

CCU

R&D STRATEGIES

2023

NASEM, 25 October 2023

POV: CCU R&D TO SUPPORT DEVELOPMENT

To mature into a relevant solution for a post-fossil circular economy, a climate solution, and/or material feedstock platform for manufacturing, a few things need to happen for CCU

- *demonstration of economic viability (projects, processes)*
- *superior CO₂-based materials, in price, performance, risk, or all three*
- *clear understanding of benefits and risks*
- *shift toward process demonstration (vs. reaction demonstration)*

In order to achieve those milestones, we need

- *efficient and effective CCU material synthesis pathways*
- *techno-economic analysis, and life cycle analysis*
- *investable / bankable projects and business models*

CCU COMMERCIAL DEVELOPMENTS

What are startups attempting?

What are investors backing?

How is private and public funding changing?

FOLLOW THE VENTURE MONEY

Investment into venture-backed climate companies tracked by CTVC since Q3 2020 (\$B)

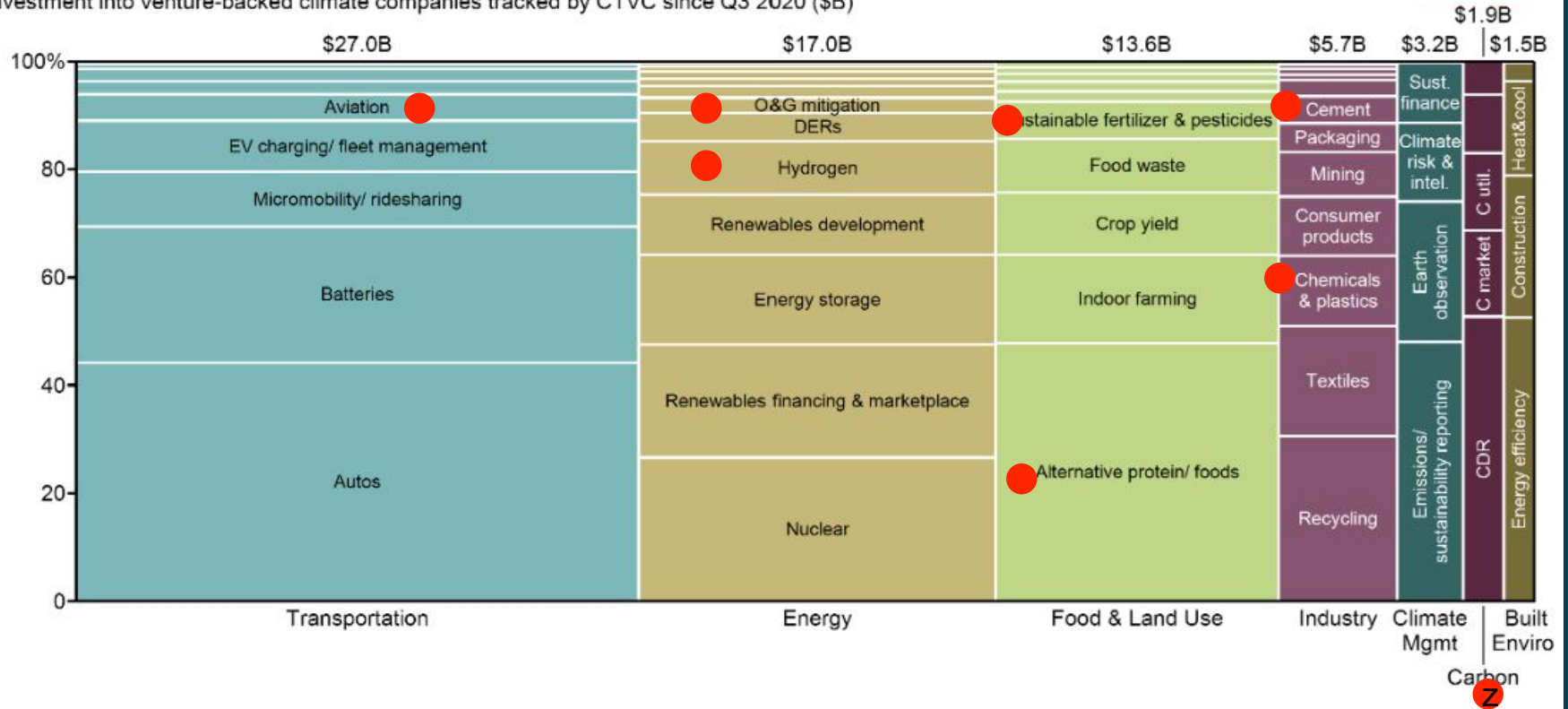
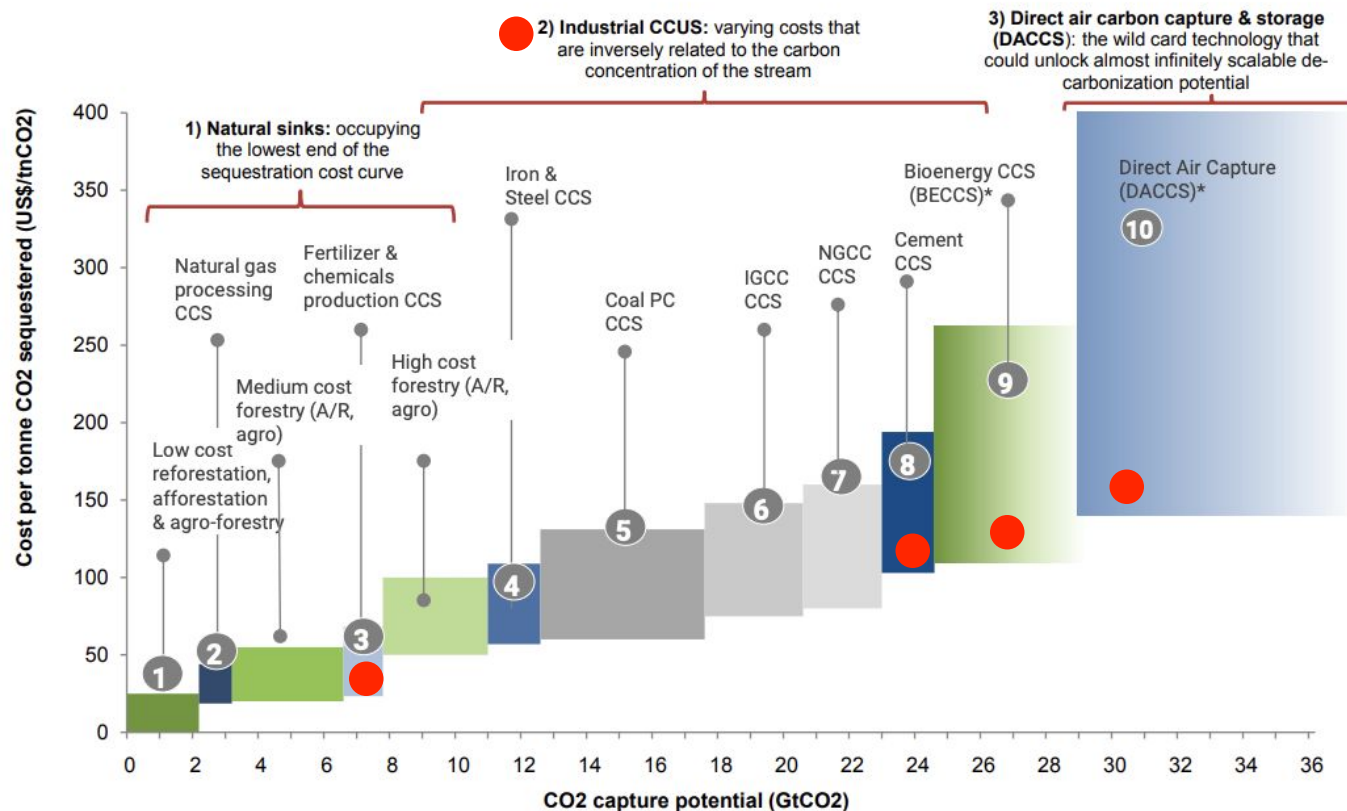


Exhibit 18: The carbon sequestration curve is less steep vs. the conservation curve but has a higher range of uncertainty given the limited investment to date and the largely pilot nature of these technologies

Carbon sequestration cost curve (US\$/tCO₂eq) and the GHG emissions abatement potential (GtCO₂eq)

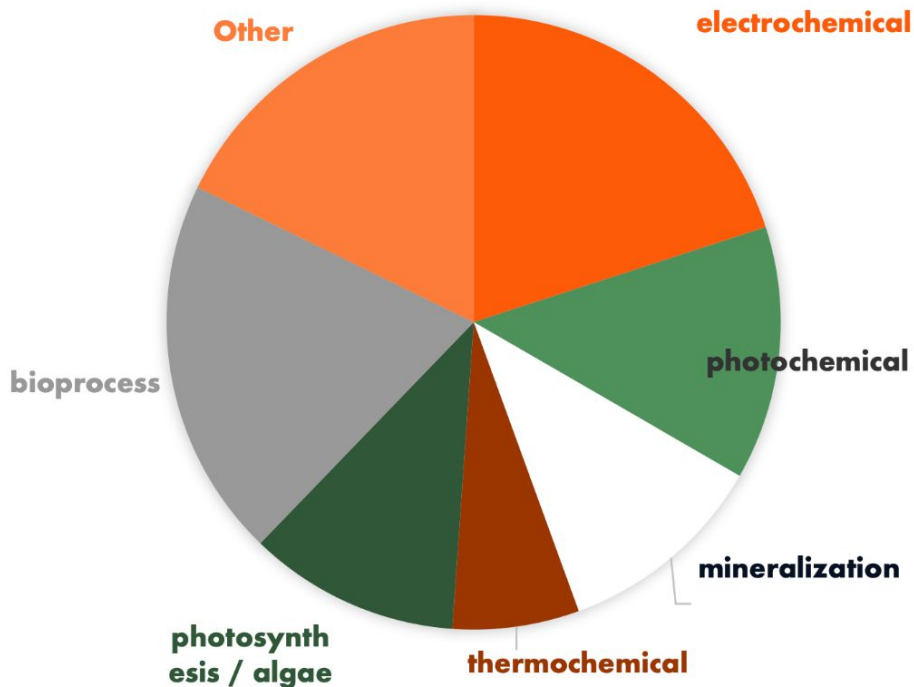


Source: Goldman Sachs
“Carbonomics”, 2023

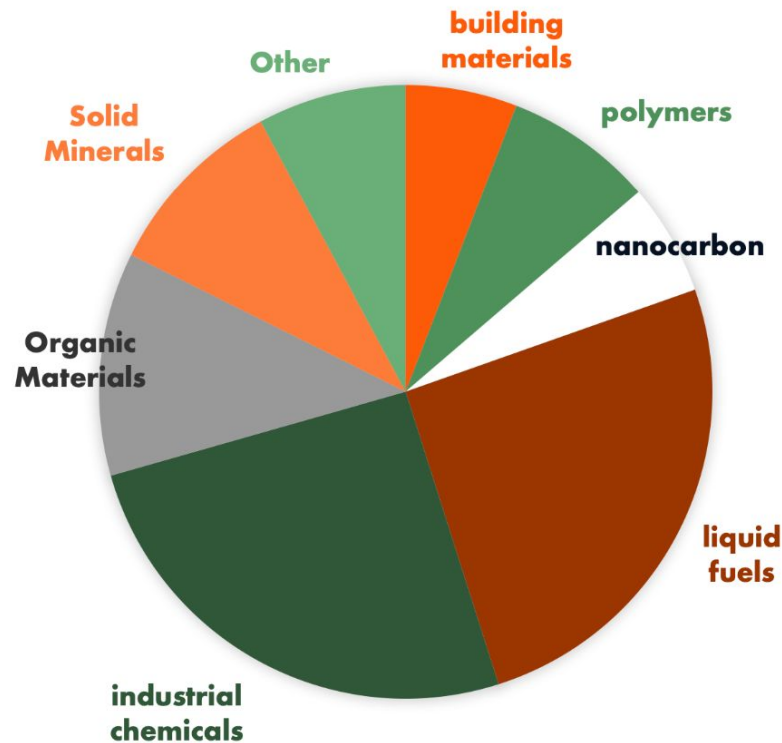
NRG COSIA CARBON XPRIZE (n=27, 2017 - 2020)

TIMECO₂

TECHNOLOGIES

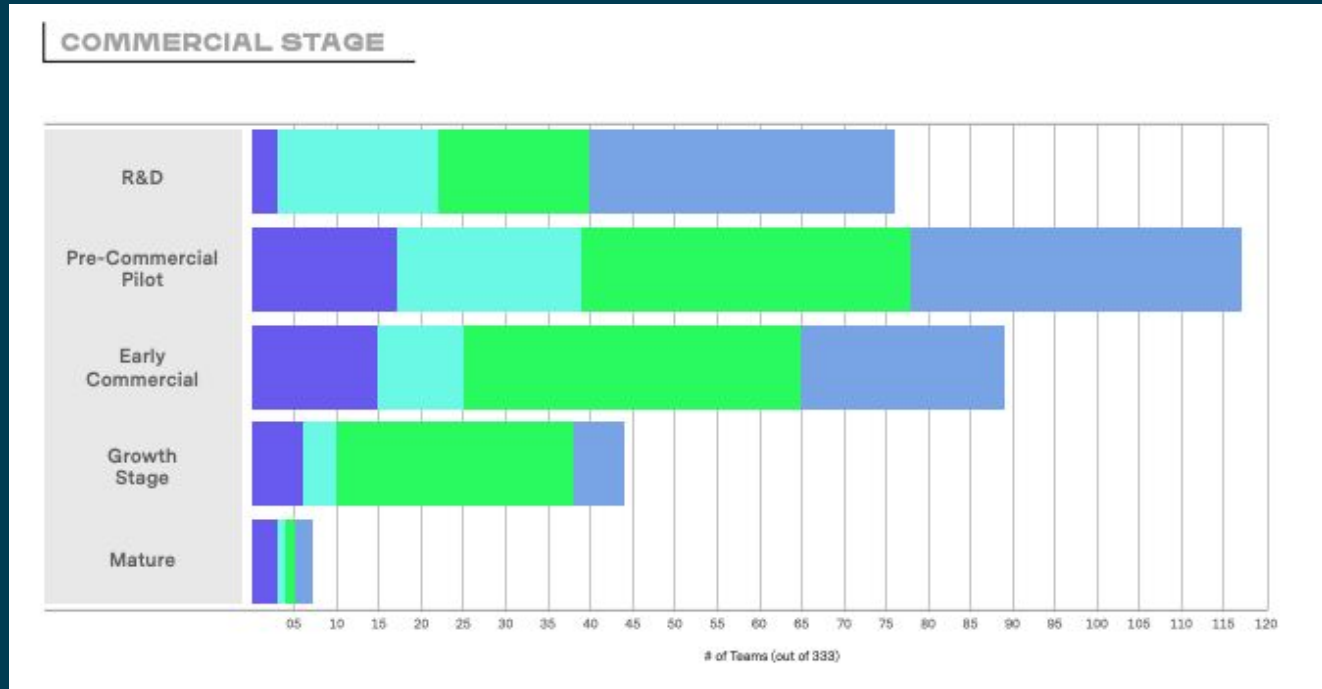
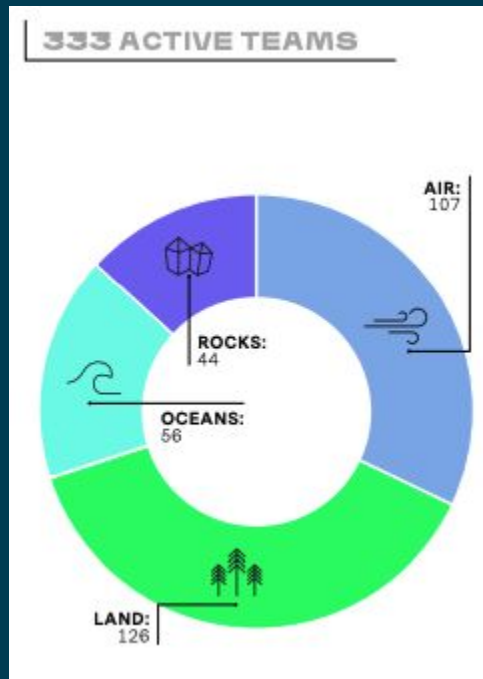


PRODUCTS

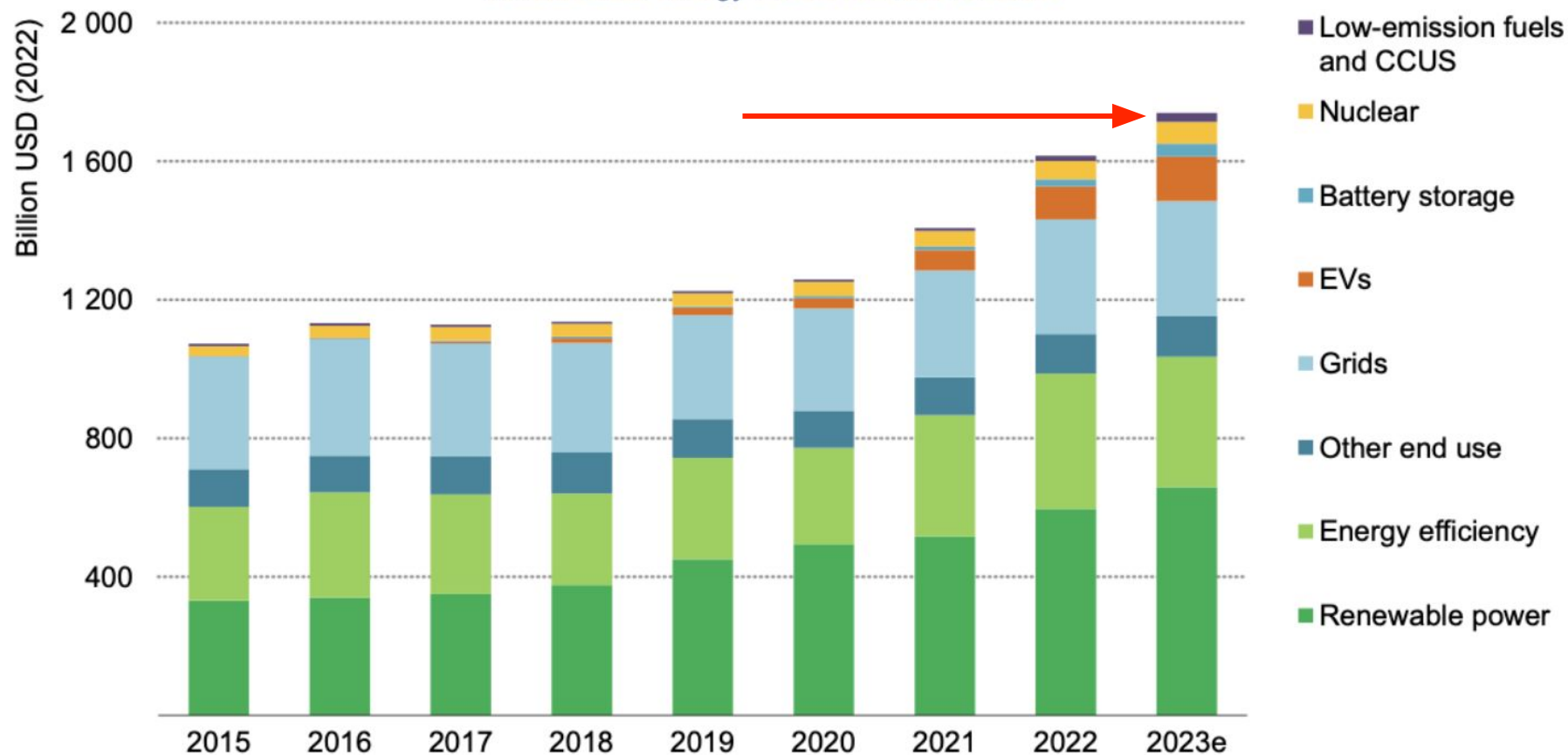


XPRIZE CARBON REMOVAL (n=333, 2023 - 2024)

Trends in carbon removal startups (which rely heavily on CO₂ products for revenue)



Annual clean energy investment, 2015-2023e

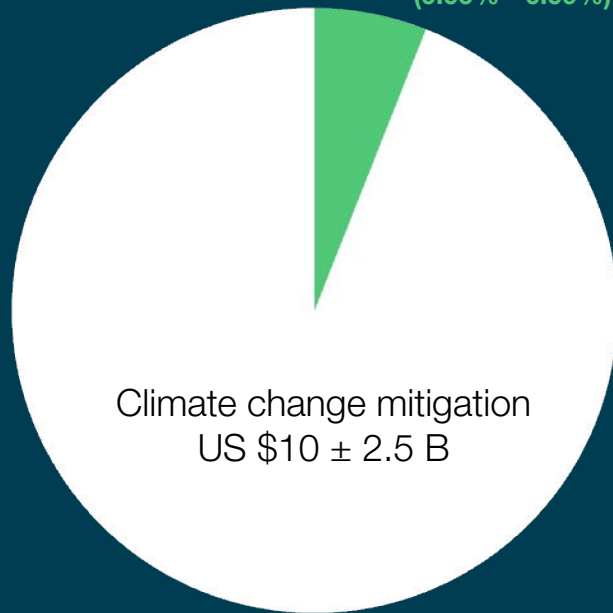


0.1% CLUB: PHILANTHROPY, GLOBAL (2021)

Climate change mitigation
US \$10 ± 2.5 B (0.9% - 1.5%)

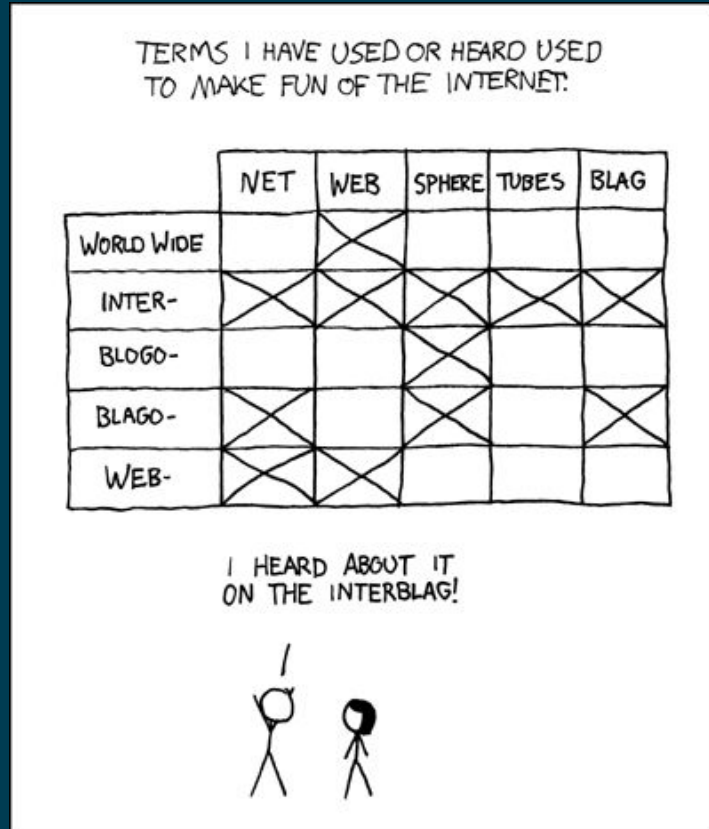


Carbon dioxide removal
US \$0.60 ± 0.15 B (6%)
(0.06% - 0.09%)



MAPPING CCU R&D NEEDS

APPLICATION AREAS	EFFORTS UNDERWAY	R&D NEEDS
JET fuel (SAF)	CO ₂ , CO, ag/forest waste, animal fat	electrochemistry, photochemistry, catalysis, low-C hydrogen, regulatory change, combustion testing, energy efficiency of process
Circular polymers & chemicals	PHA, biodegradable / ocean-safe polymers, fertilizers, foams	catalysis, industrial chemical process engineering; sustainable sourcing of biogenic feedstocks
Building materials / mineralization	Portland cement replacements, carbonate chemistry, coal fly ash, mine tailings, alternate concrete recipes	quantification of sequestration and durability (including in soils, oceans),
Hydrogen	US DOE H ₂ Hubs (!), shipping, LNG, port facilities, EU & US & MENA efforts	electrolysis, fuel cells, storage and transport, leak detection



CCU

CARBON CAPTURE

CDU

SEQUESTRATION

STORAGE

CCS

CCUS

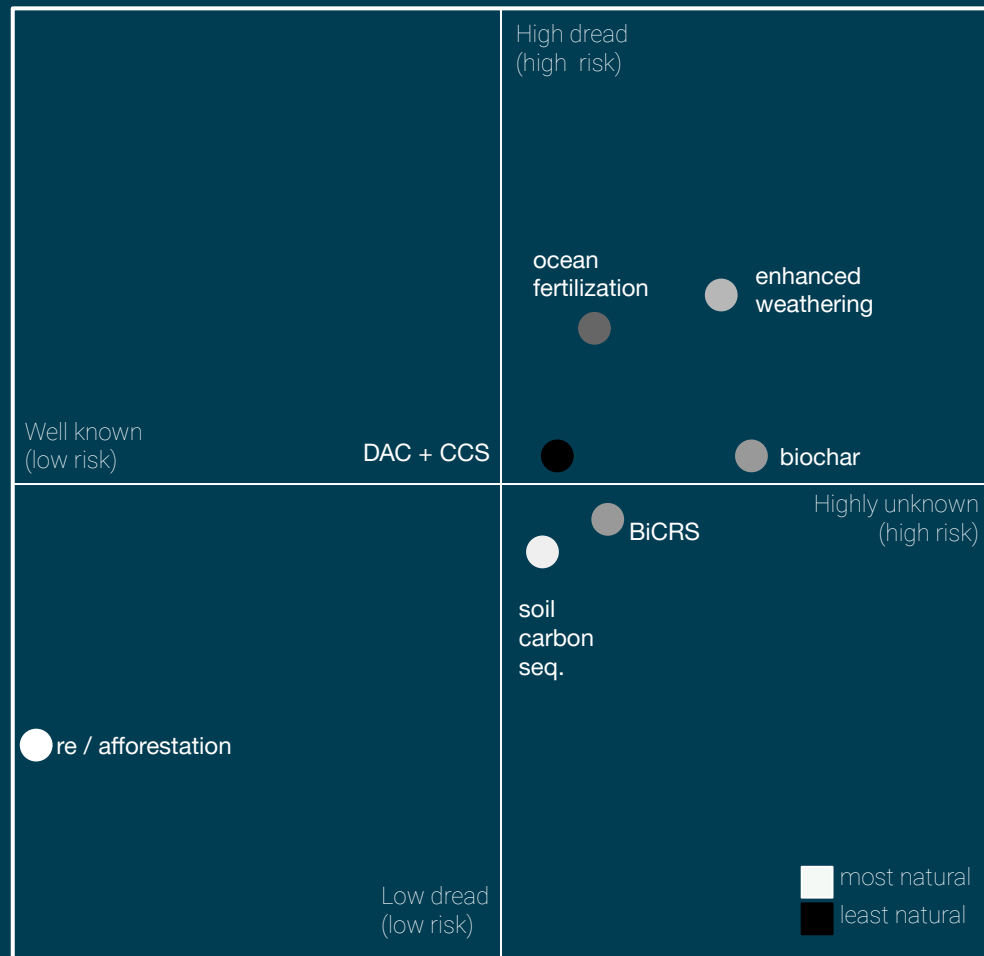
RECYCLING

CARBON MANAGEMENT

SOCIAL SCIENCE APPROACH TO PERCEPTIONS, COMMUNITY ENGAGEMENT

Public perception can inform policy, capital, and business, and the climate community, not just social acceptance

Reproduced from Behavioural frameworks to understand public perceptions of and risk response to carbon dioxide removal, T.R.Schrum et al., *Interface Focus* 10, 20200002 (2020). N = 113 Amazon MTurk participants.



THANK YOU