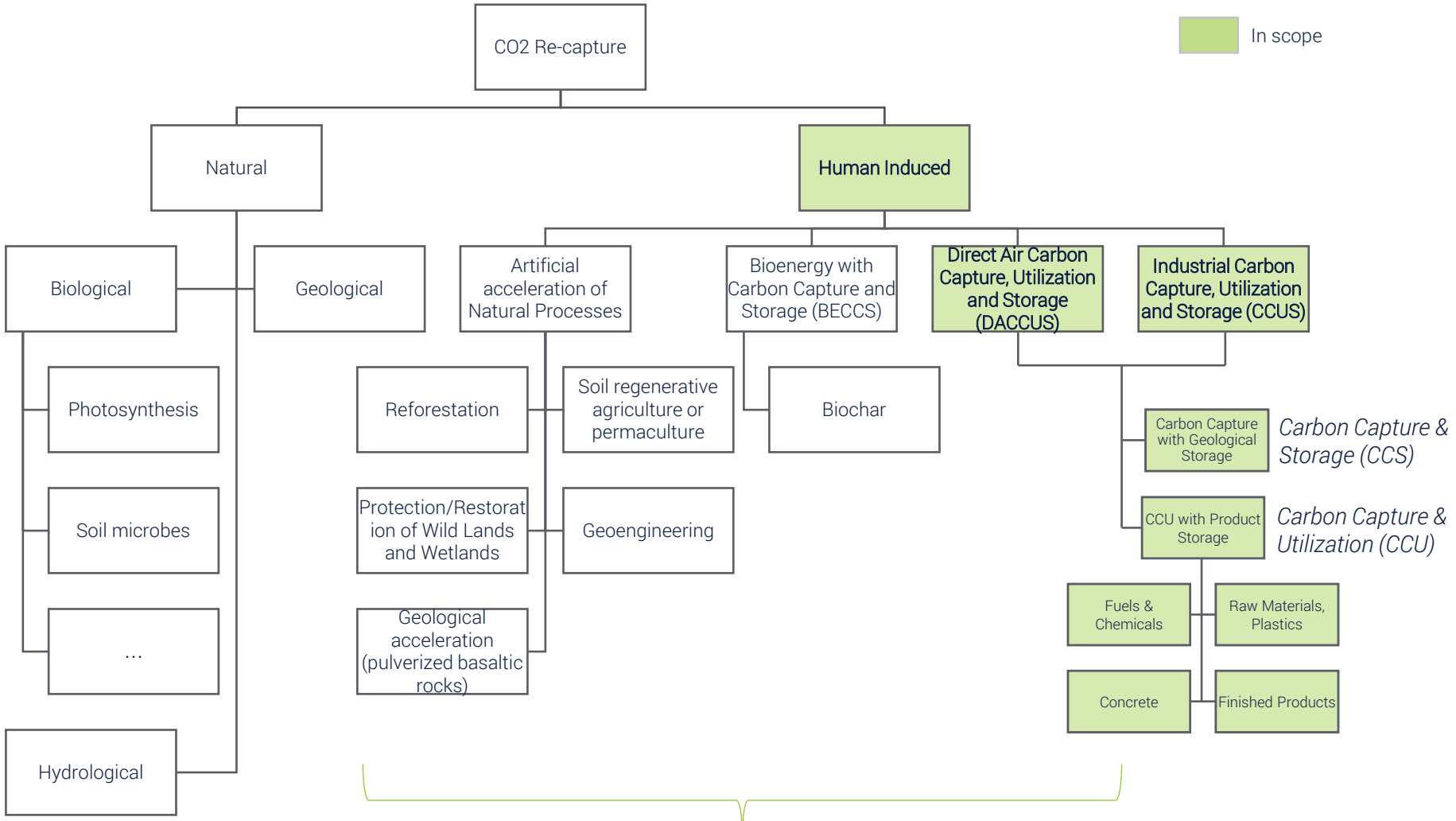
CO2 Capture, Sequestration and Utilization Solution Search

Discovery Report v2.0

For discussion

May 24, 2021

Expanded Technology Scope to emphasize DACCUS and include CCS



DIRECT CARBON CAPTURE, USAGE & STORAGE
Group of technologies that contributes both to reducing emissions in key sectors directly and to removing CO2 to balance emissions that are challenging to avoid

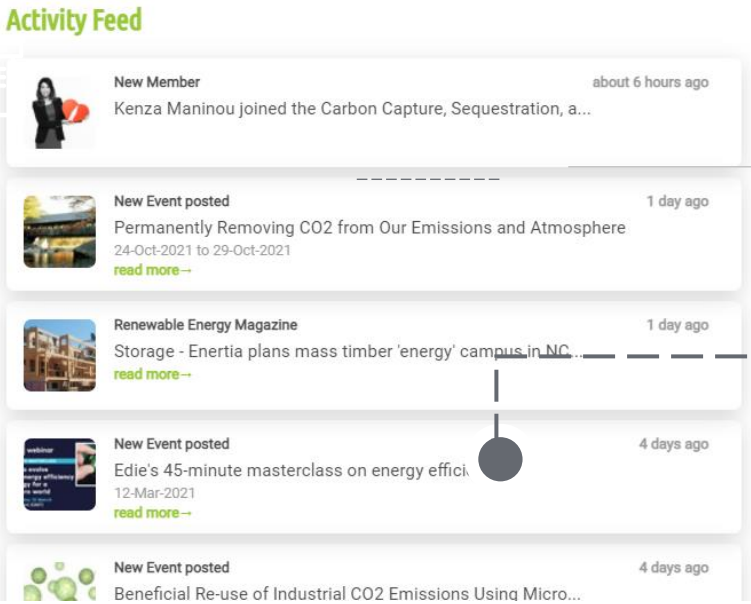
CARBON DIOXIDE REMOVAL (CDR)
Anthropogenic activities that remove CO_2 from the atmosphere and durably stores it in geological, terrestrial or ocean reservoirs, or in products

Curated Greenhouse enabled comprehensive evaluation

49
solution profiles
(82 considered)

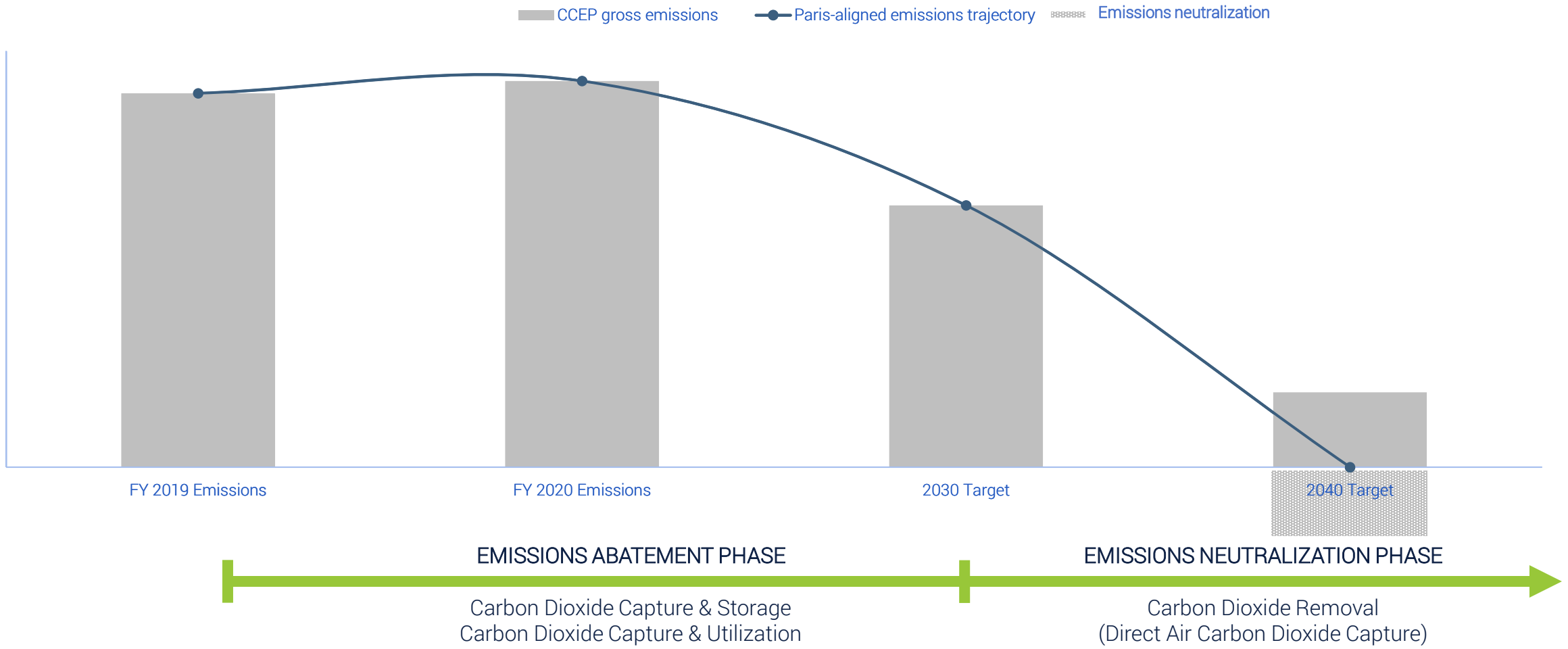
110 news articles

9 news digests



16 research papers/
knowledge posts

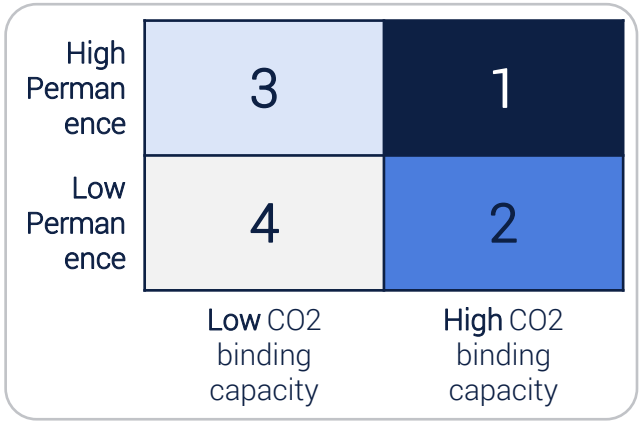
Goal: find solutions to enable mitigation strategies to reach net-zero



Conceptual Approach & Criteria for Prioritizing Solutions

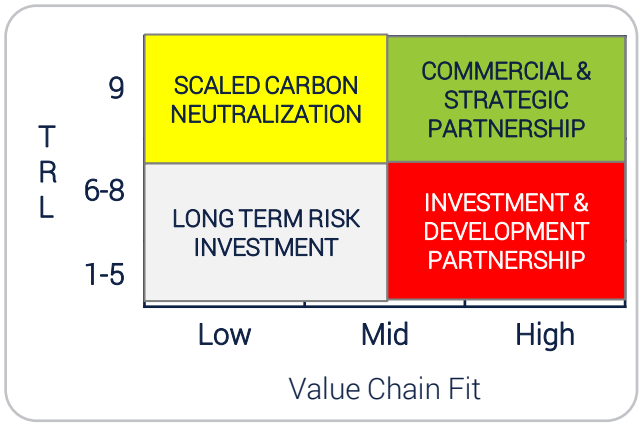
CLIMATE BENEFIT *

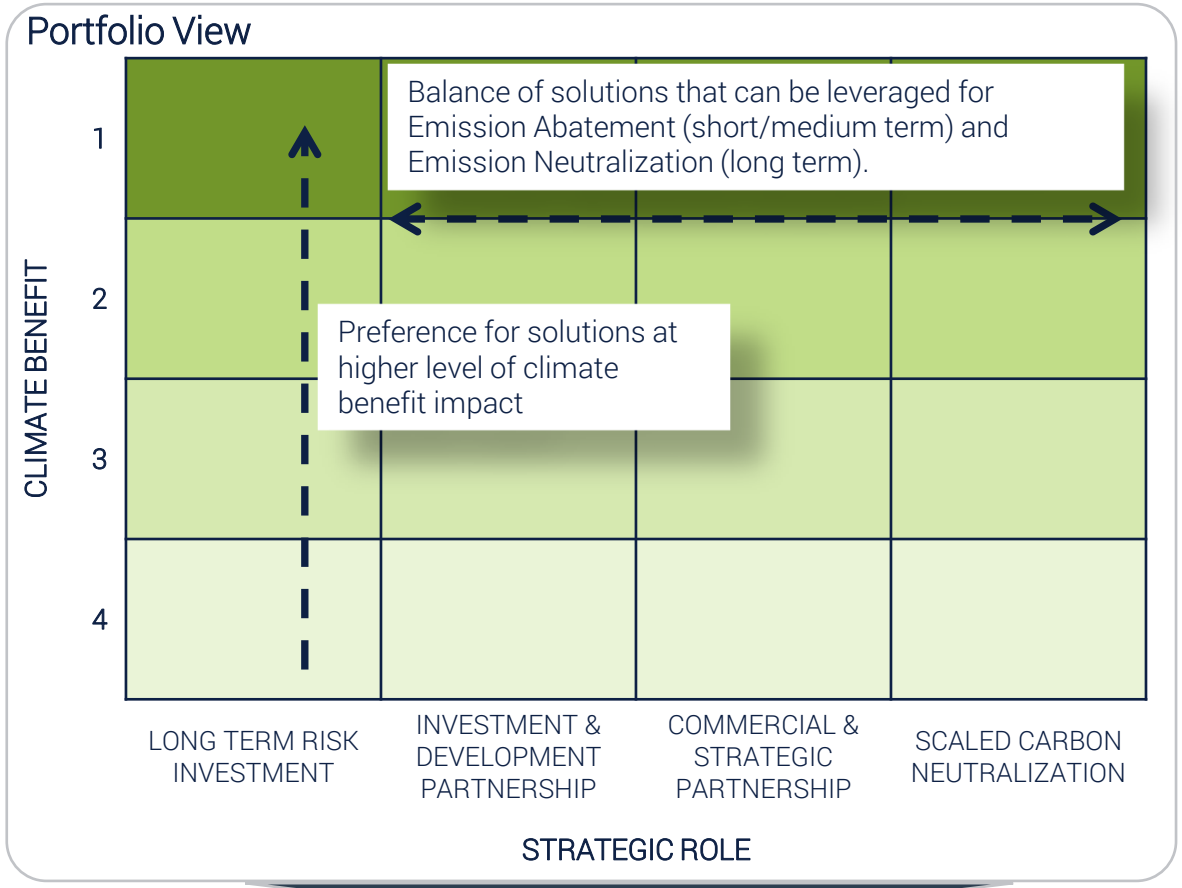
- Atmospheric removal (DACCUS) vs. Industrial (CCUS)
- Storage permanence (based on primary use)
- CO_2 binding capacity (Kg CO_2 stored/kg of product)
- *Market volume*



STRATEGIC ROLE

- Solution development level (TRL) - Early-stage solutions – higher risk, Close to market – lower risk
- Value chain fit (qualitative)





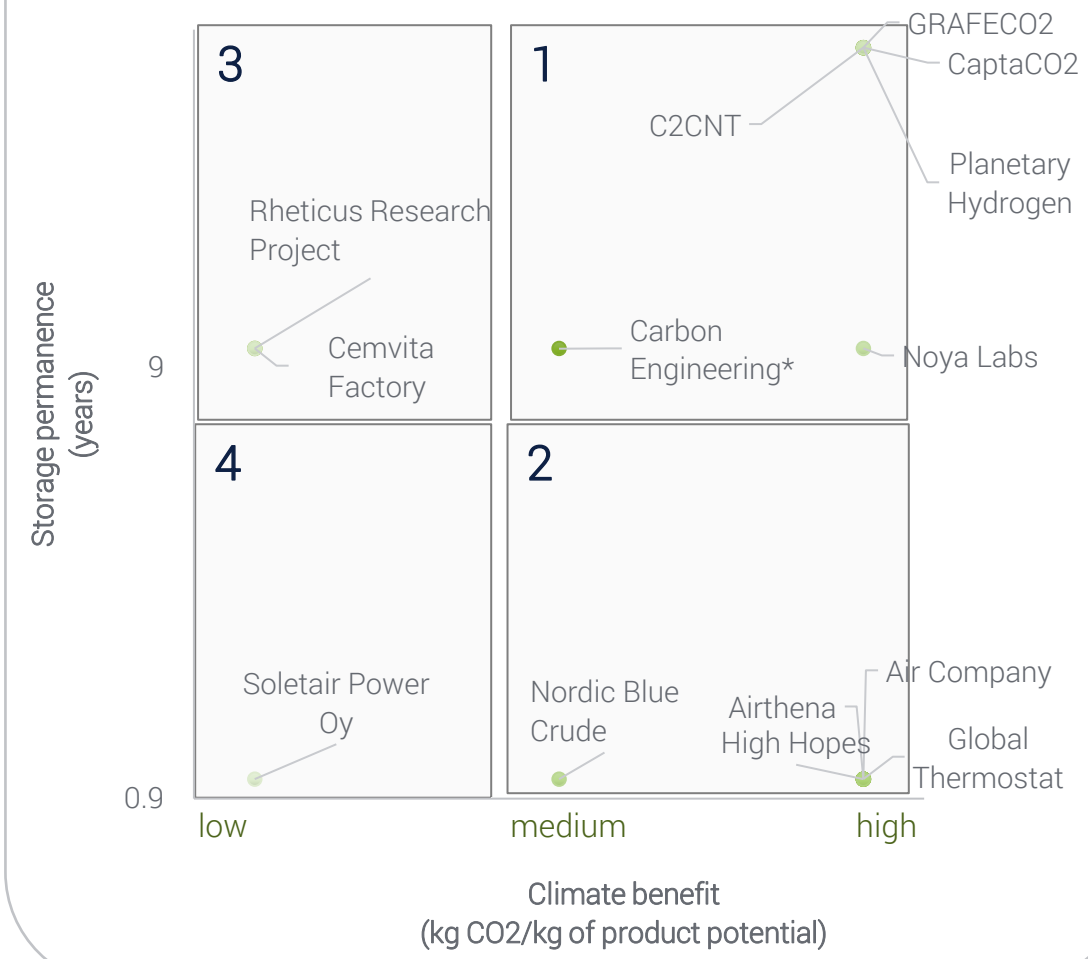
ECONOMIC VIABILITY

- Cost-benefit (€/ton of CO2)
- Technology capacity or scalability (ton of CO2/year)

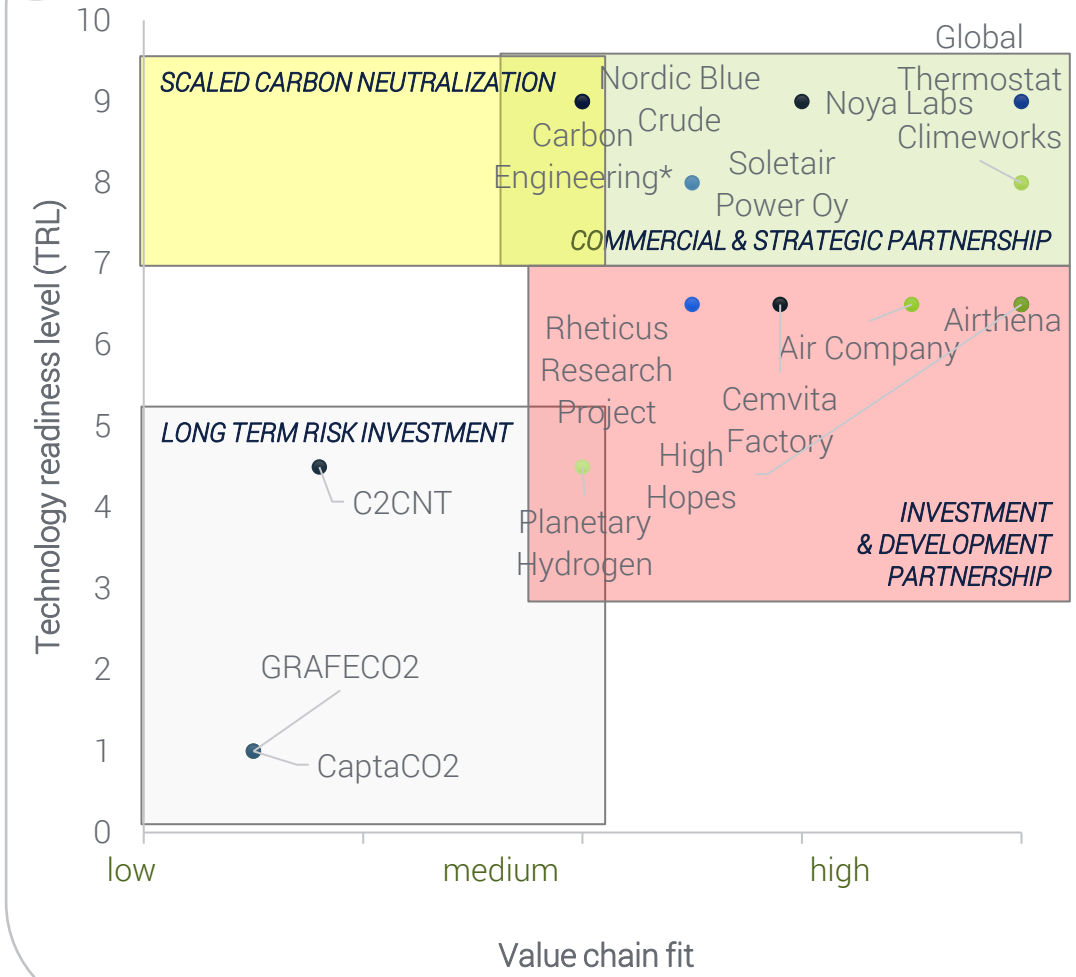
* See Appendix for scientific references for assessment

DACCUS Solutions prioritization

CLIMATE BENEFIT



STRATEGIC ROLE



DACCUS Solutions Portfolio Mapping

Climate Benefit

	Low CO2 binding capacity	High CO2 binding capacity
High Permanence	3 Rheticus Research Project, Cemvita Factory	1 CaptaCO2, GRAFECO2, C2CNT, Planetary Hydrogen, Noya Labs, Carbon Engineering*
Low Permanence	4 Soletair Power Oy	2 Nordic Electrofuel, Air Company, Airthena, Climeworks, Global Thermostat, High Hopes

Strategic Role

TRL	Low	Mid	High
9	*SCALED CARBON NEUTRALIZATION*	Nordic Electrofuel, Carbon Engineering*	*COMMERCIAL & STRATEGIC PARTNERSHIP*: Global Thermostat, Noya Labs
6-8		Soletair Power Oy; Rheticus Research Project, Cemvita Factory	Climeworks; Air Company, Airthena, *High Hopes*
1-5	*LONG TERM RISK INVESTMENT*: C2CNT, CaptaCO2, GRAFECO2	Planetary Hydrogen	*INVESTMENT & DEVELOPMENT PARTNERSHIP*

Value Chain Fit

Portfolio View

CLIMATE BENEFIT

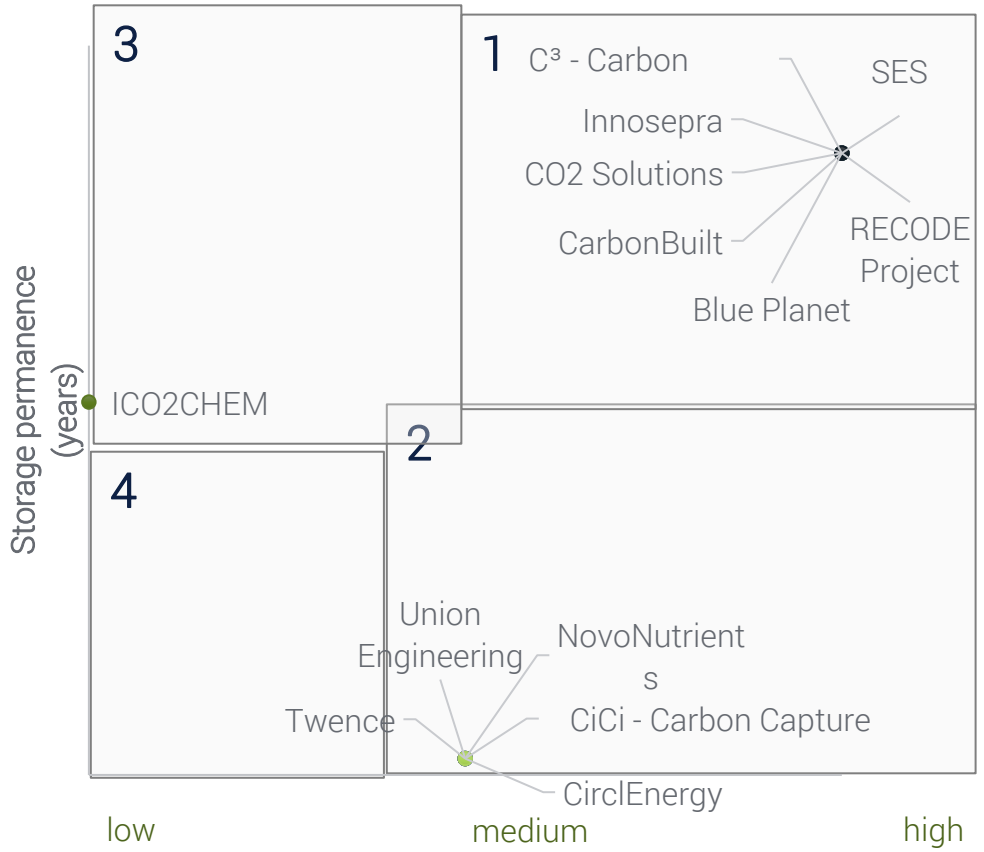
	LONG TERM RISK INVESTMENT	INVESTMENT & DEVELOPMENT PARTNERSHIP	COMMERCIAL & STRATEGIC PARTNERSHIP	SCALED CARBON NEUTRALIZATION
1	**Planetary Hydrogen**: CaptaCO2/GRAFECO2, C2CNT		**Carbon Engineering***: Noya Labs	
2	**High Hopes***	**Airthena**: Air Company	**Global Thermostat***: **Nordic Electrofuel**, *Climeworks*	
3		Rheticus Research Project, Cemvita Factory		
4			Soletair Power Oy	

STRATEGIC ROLE

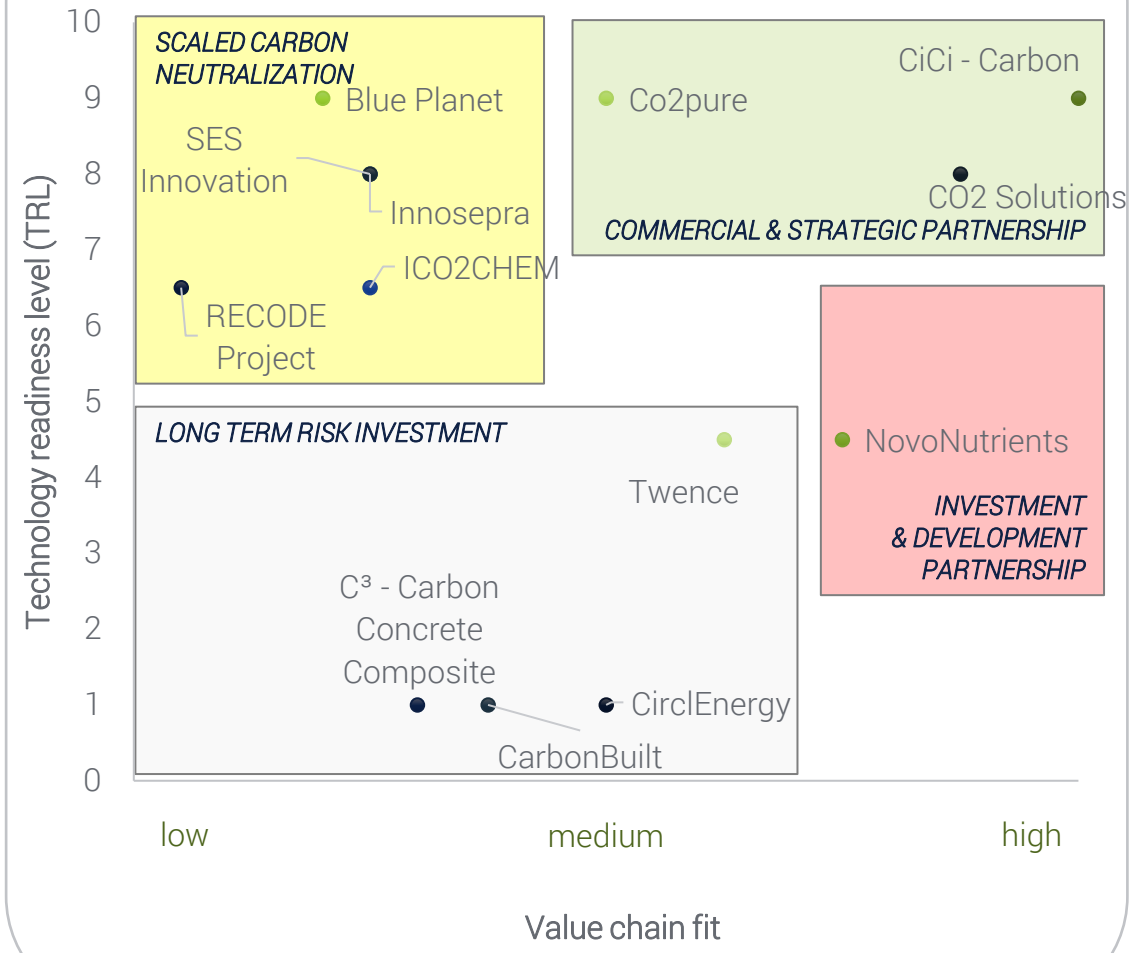
* Multiple applications

CCUS Solutions prioritization

CLIMATE BENEFIT



STRATEGIC ROLE



CCUS Solutions Portfolio Mapping

Climate Benefit

	Low CO2 binding capacity	High CO2 binding capacity
High Permanence	3 — Co2pure, ICO2CHEM	Blue Planet, CO2 Solutions, Innosepra, C³ - Carbon Concrete Composite, CarbonBuilt, RECODE Project, SES Innovation
Low Permanence	4	2 — CiCi - Carbon Capture, CirclEnergy, NovoNutrients, Twence

Strategic Role

TRL	Low	Mid	High
9	*CARBON NEUTRALIZATIION* BluePlanet	CO2pure	*COMMERCIAL & STRATEGIC PARTNERSHIP* CiCi – Carbon Capture
	Innosepra, SES Innovation		CO2 Solutions
6-8	*LONG TERM RISK INVESTMENT* ICO2CHEM, RECODE Project		*INVESTMENT & DEVELOPMENT PARTNERSHIP*
1-5	C³ - Carbon Concrete Composite, CarbonBuilt	Twence, CirclEnergy	NovoNutrients

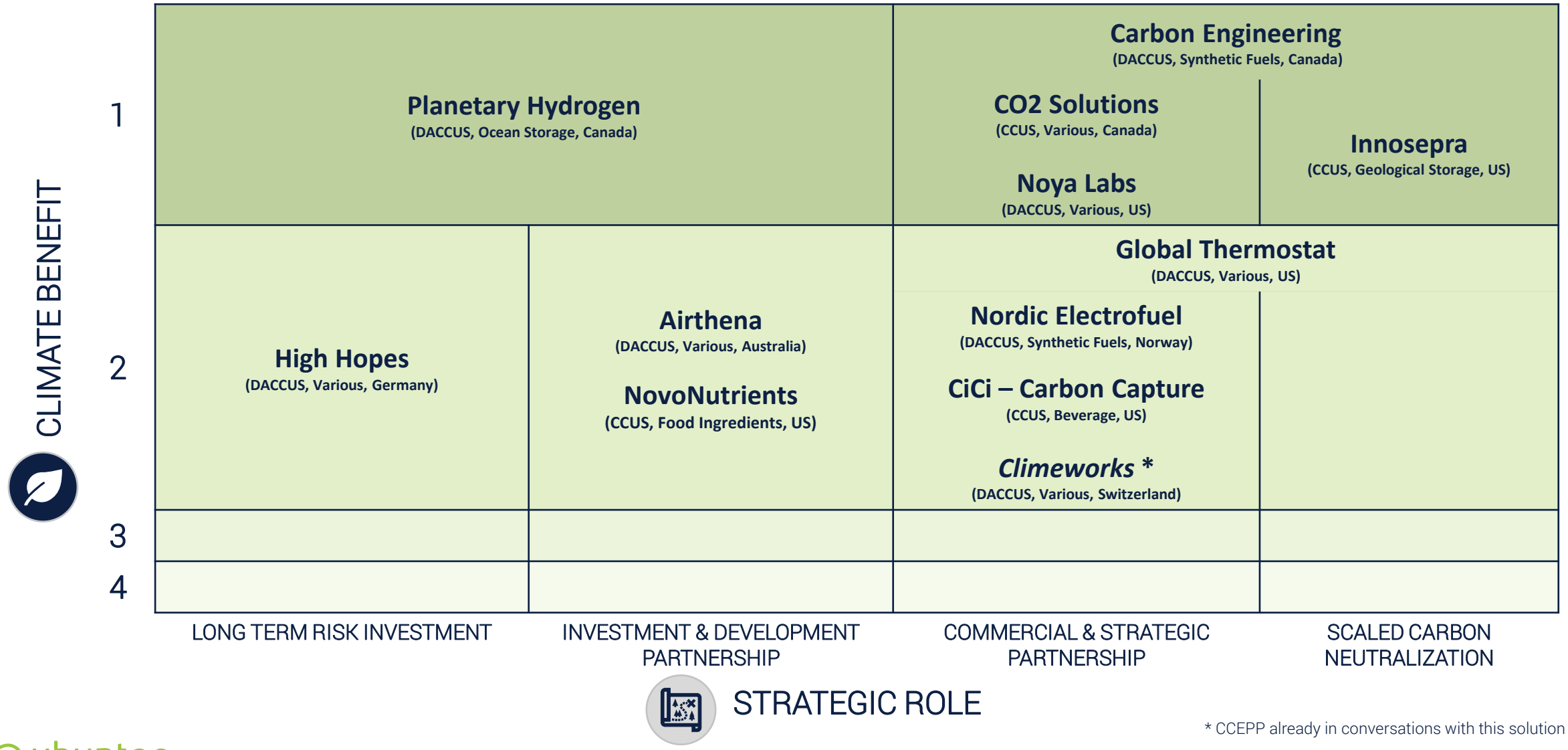
Value Chain Fit

Portfolio View

CLIMATE BENEFIT	LONG TERM RISK INVESTMENT	INVESTMENT & DEVELOPMENT PARTNERSHIP	COMMERCIAL & STRATEGIC PARTNERSHIP	SCALED CARBON NEUTRALIZATION
1	RECODE Project, C³ - Carbon Concrete Composite, CarbonBuilt		**CO2 Solutions**	**Innosepra**, BluePlanet, SES Innovation
2	CirclEnergy, Twence	**NovoNutrients**	**CiCi – Carbon Capture**	
3	ICO2CHEM		CO2pure	
4				

STRATEGIC ROLE

Complete Portfolio Map: Top 12 Solutions for Next Phase



* CCEPP already in conversations with this solution

Commercial & Strategic Partnerships – Ready Now

GLOBAL THERMOSTAT

- Modular Direct Air Capture (DACCS) leveraging low-cost process heat. CO2 is then used profitably in multiple industrial applications.
- Each module captures up to 40,000 tonnes of CO2/year and can be retrofitted into existing facilities and extended as needed.
- When not attached to an industrial facility, GT plants can generate their own heat and power, so location is extremely flexible.

STATUS
In 2020, Global Thermostat signed a contract with ExxonMobil that will help bring its to the scale. In 2021 it partnered with Chilean HIF to combine GT's technology with HIF clean-fuel production, resulting in carbon negative fuels.

CLIMATE BENEFIT
DACCUS technology, with application at industrial sites. CO2 storage or utilization applications are flexible.

STRATEGIC ROLE
Potential for Commercial/Strategic Partnership - TRL 8 – Scale up - CO2 use for SSD & polypropylene carbonate polymer

ECONOMIC VIABILITY
Estimated cost per tonne of CO2 IS 78 EURO (94 USD). Scalability and modularity is high and impact is scalable considering strong capture potential, particularly in industrial facilities.

Read more HERE

CiCi CARBON CAPTURE

- EarthlyLabs (a B-corp) offers CiCi, a small-scale (about the size of a refrigerator) carbon capture technology (CCUS) to serve emission sources like breweries, indoor grower, or other industry.
- CiCi provides hardware, software, installation, engineering, real-time remote maintenance services, and a marketplace called The Exchange:

STATUS
Being rolled out across the US South West and Mid West, focused on independent breweries. Earthly Labs' "Exchange" created a CO2 circular loop between breweries and cannabis growing facilities in Colorado

CLIMATE BENEFIT
Moderate impact given it's industrial capture at very small scale, and applications have very low durability.

STRATEGIC ROLE
TRL 8-9, with immediate applications in beverages, small footprint and low cost for pilot.

ECONOMIC VIABILITY
Most popular unit priced ~USD $75k, captures between 45,000 and 113,000 kg of CO2 per year (depending on source).

Read more HERE

Commercial & Strategic Partnerships – Multiple Use Solutions

CARBON ENGINEERING

- Canadian company that focus on the global deployment of large-scale Direct Air Capture technology. Carbon Engineering provide a range of solutions from ultra-low carbon fuels to permanent removal of the carbon emissions through geological storage.

STATUS

CE launches new carbon dioxide removal service with Shopify as its first customer. The service allows customers to purchase the removal of carbon dioxide from the atmosphere. The CE's first industrial-scale facility is expected to be operational in 2024.

CLIMATE BENEFIT

CE is working to build Direct Air Capture facilities around the world that will capture one million tons of CO2 per year each.

STRATEGIC ROLE

With TRL 9 (in market), CE's megaton-scale Direct Air Capture technology continuously captures CO2 from atmospheric air and delivers it as purified, compressed gas.

ECONOMIC VIABILITY

CE states that their DAC technology can capture CO2 from the air for approximately 84 €/ton.

Read more HERE

NORDIC ELECTROFUEL

- Nordic Electrofuel is a Norwegian company that owns a technology that can either capture CO2 from the air or from concentrated industrial emissions and coverts the capture CO2 into blue fuel products through a catalytic process with renewable energy as input.
- The final products consist of wax enhanced premium diesel and naphta.

STATUS

Aker Solutions and Nordic Electrofuel (NBC) have signed a contract for FEED of a new e-Fuel facility in Porsgrunn, Norway. The plant is planned to produce CO2-neutral fuel by using green hydrogen and furnace gas from an existing factory. The FEED work is planned to be completed in Q3/2021.

CLIMATE BENEFIT

The first plant will produce 8,000 ton/year of Blue Crude. The yearly production volume will avoid 21,000 ton of CO2 emissions. The target price per liter is below two euros.

STRATEGIC ROLE

Already in the market stage (TRL 9), blue fuel provide a good opportunity for reducing emissions from business travel or distribution fleet.

ECONOMIC VIABILITY

NBC received a substantial subscription for new shares from Parkshore Holding GmbH in April 2021, which is an investment company controlled by Bastian Mueller.

Read more HERE

Commercial & Strategic Partnerships – Multiple Use Solutions

CO_2 SOLUTIONS

- CO2 Solutions is a Canadian-based company that provides a technology that recover, purify and converts unavoidable industrial emissions into 99.95% (or more) purified CO2 stream.
- Co_2 emissions from stationary installations can be captured at the source and recovered so then it can be reused on-site.

STATUS
The technology is based on an innovative process for the enzymatic capture of CO2 that does not use or emits toxic products. Saipem has acquired CSI capture technology in January 2020.

CLIMATE BENEFIT
CO2 Solutions captures polluting emissions directly at the exit of the chimneys and is a good alternative for emissions-intensive companies willing to reduce their scope 1 emissions.

STRATEGIC ROLE
On-site recover and reuse of CO_2 for multiple purposes. Solution is on the scale-up stage (TRL 8).

ECONOMIC VIABILITY
CO2 Solutions technology is sized to produce at least 30 ton CO_2/day (11,00 ton/year) and the quantity of electrical energy required to operate the unit translates into a cost of 4 €/ton.

Read more HERE

NOYA LABS

- USA-based DACCUS technology and resale company. Noya takes the CO_2 pulled from the atmosphere and re-packages it for sale to industrial CO_2 consumers.
- Noya is partnering with industrial equipment owners to deploy this carbon capture process onto their equipment. As a distributed direct air capture company, Noya retrofits their customers' cooling tower to capture CO_2 and pays them for all the CO_2 it captures.

STATUS
Noya Labs raised $1.2 million from the frontier tech investment firm Fifty Years to develop the initial pilot plant and build out its team.

CLIMATE BENEFIT
Noya Labs is developing a pilot plant that will capture between half to a ton per day.

STRATEGIC ROLE
Multiple CO_2 uses seem to be feasible.

ECONOMIC VIABILITY
Noya Labs estimates commercial CO_2 price ranges between 83 and 4,000 €/ton

Read more HERE

ubuntoo

Scaled Carbon Neutralization – Pure Geological Storage

InnoSepra

- USA-based technology can **capture** post-combustion CO2 from several sources including coal and natural gas-based power plants.
- The technology is based on physical sorbents. 40% reduction in capital and operating cost (projected CO2 capture cost less than $40/ton) and can make carbon capture viable for multiple applications.

InnoSepra's carbon capture technology can create significant value through up to 40% reduction in the cost of capture from flue gases and using the captured carbon dioxide for sequestration. This can significantly reduce the carbon footprint of power generation.

CLIMATE BENEFIT
The technology has been successfully demonstrated in a coal-fired power plant at 1 ton CO2 per day scale.

STRATEGIC ROLE
The company is in TRL 8 scale up stage. The carbon capture technology can be applied in a number of sources incl. coal and natural gas-based power plants.

ECONOMIC VIABILITY
The projected CO2 capture cost of less than $40/ton

Read more HERE

Investment & Development Partnerships – Collaborative Moon Shots

AIRTHENA

•Australian company Airthena uses crystal sponges, known as metal-organic frameworks, which work to capture and recycle carbon dioxide from the air for use in a wide range of applications. Airthena™ is a direct air capture (DAC) technology can convert CO2 from ambient air into pure CO2.

STATUS

The company is currently working on building an Airthena model that can capture 200 tons of CO2 a year per unit.

CLIMATE BENEFIT

The latest Airthena™ unit is capable of capturing two tonnes of CO2 from the atmosphere a year and is suitable for small-scale applications, such as beverage carbonation and industrial cleaning.

STRATEGIC ROLE

Airthena is in conversation with companies to pilot their technology in a number of applications including beverage carbonation, food, cement, greenhouses etc.

ECONOMIC VIABILITY

Cost of the technology is expected to be approximately a few hundred euros per ton of CO2 depending on the level of purity required.

Read more HERE

NOVONUTRIENTS

- NovoNutrients transforms untreated industrial CO2 waste emissions into low-cost feed and food ingredients. This is achieved through their platform technology infusing hydrogen and based on industrial biotech and biological innovation using natural microbes to break down molecules and reassemble them.

STATUS

NovoNutrients was included in the 2020 "50 to Watch List" as one of the Companies Finding Solutions to Combat the Climate Crisis.

CLIMATE BENEFIT

NovoNutrients expects their technology to capture up to 1.9 tons of CO2 per ton of feed produced. NovoNutrients' approximates that one commercial manufacturing plant will capture and convert over 200,000 tons/yr of CO2 into over 100,000 tons/yr of high-protein feed.

STRATEGIC ROLE

Their main product line is protein flours. Their initial market focus is on fishmeal protein for fish farming. The systems will also make inputs for protein companies.

ECONOMIC VIABILITY

Novonutrients received a $300,000 investment from the U.S. Department of Energy to speed up their modeling phase.

Read more HERE

Long Term Risk Investment – the Moon Shots

HIGH HOPES

•High hopes is an Israeli company that is using hot-air balloons retrofitted with carbon capture tech to extract CO2 at colder temperatures and bring it back to the ground for storage.

STATUS

For large-scale implementation, the team is looking at sub-Saharan Africa for its ideal temperature, abundant geo-sequestration potential, and relatively clear flight plan.

CLIMATE BENEFIT

High Hopes is a DACCUS technology, with multiple uses and storage possibilities. The solution can remove approx. 18,250 tons of CO2/year.

STRATEGIC ROLE

The company is currently in the pilot stage.

ECONOMIC VIABILITY

High Hopes proposes a price starting off at around US$100/ton and the company believes it can reach US$50-60 a ton with scale.

Read more HERE

PLANETARY HYDROGEN

- Planetary Hydrogen is a Canadian company which uses its patented Ocean Capture technology (OAC) to produce green hydrogen while capturing and removing CO2 from the atmosphere. For each 40 kg of CO2 removed from the atmosphere, Planetary Hydrogen produces 1 kg of hydrogen.

STATUS

Shopify will be purchasing the negative CO2 emissions generated by Planetary Hydrogen's pilot plant to help fund their pilot project. Planetary Hydrogen will start running its pilot plant by 2022.

CLIMATE BENEFIT

The pilot plant goal is to produce up to 50 kg/d of hydrogen, while capturing 1–1.5 t/d of CO2. If successful, the next step is a 10 MW facility in 2024/2025 which could sequester up to 25,000 t/y of CO2.

STRATEGIC ROLE

The hydrogen created in this process has a number of uses including derivatives like ammonia or methanol for shipping, storage, and producing low or even negative carbon intensity fuel.

ECONOMIC VIABILITY

Planetary Hydrogen received funding of $600,000 from Capital Angel Network, Toronto-based Ramen Ventures, and other local investors.

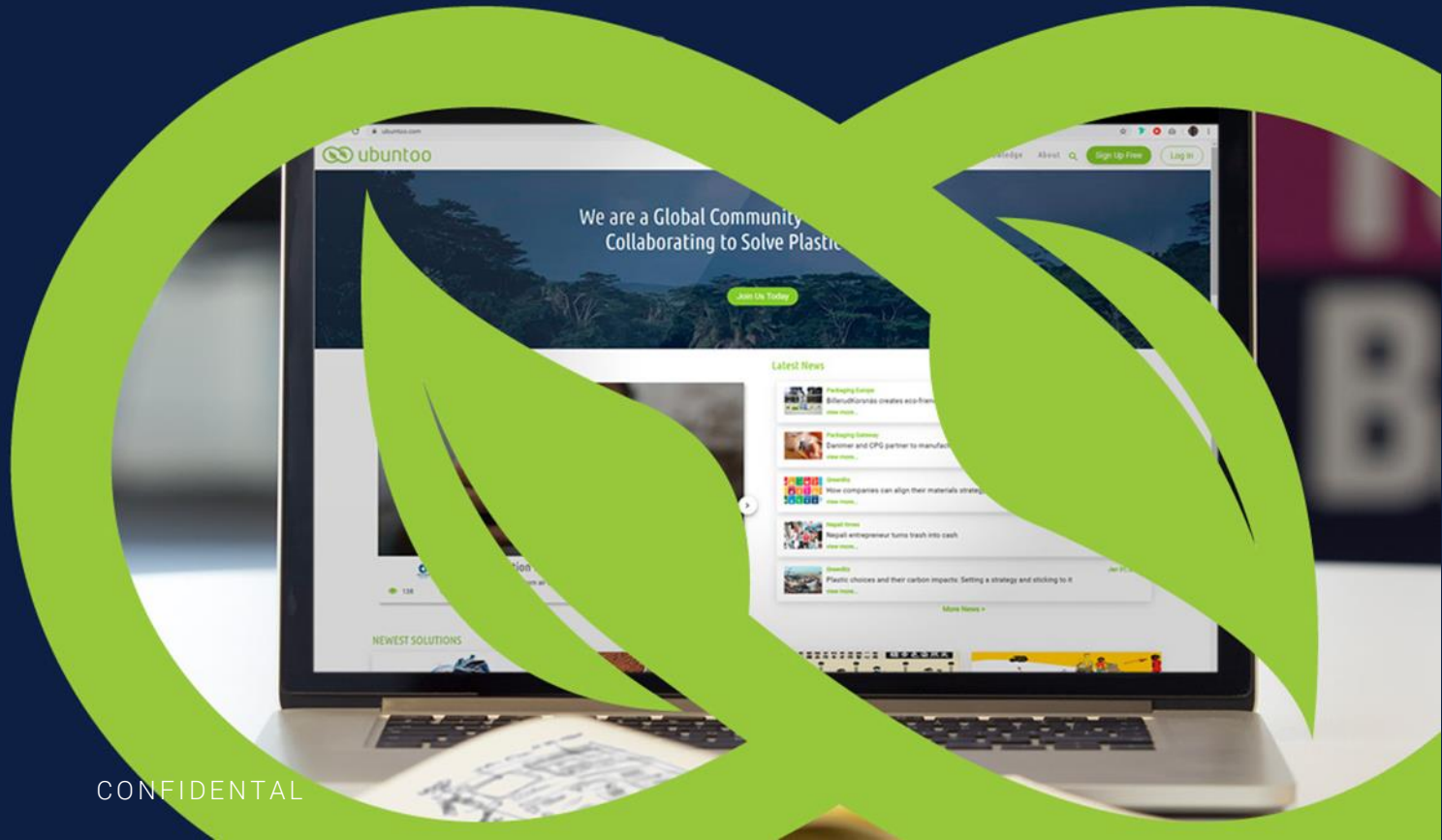
Read more HERE

Next Steps

1. Develop final presentation to CCEPP management (Craig/Simon + Ubuntoo)
2. Introduction to key contacts in selected solutions (Ubuntoo)
3. GreenHouse will continue to be curated and accessible for 3 months (until end of August) (Ubuntoo)
   - New solutions, news and knowledge posts will continue to be uploaded
   - CCEPP can download profiles from GH as deemed appropriate
   - *Considering the amount of activity in this space, we recommend Trend Tracker GreenHouse*

APPENDIX

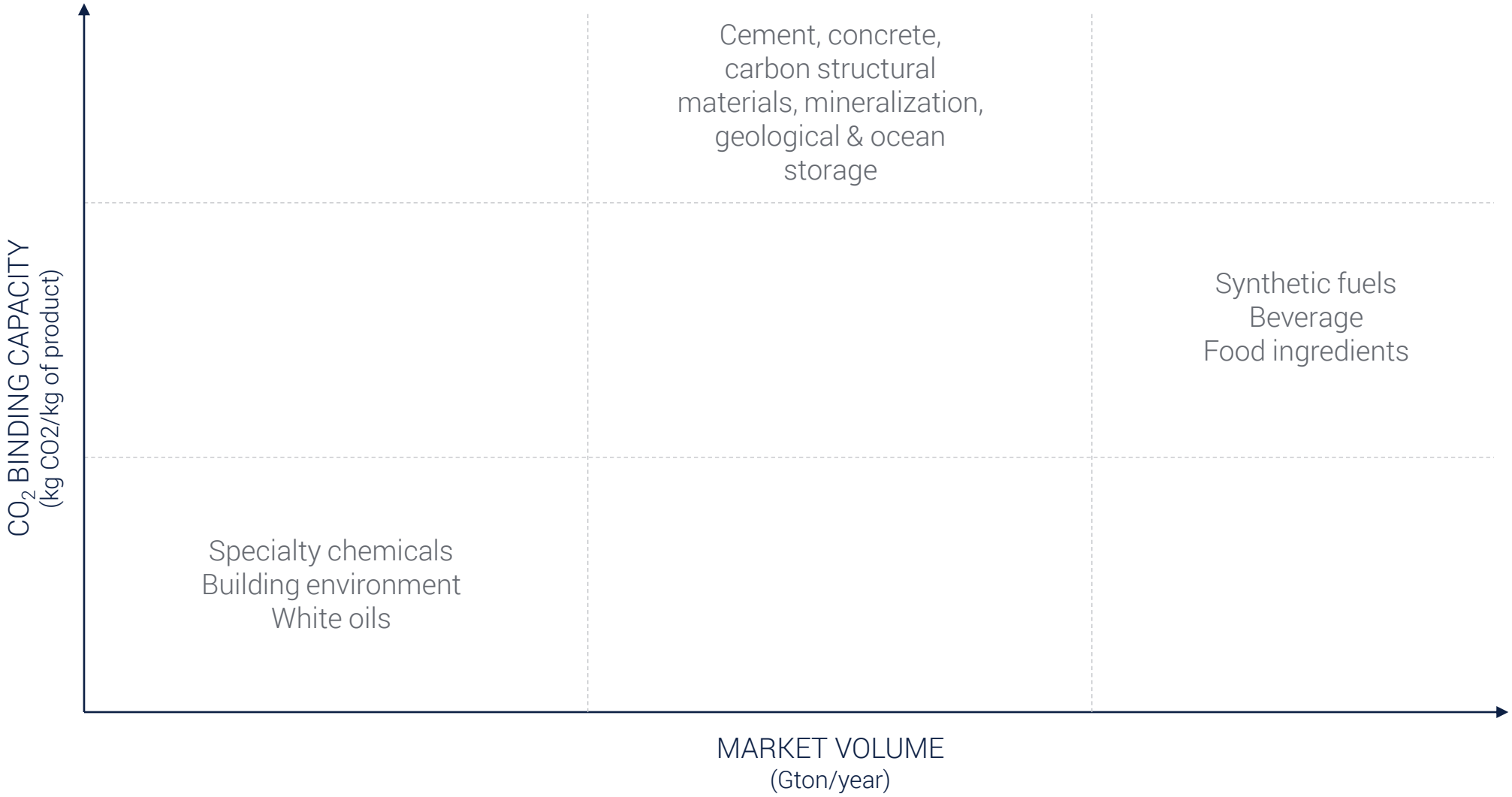
ubuntoo



References

- CE Delft, 2019. Identification and analysis of promising carbon capture and utilisation technologies, including their regulatory aspects. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/7656142c-7083-11e9-9f05-01aa75ed71a1/language-en
- IPCC, 2018. Carbon Dioxide Capture and Storage. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf
- Hepburn, C., Adlen, E., Beddington, J. *et al.* The technological and economic prospects for CO_2 utilization and removal. *Nature* **575,** 87–97 (2019). https://doi.org/10.1038/s41586-019-1681-6
- IEA, 2019. Putting CO2 to use. Retrieved from https://www.iea.org/reports/putting-co2-to-use
- SBTi, 2020. Foundations for science-based net-zero target setting in the corporate sector. Retrieved from https://sciencebasedtargets.org/resources/files/foundations-for-net-zero-full-paper.pdf

Climate benefit classification



Value chain fit classification

LOW – Score from 0 to 1.4

- Cement and concrete
- Graphene and carbon structural materials
- Mineralisation
- White oils

MEDIUM – Score from 1.5 to 2.9

- Synthetic fuels
- Specialty chemicals
- Building environment
- Geological and ocean storage

HIGH – Score from 3 to 4

- Beverage
- Food
- Multiple CO_2 uses

Storage permanence classification

Storage permanence of 1 year

- Synthetic fuels
- Food
- Beverage & various CO_2 usages

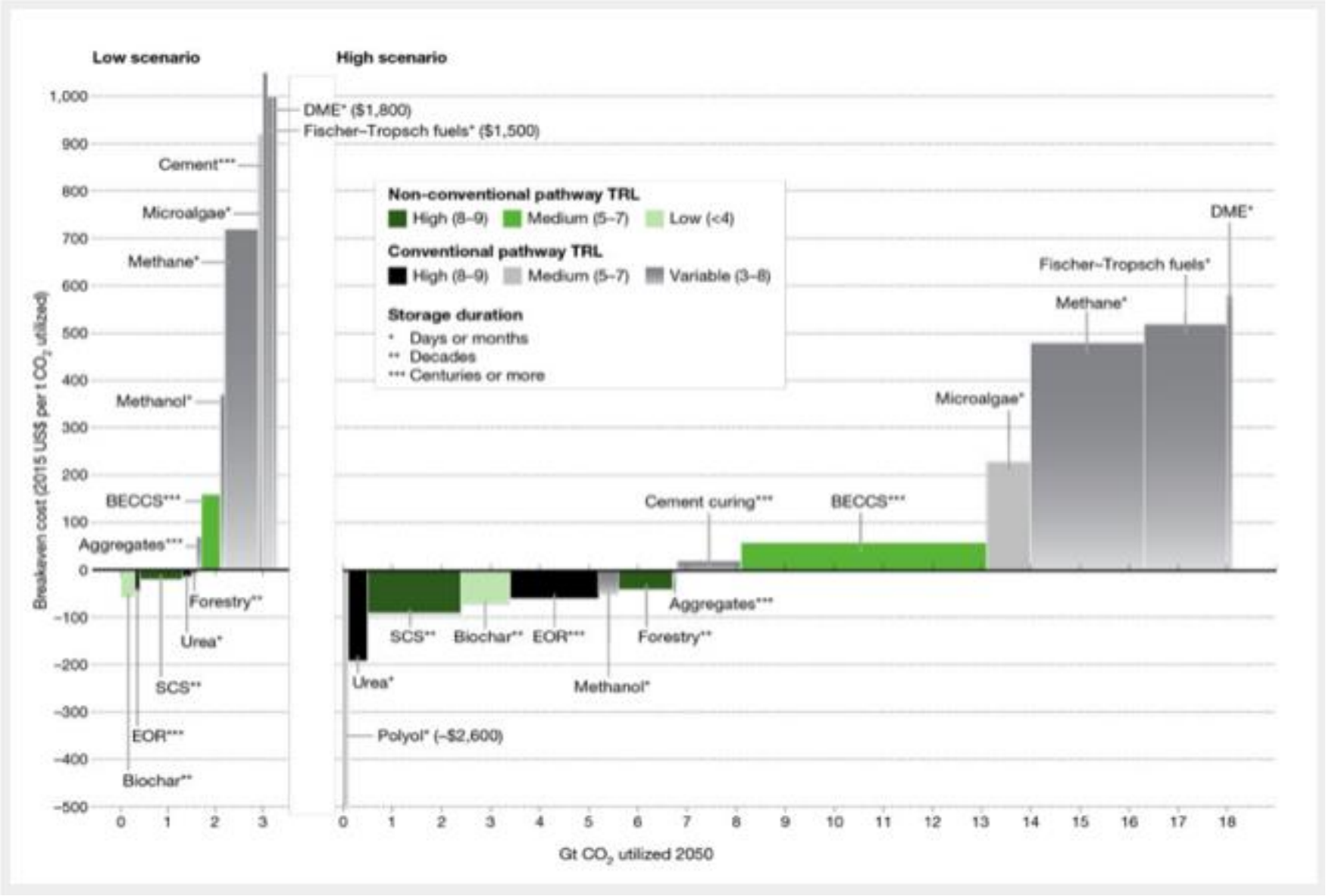
MEDIUM – Score from 5 to 10 years

- Specialty chemicals & white oils
- Various CO2 uses

HIGH – Score from 3 to 4

- Building environment
- Geological and ocean storage
- Cement and concrete
- Graphene and carbon structural materials
- Mineralisation

Estimate CO_2 utilization potential and breakeven cost



Phase 1 v1.0: Summary Assessment of Top Solutions

SOLUTION	DESCRIPTION	TECHNOLOGY SCOPE	TRL	LOCATION	FUNDING STAGE
Nordic Electrofuel	High quality, carbon neutral, synthetic fuels from atmospheric CO2 removal	CDR & CO_2 Utilization	TRL 9- In Market	Norway	Funding Undisclosed, top investor Marquard & Bahls
Dimensional Energy	Transforming CO2 into fuels using sunlight	CO_2 Utilization	TRL 8 – Scale Up	US	Raised $75K over 3 rounds. Latest: Oct 30, 2020 - Convertible Note.
CERT	Turning CO2 into fuels and chemical feedstocks using water and electricity	CO_2 Utilization	TRL 6&7- Pilot	Canada	Estimated Revenue Range Less than $1M
Opus12	Converting CO2 into cost-competitive chemicals and fuels	CO_2 Utilization	TRL 2&3- Prototype	US	$350K in funding over 6 rounds. Latest: May 30, 2019 - Seed round
Photanol	Technology to convert CO2 and sunlight into valuable organic compounds.	CO_2 Utilization	TRL 8 – Scale Up	Netherlands	Raised €8M over 3 rounds. Latest: Sep 7, 2018 from a Venture - Series Unknown round.
Carbon Smart	Developing Sustainable Products using Ethanol Produced from Recycled Carbon	CO_2 Utilization	TRL 8- Scale Up	US	LanzaTech has raised $276.3M over 6 rounds. Latest: Aug 6, 2019 - Series E round.
RenewCo2	Catalysts that can convert carbon dioxide into plastics, fabrics, resins and other products	CO_2 Utilization	TRL 2&3- Prototype	US	US Department of Energy Phase I SBIR Grant $200,000
Newlight Technologies	Harnessing greenhouse gas capture technology to produce high-performance bioplastics from emissions	CDR & CO_2 Utilization	TRL 9- In Market	US	Raised $106.6M over 6 rounds. Latest: Sep 22, 2020 - Series F.
Minus CO2	CO2 removal and storage into bio-carbons with different binders as polymers, biopolymers, silicates, minerals and others	CDR & CO_2 Utilization	TRL 9- In Market	Germany	Raised undisclosed amount / Non Equity Assistance from SpinLab - The HHL Accelerator
Kiverdi Technology	Turns Carbon Dioxide into Oils and Food using microbes	CO_2 Utilization	TRL 2&3- Prototype	US	Raised undisclosed amount from Kapor Capital in 2014.. Est. revenue 1-10M
Graphenstone	Natural lime-based paint that absorbs CO2	CDR & CO_2 Utilization	TRL 2&3- Prototype	Spain	Unfunded/No Info
CiCi-Carbon	Plug-and-play CO2 capture developed specifically for the brewery and carbonated beverage space.	CCU	TRL 9- In Market	US	Estimated Revenue Range Less than $1M, no other info about funding
Cemvita	Using CO2 for the sustainable production of chemicals and polymers	CO_2 Utilization	TRL 6&7- Pilot	US	Raised an undisclosed amount Series Unknown from Oxy Low Carbon Ventures in 2019
Carbon Kapture	Creating a new market in seaweed-based carbon services	CDR	TRL 2&3- Prototype	UK	Crowdfunding: Raised £1,965 with 21 supporters in 85 days On Nov 26, 2020
Econic	Innovative catalyst technology allowing CO2 to be captured and recycled for polypol production	CDR & CO_2 Utilization	TRL 9- In Market	UK	Raised $30M over 8 rounds. Latest: Feb 21, 2018 from a Venture - Series Unknown round.

“In Africa we have a concept known as ubuntu based upon the recognition that we are only people because of other people”

NELSON MANDELA