COLUMBIA | SIPA
Center on Global Energy Policy

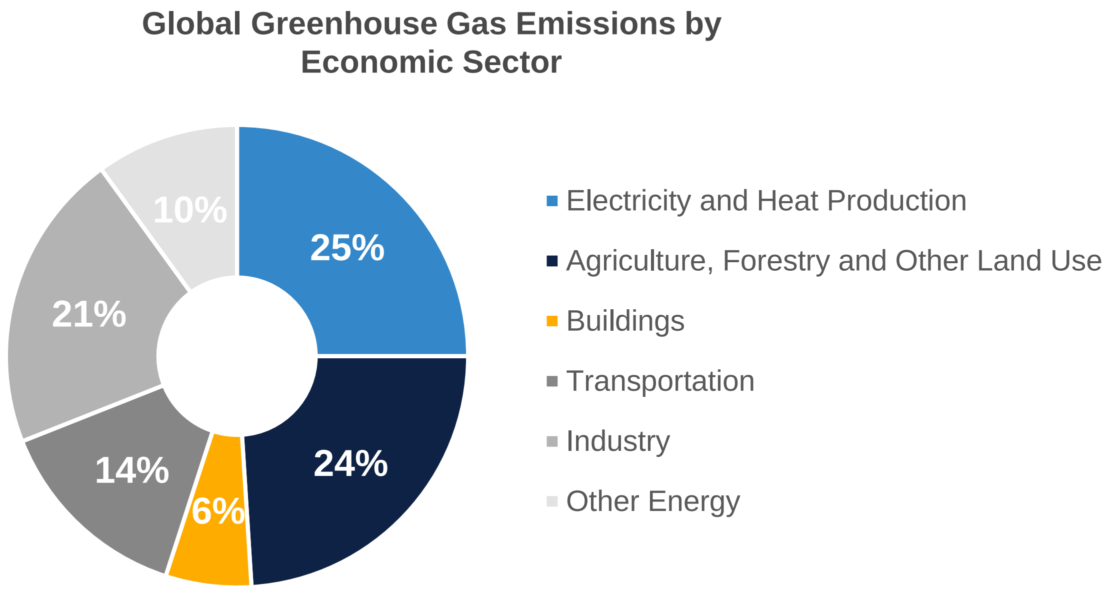
Clean Industry for America: Options, Costs, and Policy Considerations

Dr. S. Julio Friedmann, Center on Global Energy Policy at Columbia Univ.

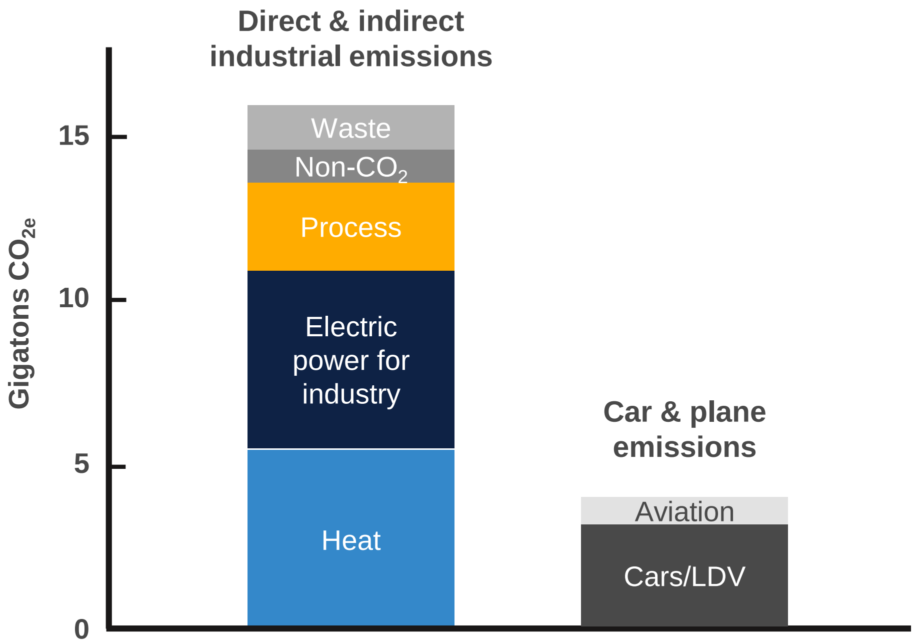
EESI "Climate Camp" Feb 27th, 2021

Industrial heat emissions: ~10% global emissions

Can't make key climate goals without solutions



EPA 2016



IPCC (2014); IEA (2017, 2019)

Industry emits more than transportation

Heat for industry emits more than cars & planes combined

The core arithmetic of net-zero is clarifying:

All sectors
All approaches

Only one way to stabilize climate: net-zero everywhere

- Any emissions anywhere add to atmospheric CO_2 concentration
- Every year of delay makes problem worse
- We haven't yet fielded solutions for about 50% of the portfolio

For net zero: CO_2emissions - CO_2removals = 0

- Any residual emissions must be balanced by removal
- Likely need 10 Gt/y CO_2 removal by 2050
- Any delay or failure requires more CO_2 removal

Carbon from the earth must be returned to the earth

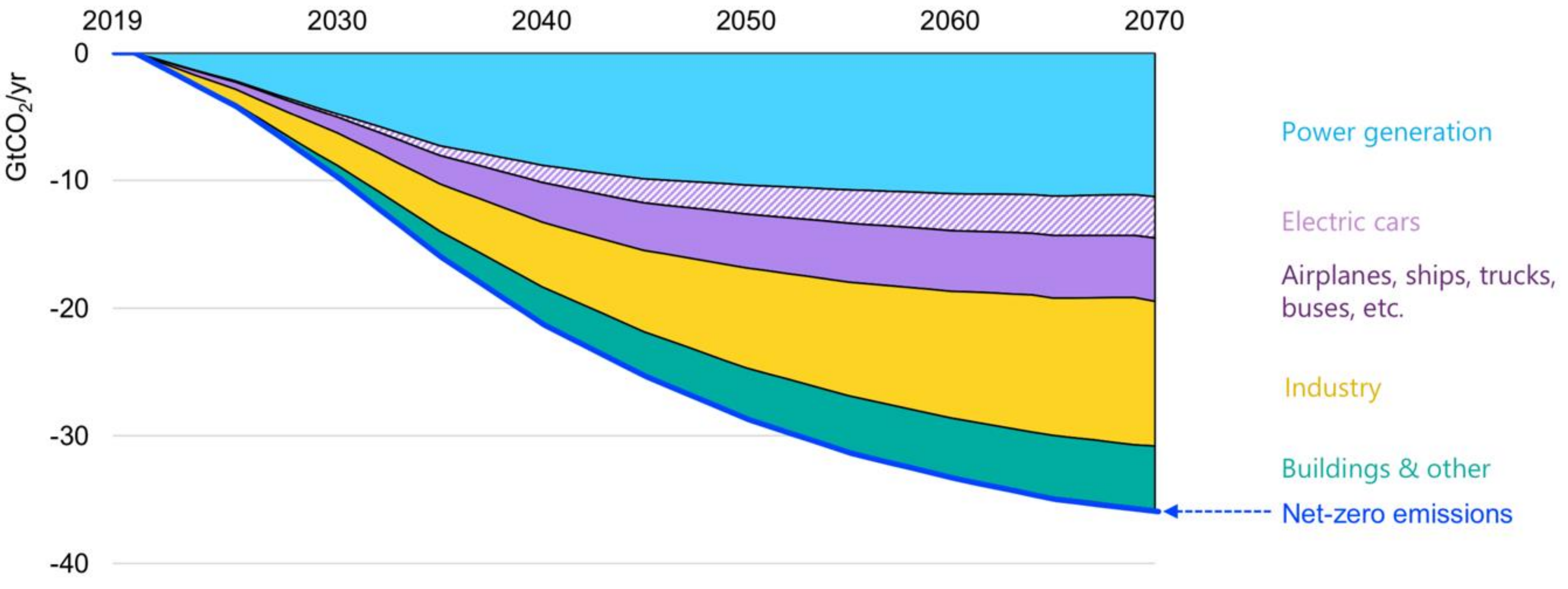
- Natural systems must return to balance
- Biosphere has limited capacity
- Risk of return is getting worse

CO_2 return to the geosphere anchors the net-zero global economy

Industry is huge and hard

Trade exposed, few technology options, expensive

Global CO_2 emissions reductions in the IEA Sustainable Development Scenario (2 °C) relative to baseline

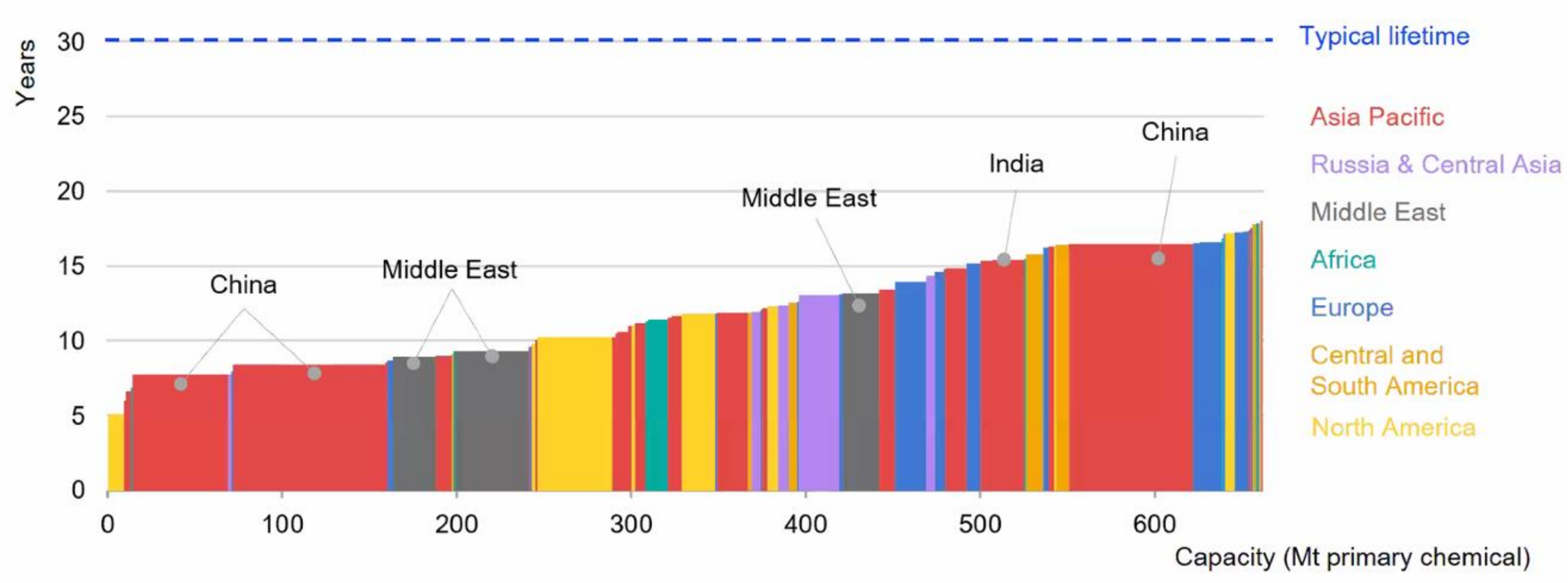


Source: IEA 2020

CCUS key benefits: saves time, saves money, reduces risk

Can decarbonize existing assets without waiting for retirement

Age profile of primary chemical production facilties

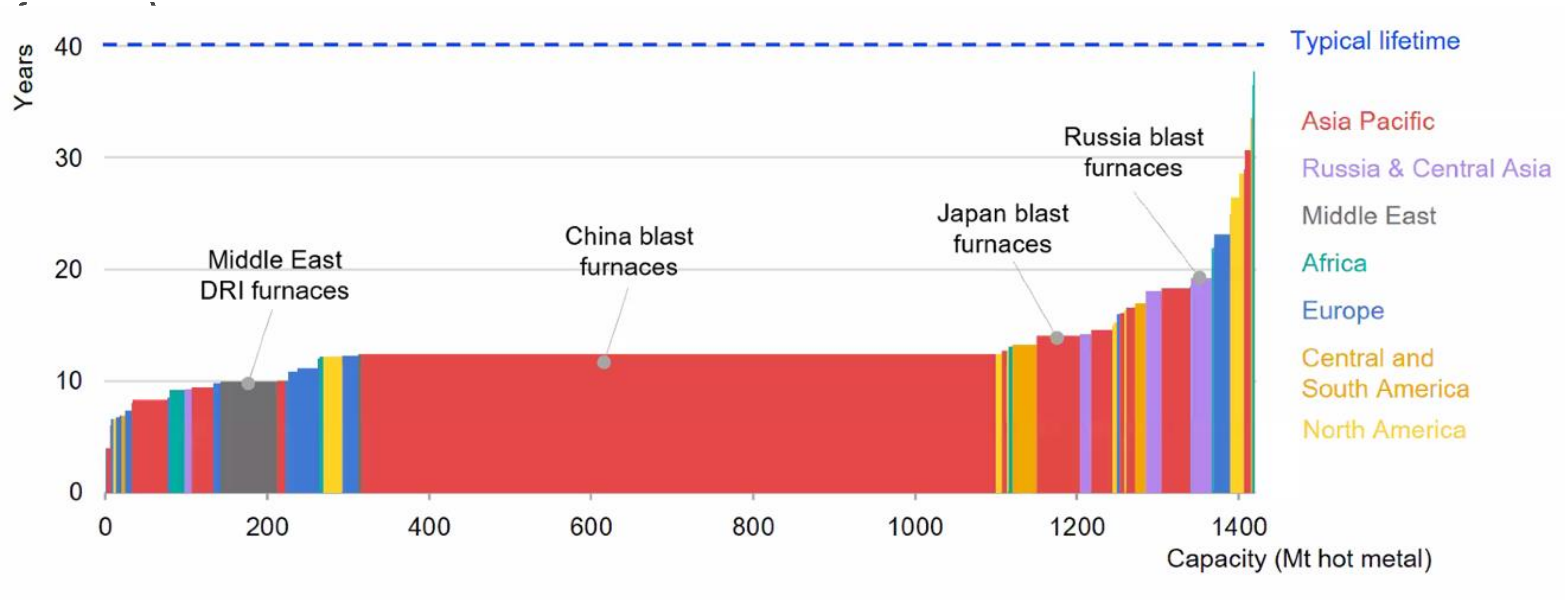


Source: IEA 2020

CCUS key benefits: saves time, saves money, reduces risk

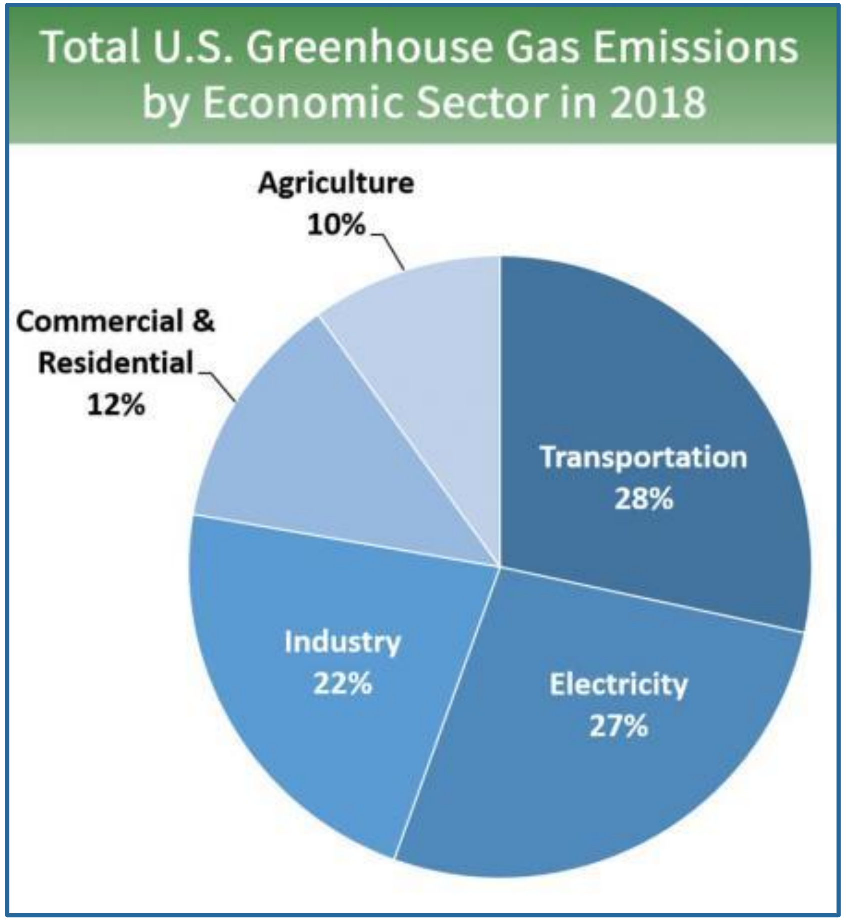
Can decarbonize existing assets without waiting for retirement

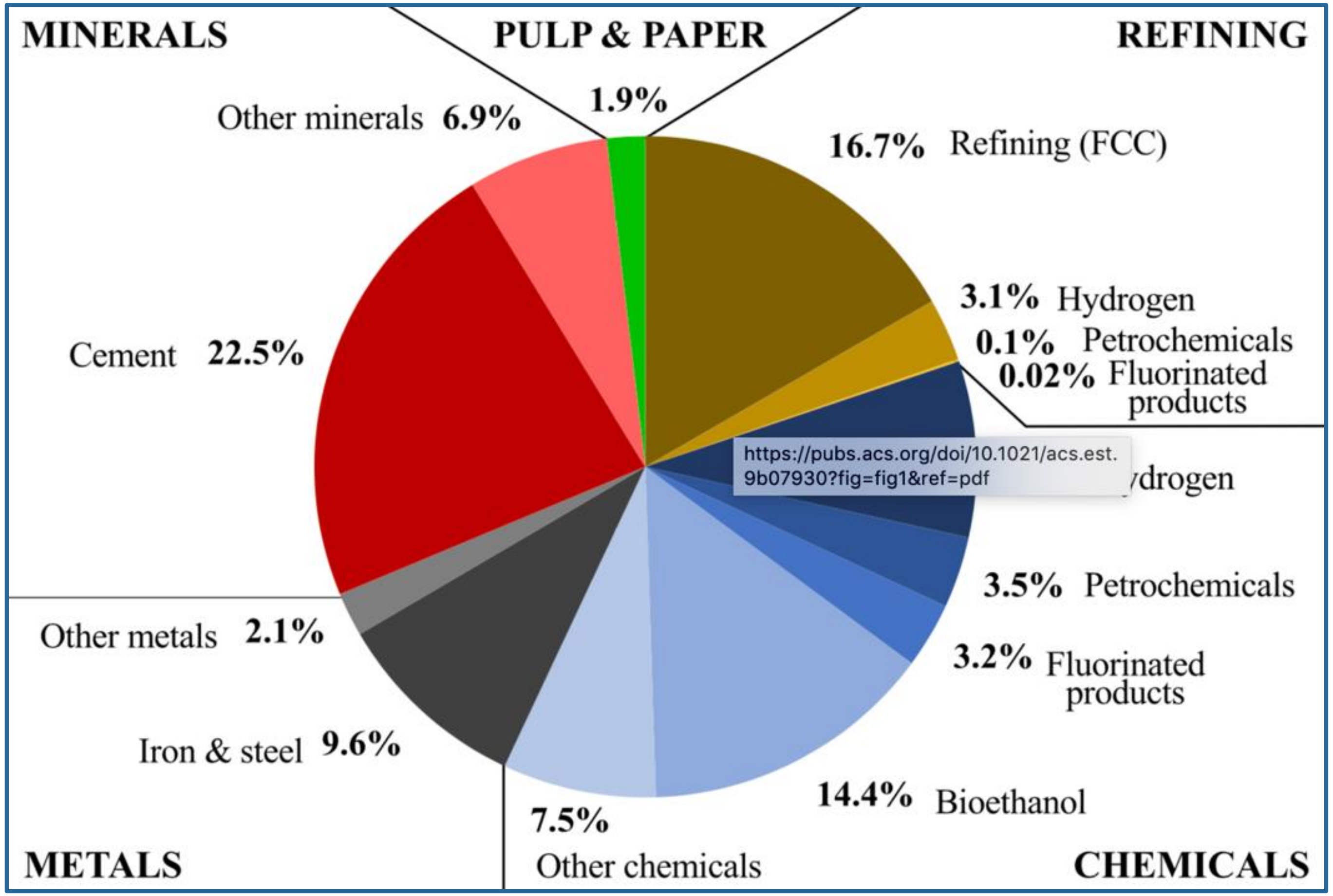
Age profile of primary steelmaking from iron ore (mostly blast



Source: IEA 2020

US industrial emissions by sector

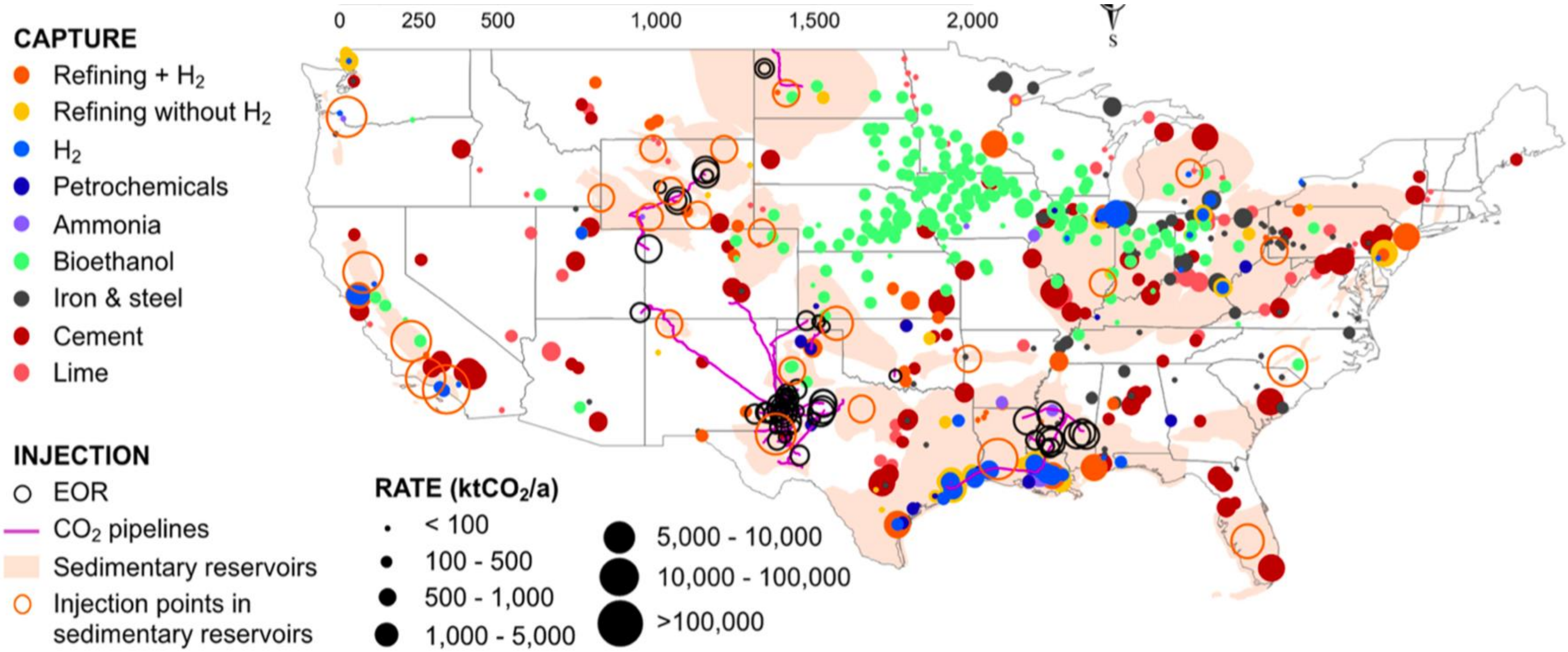




Sources: EPA (2018) & Pilorgé et al., 2020

US industrial source locations by sector

Many are near viable CO_2 storage resources



Source: Pilorgé et al., 2020

Low C Heat: Applications & Sources

Not that many options for high-quality, large volume heat

Hydrogen

- Green: electrolysis of water from zero-C power
- Blue: From natural gas, with CCS (90%)
- Gray: From natural gas, but not low-C

Electricity

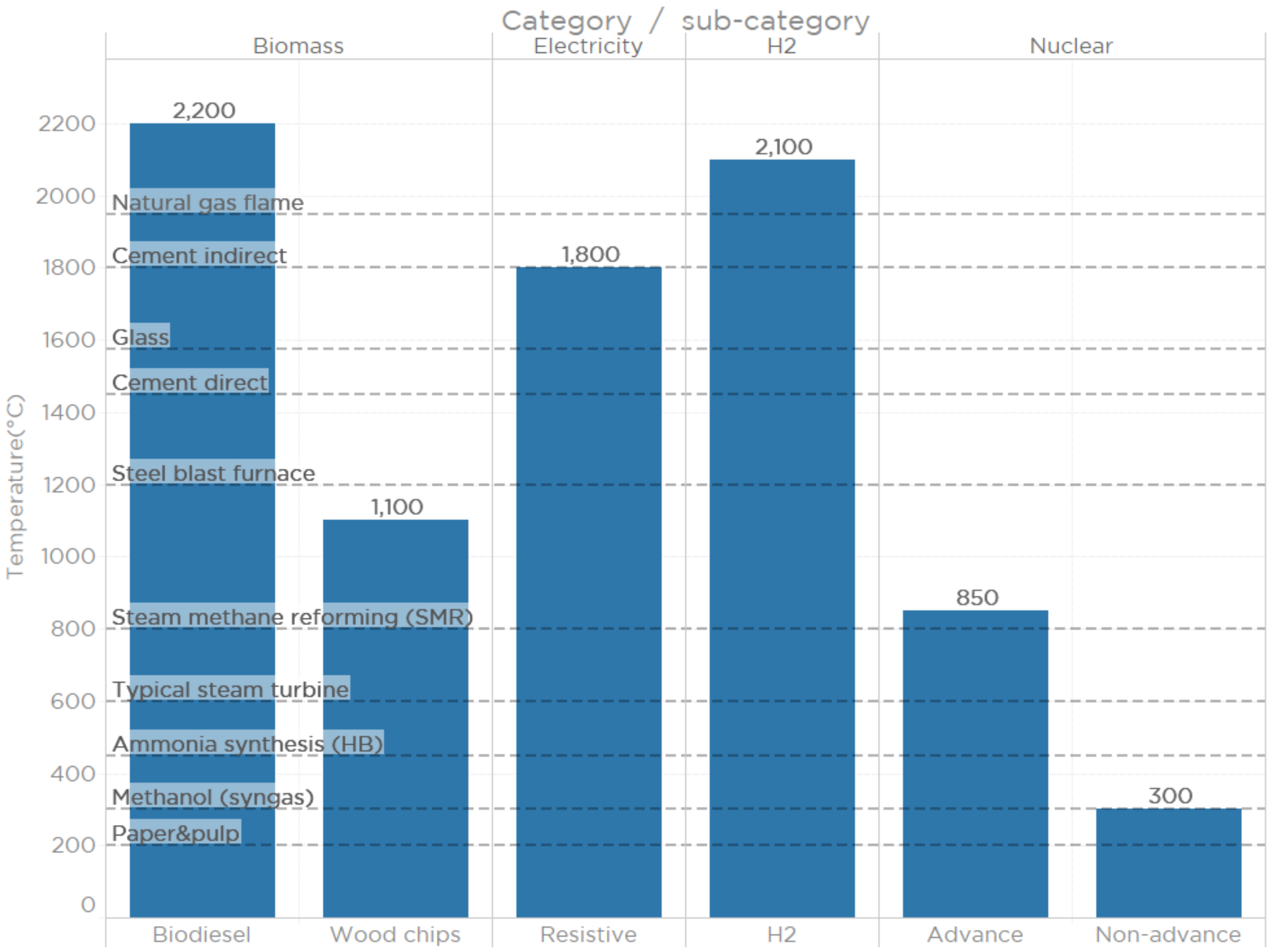
- Must be zero-C supply & 90% capacity
- Radiant & resistive heating most mature

Biomass

- Must be low-C on a life-cycle basis
- Wood chips & biofuels most mature
- Biogas supplies are problematic

Carbon Capture

- Captures both heat and process emissions
- Lower cost than many options
- Requires CO2 storage sites & infrastructure



Hydrogen: Essential for speed, cost, and versatility

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

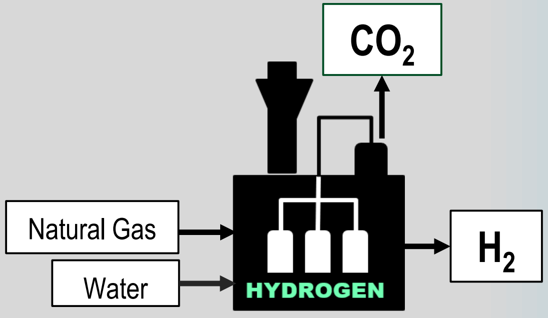
- Alternative power storage (like a long-duration battery) with stationary fuel cells
- Get value from power congestion & curtailment

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 CO2 removal systems)

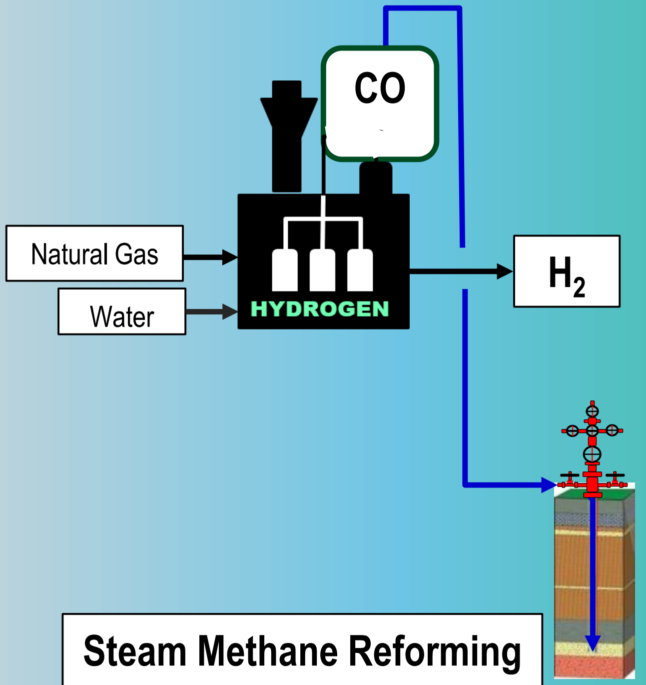
How hydrogen is made

GRAY



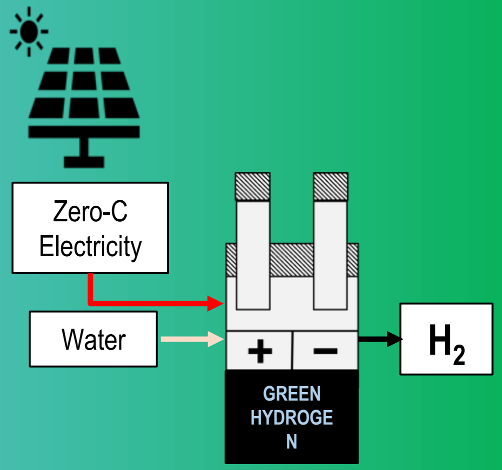
Steam Methane Reforming

BLUE



Steam Methane Reforming with CO_2 Capture and Storage

GREEN



Electrolysis of Water with Zero-Carbon Energy

Source: Air Products, 2020

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)

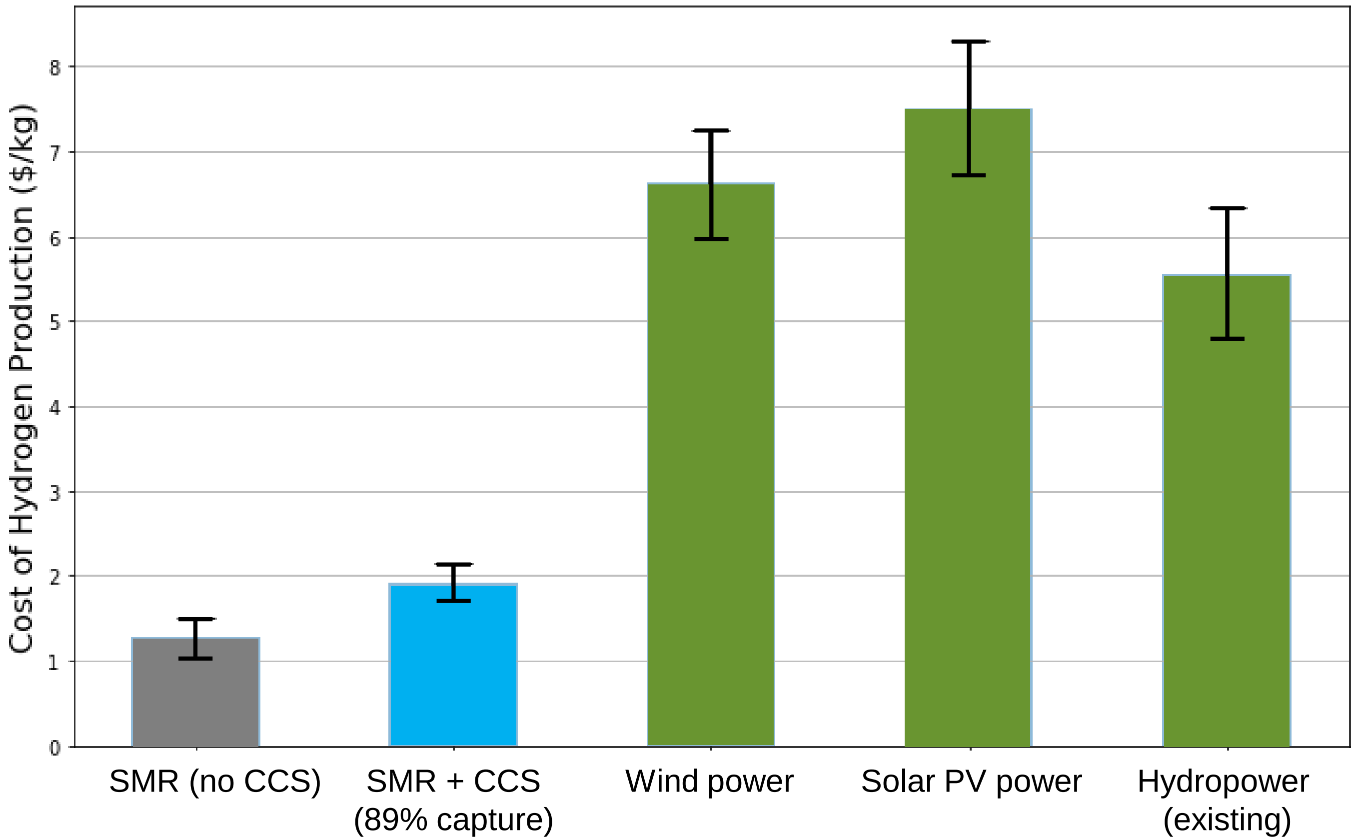
Manufacturing limits

- No mass manufacturing: bespoke production
- China, Germany, Korea, Norway, Japan trying to change

Infrastructure limits

- Massive build of transmission & zero-C electricity (26,000 TWh = 530 Mtpa)

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

Source: Friedmann et al., 2019

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)

Chemicals: 3% of global CO_2 emissions

Heat for chemicals: ~1.5% of global CO_2 emissions

Wide range of processes, uses, footprints, options

Grangemouth ethylene plant, Scotland

Best options (cost & footprint)

- **Hydrogen (first blue H_2 then green)**
- **Biogas, biomethane**
- **Partial electrification (e.g., steam)**

Other decarbonization options:

- **Efficiency (large opportunity)**
- **Novel processes (e.g., electrolytic chemical production; CO_2 upcycling)**

Iron & Steel: 5% of global CO_2 emissions

Heat for Iron and Steel: ~2.5% of global CO_2 emissions

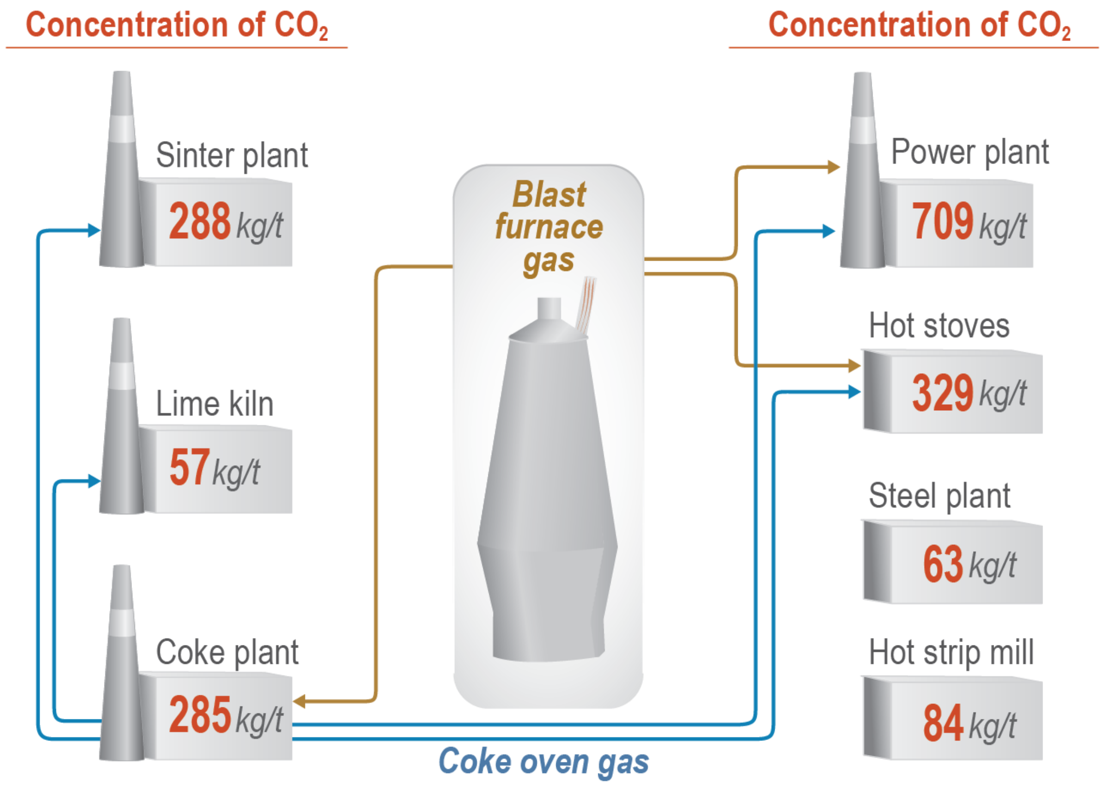
Requires 1200° C and continuous operation

Best options (cost & footprint)

- CCS on whole system
- ”Biocoke”
- Some hydrogen (Nippon Steel)

Other decarbonization options:

- Efficiency
- Modified coking
- Adopting EAF (w/ DRI & zero-C H_2)
- Novel processes (e.g., upgraded smelting, electrical reduction of ore)



Cement industry: 6% of global CO_2 emissions

Heat for cement : ~2% of global CO_2 emissions

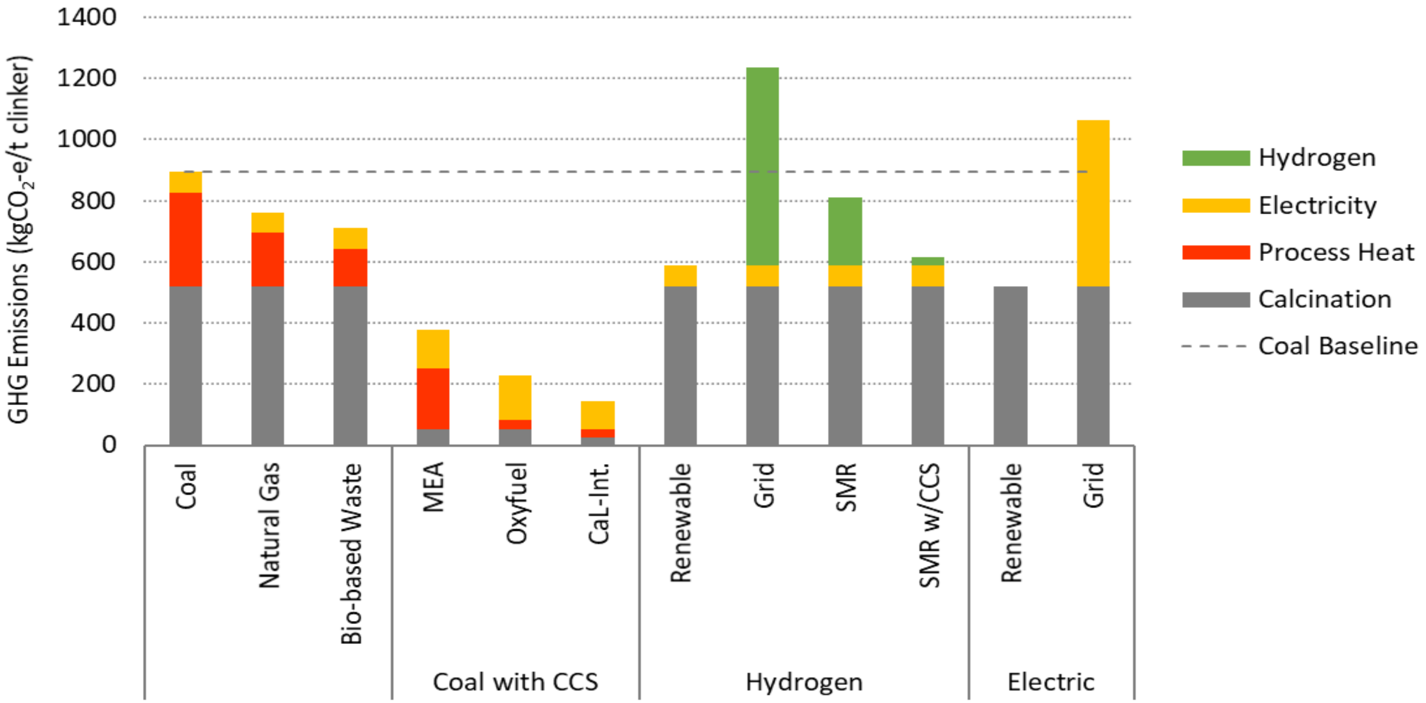
Requires 1450° C and continuous operations

Best options (cost & footprint)

- **CCS on whole system**
- **Biomass mix**

Other decarbonization options:

- **Clinker substitution**
- **Efficiency**
- **Alternative binders**
- **Novel processes (e.g., Ca-L, electrical decomposition)**



Policy options for US low-C industrial development

Incentives
- Buy-clean procurement: cement & steel & fuels
- Tax credits: PTC/ITC for low-C hydrogen, expanded 45Q, etc.
- DOE grants: Demonstration & pilot testing
- Asset replacement assistance

Infrastructure
- CO_2 pipelines & storage facilities, hydrogen pipelines
- High-voltage transmission lines
- Port upgrades

Regulations etc.
- Emissions standards & caps (+/- trading)
- Border tariffs vs. output-based rebates

Innovation is essential and underserved

Wage, equity & labor considerations are essential

MORE ANALYSIS IS GOOD

Levelized Cost of Carbon Abatement (LCCA) is an improved tool for net-zero decisions

It allows one to assess the most cost-effective way to reduce emissions

Key findings for decision-makers

- **Net-zero framework** requires improved methodologies focused on **carbon reduction & removal**.
- LCCA is keyed to **specific displacements of emissions**, which varies greatly by geography, market, technology, policy specifics, and what is displaced.
- LCCA can serve to make rigorous "**apples-to-apples**" comparisons of policies or potential investments.
- LCCA is **powerful** but is only one metric and concern.