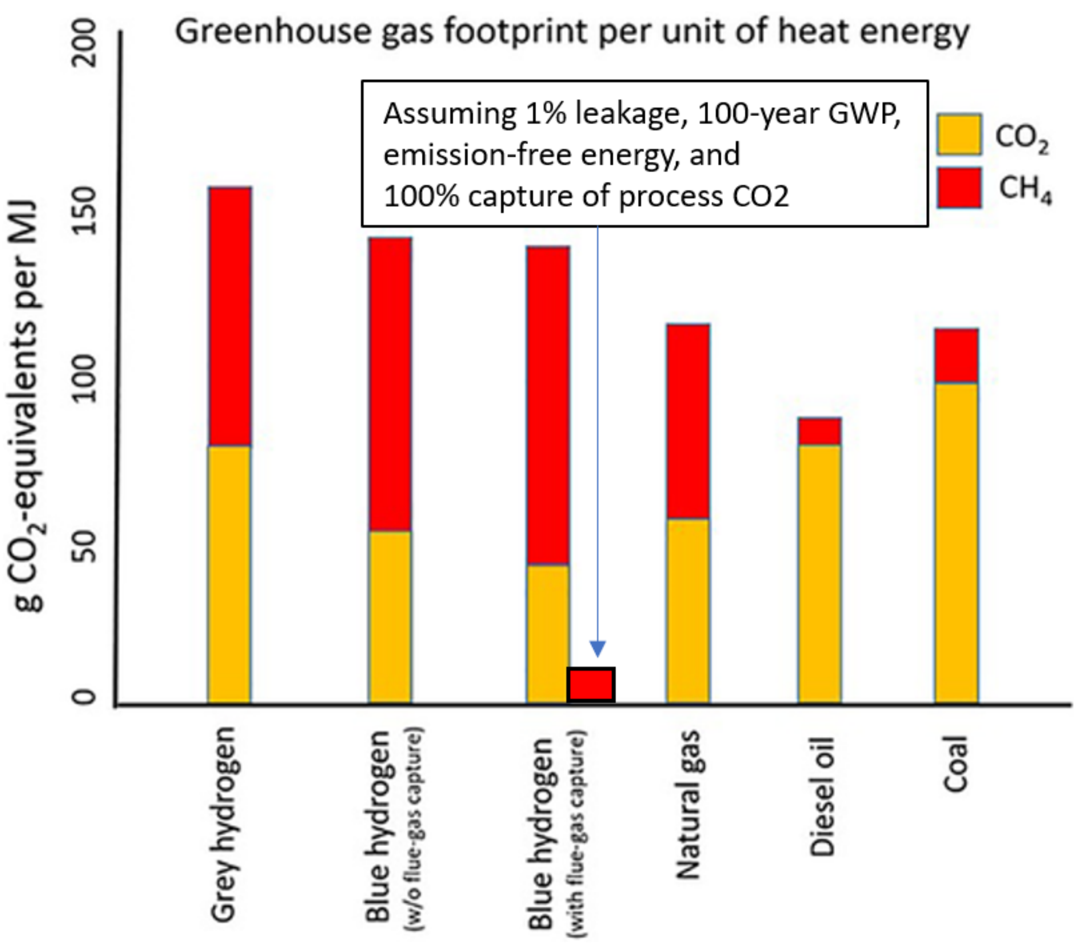
- **Assessed steam methane reforming (SMR)**
  - New projects use an ATR, not an SMR. This allow both higher capture rates and lower costs.
- **Low capture rate** - only 65% capture.
  - New projects are >90% and may are >95%
- **High methane leakage rates** - 3.5% fugitive emissions.
  - US Average: 1.25 (0.85-1.75 range)
  - Best in class: 0.2%
- **Large methane consumption in capture tech** – liquid solvent adder
  - Factually incorrect
    - Capture from an SMR requires almost no energy
    - Does not use liquid solvent approach for 60% capture
    - This is important, since the incorrectly assumed extra energy would leads to extra methane emissions (& extra fugitive).
- **Using a 20-year warming potential for methane**
  - This is debatable: IPCC uses 100-year.
  - 20-year impacts higher than 100-year impacts

Conclusion: Blue H_2 could not be clean & could never contribute to a net-zero world

Informal revisions of H&J key figure



Romano: 2021



Caldeira: 2021