©Pixabay

Fraunhofer-Gesellschaft

Fraunhofer Twin Transition Series

Carbon removals for climate neutrality – A pathway to Europe's decarbonization

September 27, 2023

Fraunhofer ISE

Fraunhofer ISI

Fraunhofer UMSICHT

Carbon removals for climate neutrality - A pathway to Europe's decarbonization

Fraunhofer Twin Transition Series

The Fraunhofer-Gesellschaft

At a glance

Applied research focusing on key future-relevant technologies and the commercialization of findings in business and industry. A trailblazer and trendsetter in innovative developments.

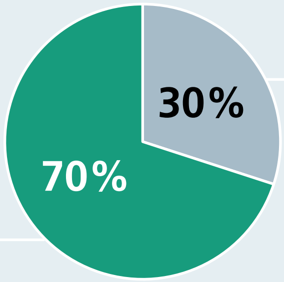
> 30,800 employees

76 institutes and research units

€ 3.0 billion business volume
€ 2.6 billion contract research

Base funding from Germany’s federal and state governments

Industrial contracts and publicly-funded research projects



Restricted

Fraunhofer

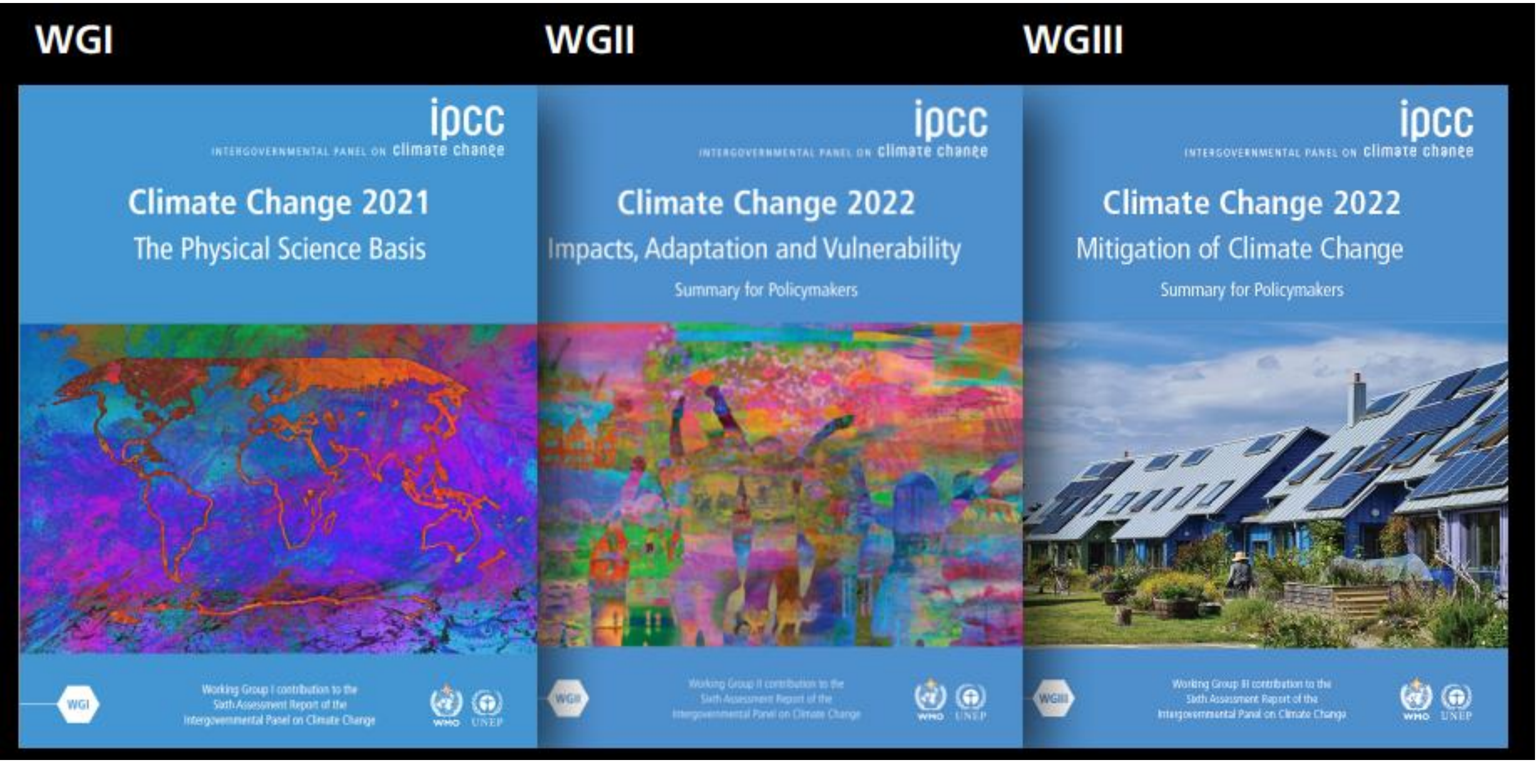
Introduction

Dr. Peter Schossig

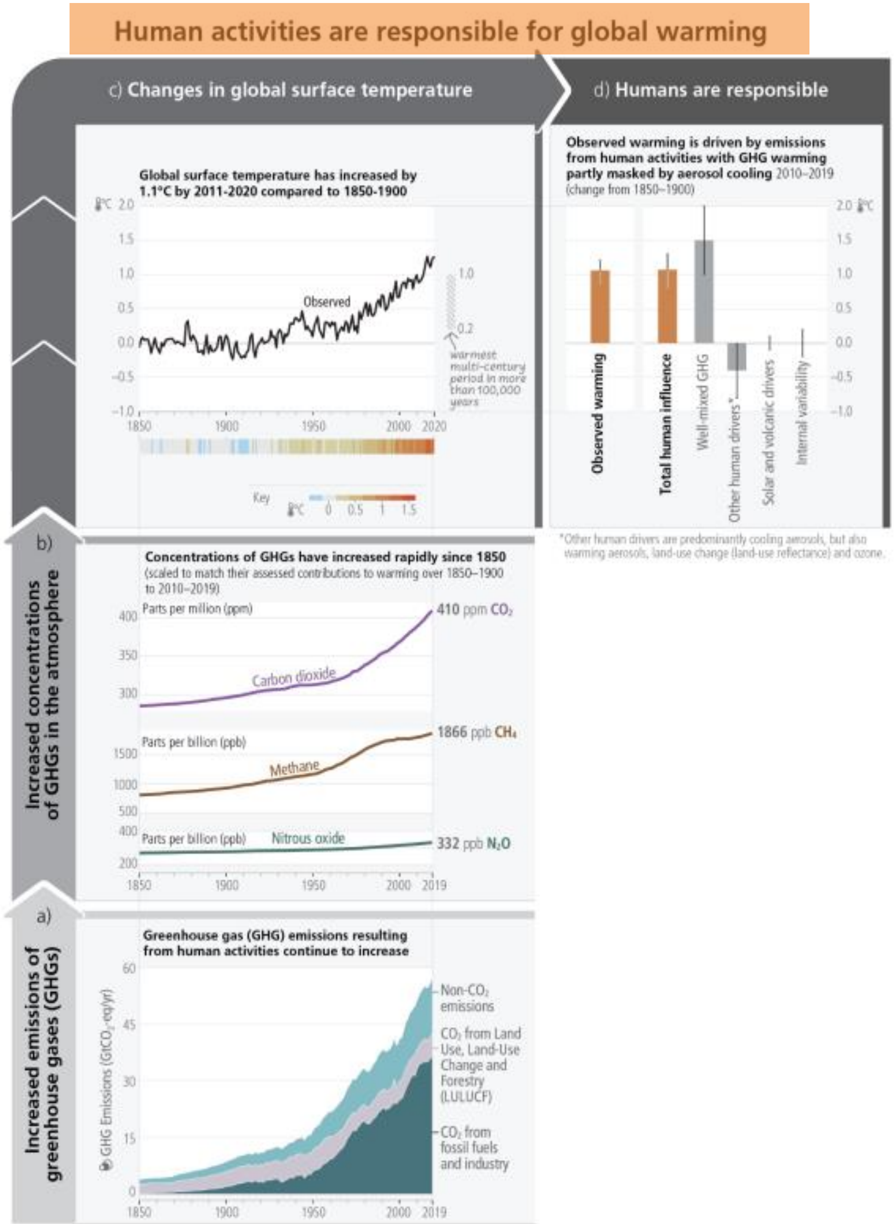
Director „Heat and buildings“
Fraunhofer Institute for Solar Energy Systems ISE

Intergovernmental Panel on Climate Change (IPCC)

Sixth Assessment Report



Assessment Report 6: Working Groups I-III Full Report (2021/22)



Synthesis Report (2023)

https://www.ipcc.ch

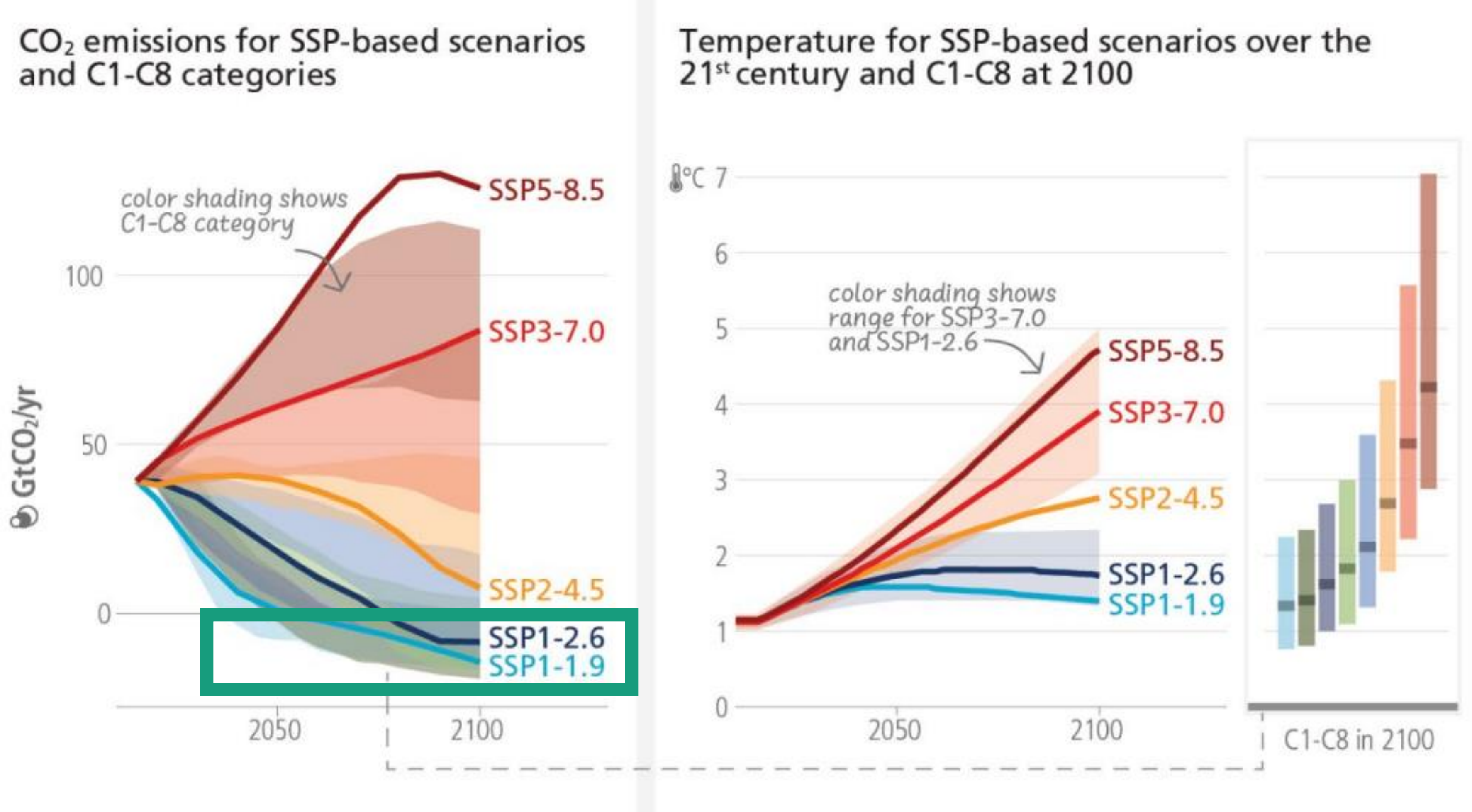
https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf, 31.03.2023

Fraunhofer

Anthropogenic global warming

Climate scenarios

Basically all scenarios that limit warming to 2°C in 2100 include negative emissions.



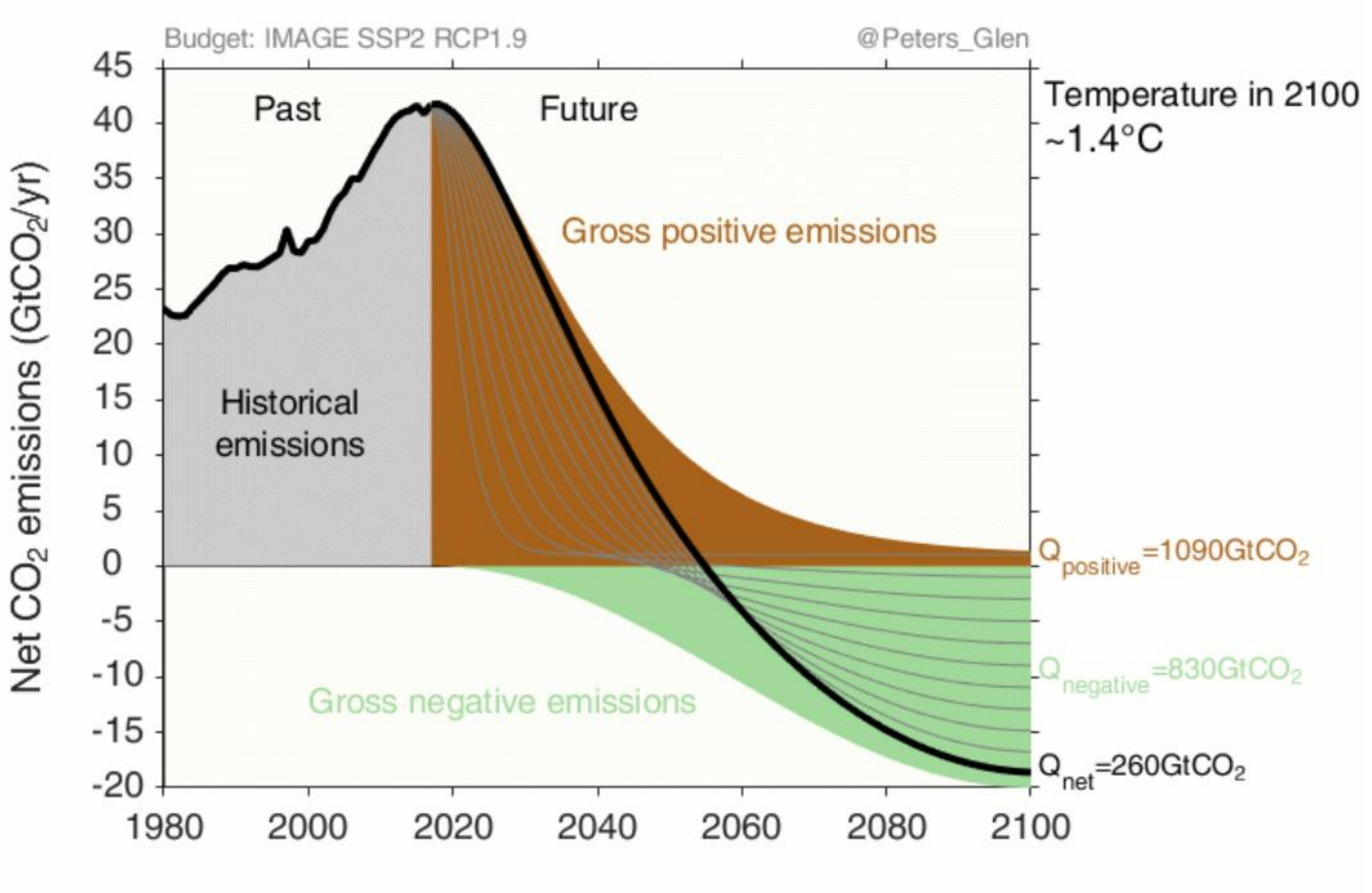
https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf, entnommen am 31.03.2023

Fraunhofer

Anthropogenic global warming

Negative Emission

The need for negative emissions increases significantly with the residual budget of positive emissions.



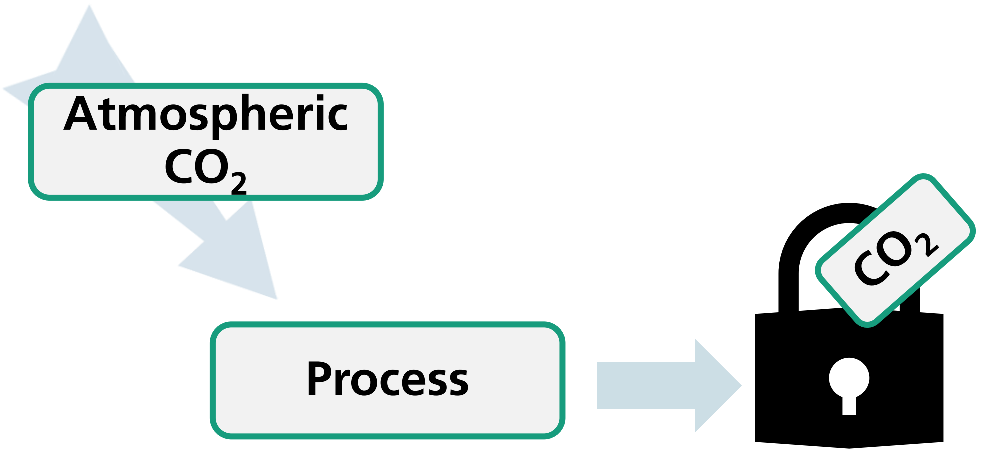
https://www.cicero.oslo.no/en/articles/stylised-pathways-to-well-below-2c, 4.9.2018, entnommen 31.03.2023

Carbon Dioxide Removals and Negative Emission Technologies

A definition

Carbon Dioxide Removals (CDR) refers to the general process of removing carbon dioxide (CO_2) from the atmosphere or a point source.

Negative Emission Technologies (NETs) are specific CDR technologies or methods aimed to remove CO_2 from the atmosphere for long durations, thus generating "negative emissions."

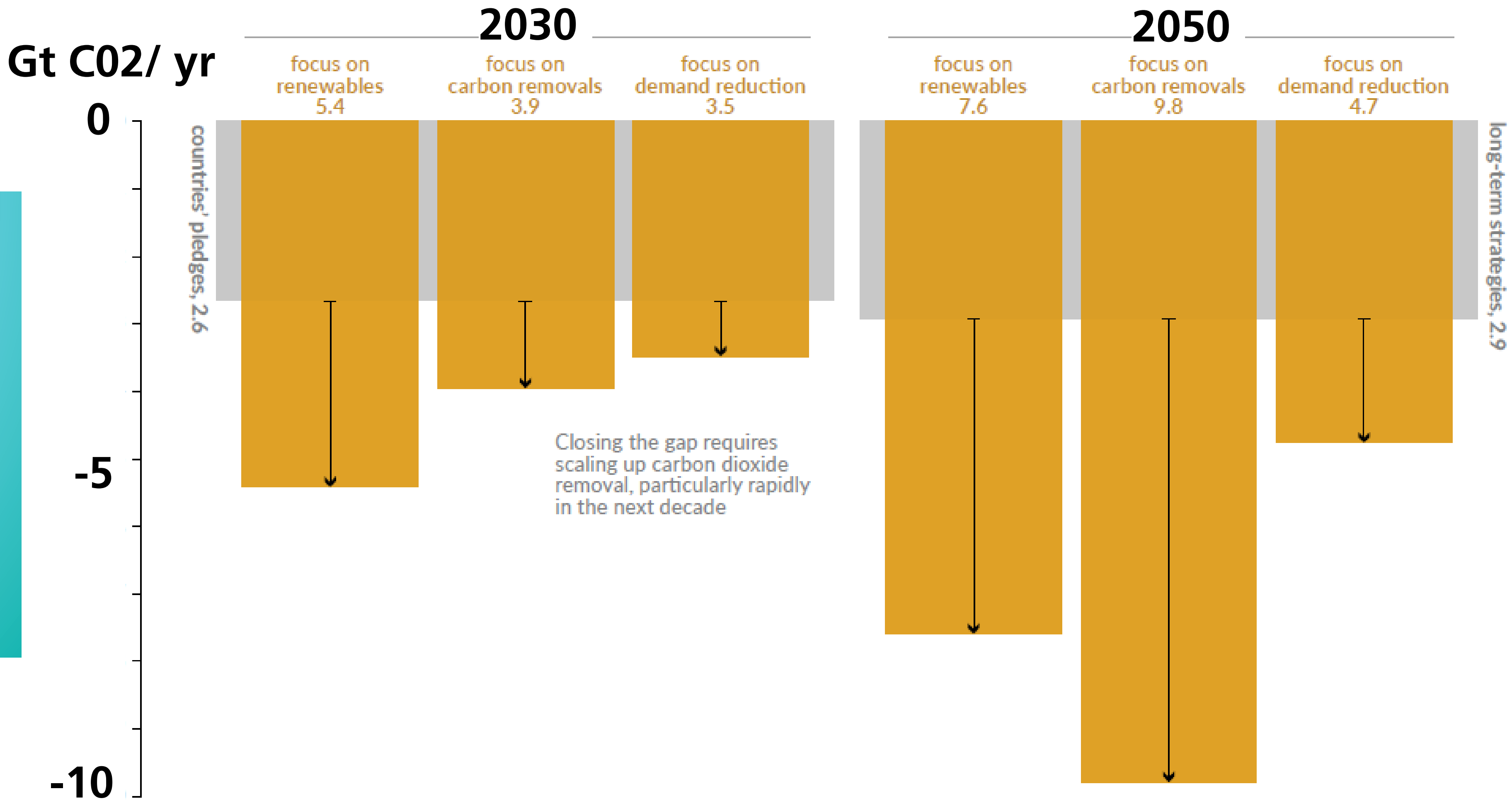


Clear definitions need to be agreed on

  Restricted Fraunhofer

The gap…

A gap between proposed negative emission and what is needed exists
→ Rapid growth of negative emissions capacity is needed!



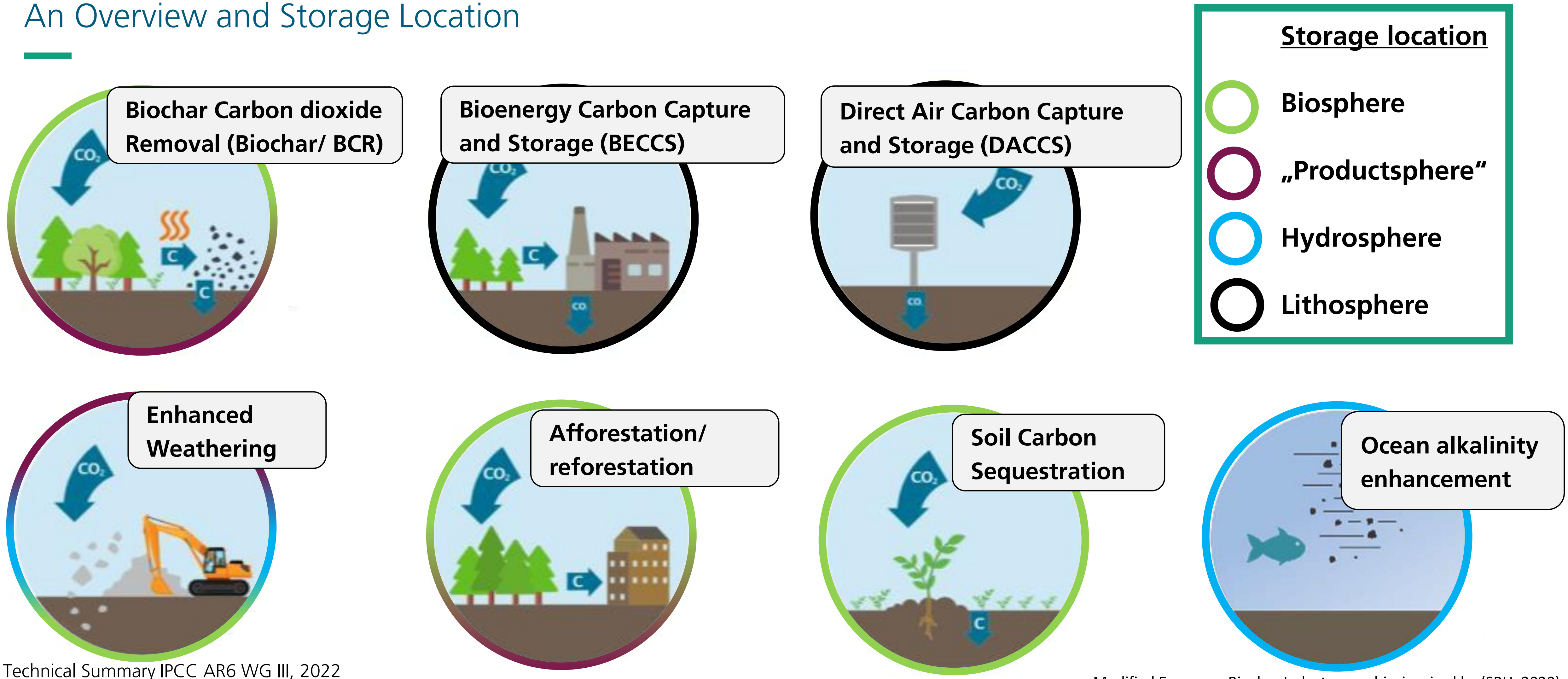
The State of Carbon Dioxide Removal - 1st Edition. The State of Carbon Dioxide Removal. doi:10.17605/OSF.IO/W3B4Z

  Restricted

Fraunhofer ISE

Negative Emission Technologies

An Overview and Storage Location



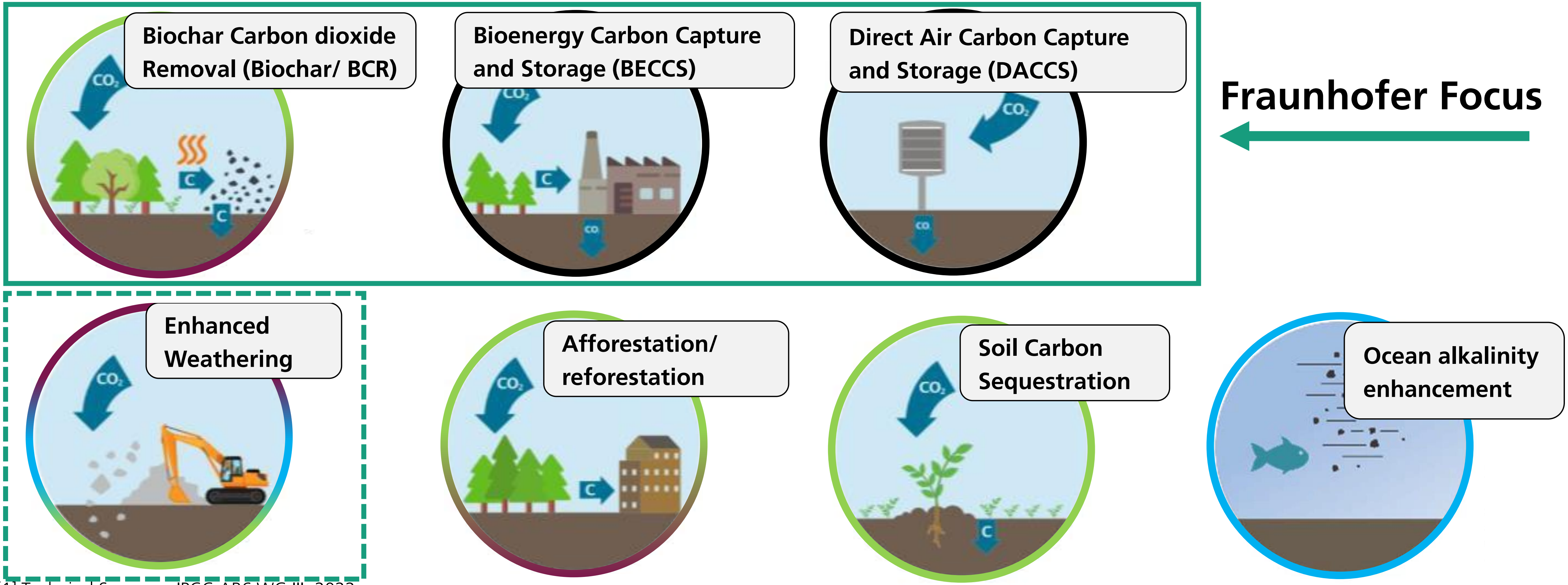
[1] Technical Summary IPCC AR6 WG III, 2022
[2] https://www.wissenschaftsplattform-klimaschutz.de/files/WPKS_Gutachten_MCC_PIK.pdf

Modified European Biochar Industry graphic, inspired by (SRU, 2020)

Fraunhofer

Negative Emission Technologies

An Overview and Storage Location



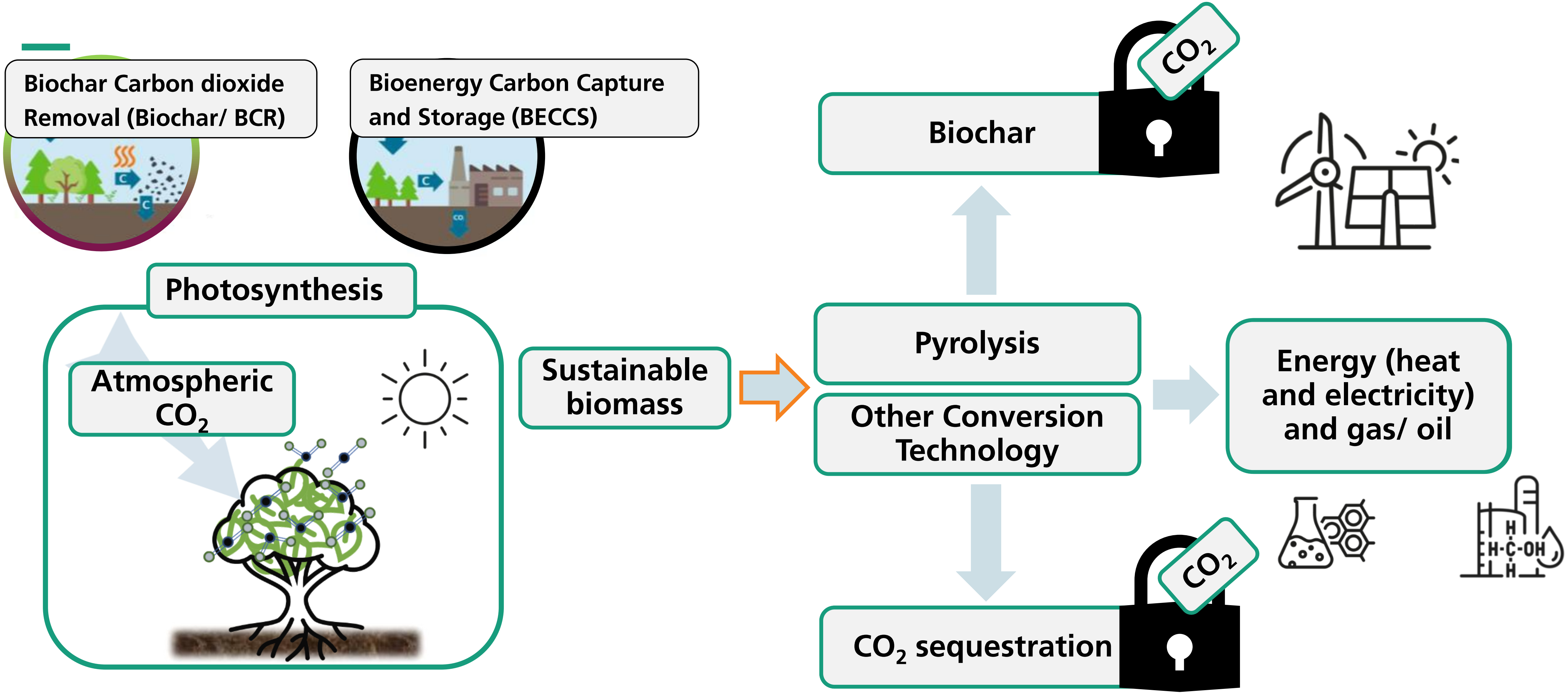
[1] Technical Summary IPCC AR6 WG III, 2022
[2] https://www.wissenschaftsplattform-klimaschutz.de/files/WPKS_Gutachten_MCC_PIK.pdf

Modified European Biochar Industry graphic, inspired by (SRU, 2020)

  Restricted

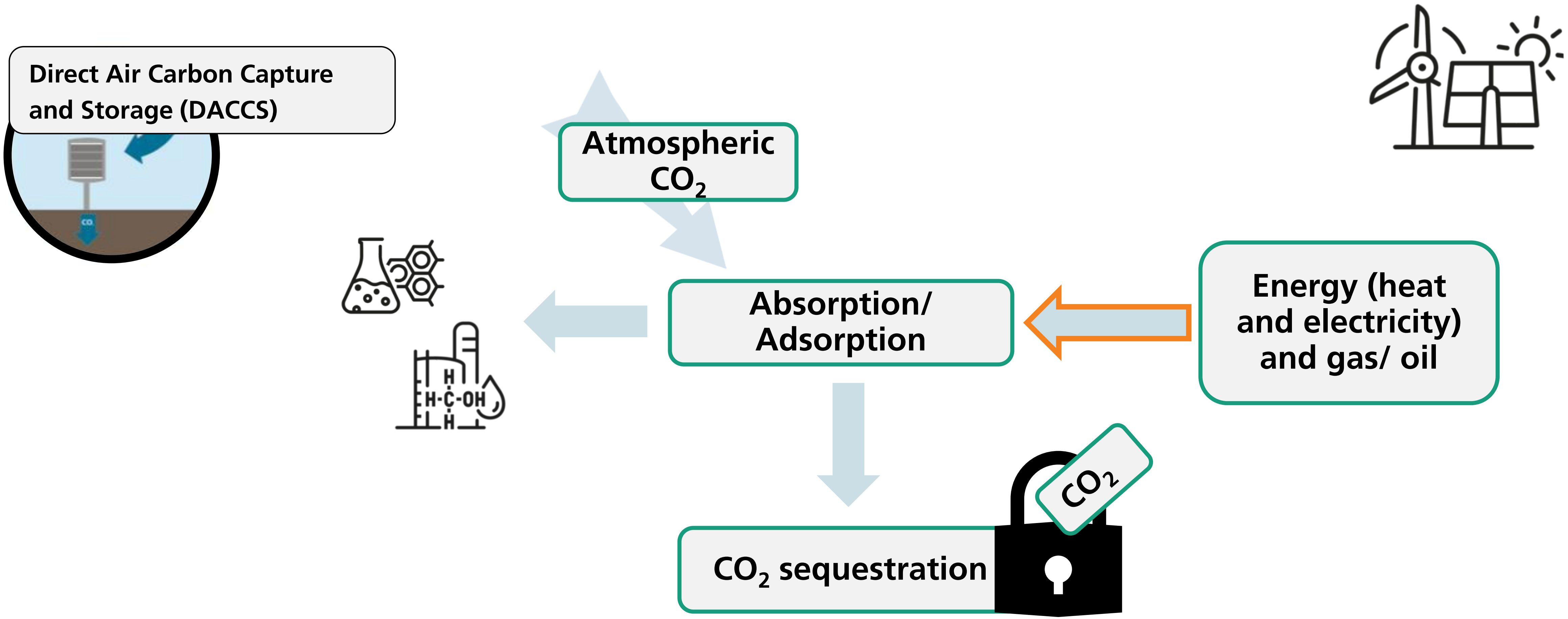
Fraunhofer

How do BCR and BECCS work?

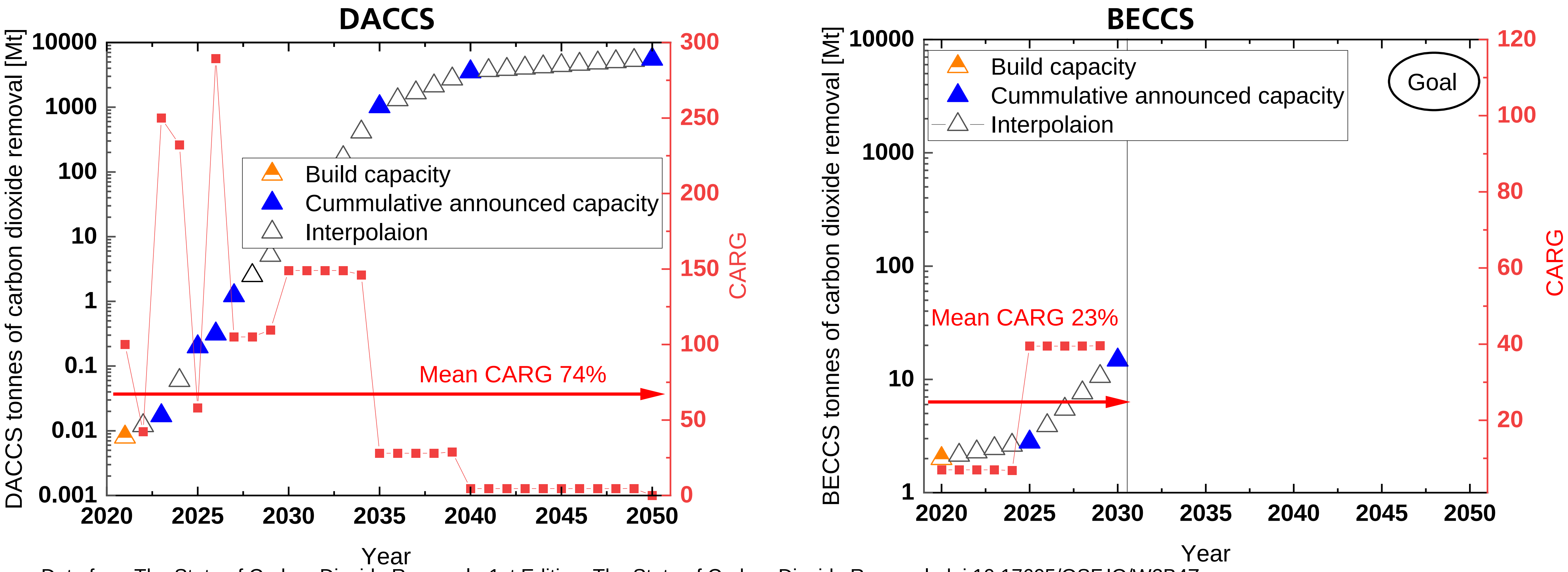


Fraunhofer

How does DACCS work?

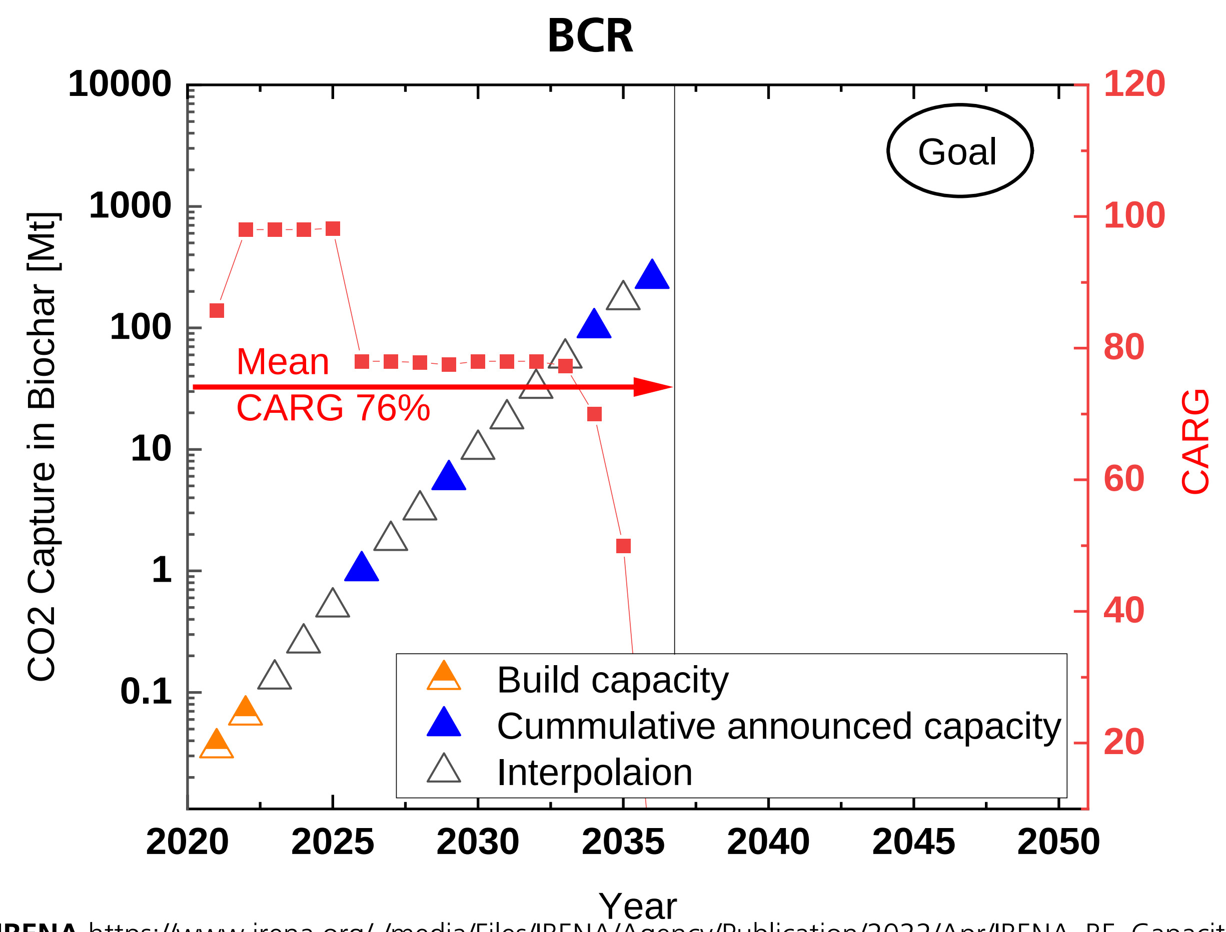


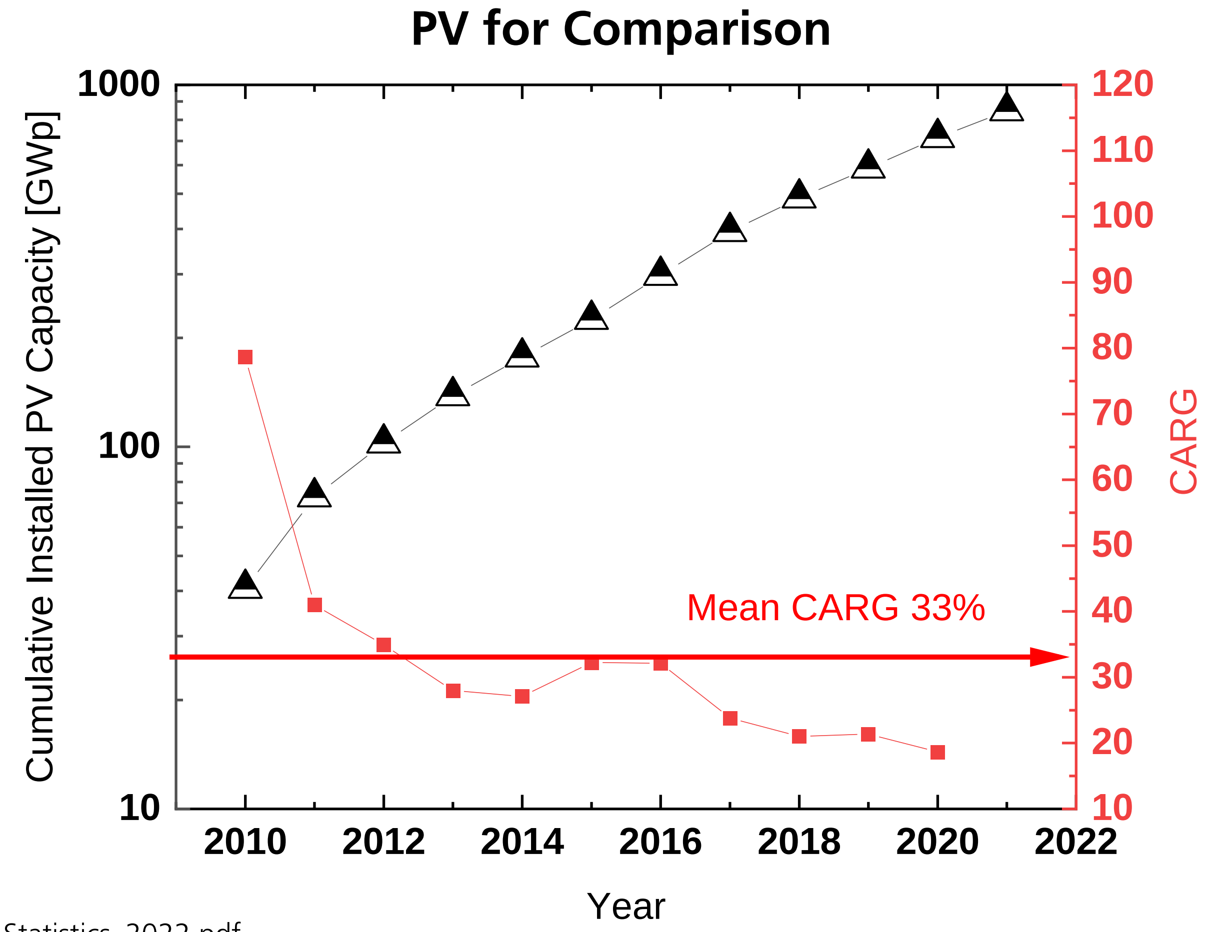
Predicted market Growth



Data from The State of Carbon Dioxide Removal - 1st Edition. The State of Carbon Dioxide Removal. doi:10.17605/OSF.IO/W3B4Z

Predicted market Growth





IRENA https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf

Data from The State of Carbon Dioxide Removal - 1st Edition. The State of Carbon Dioxide Removal. doi:10.17605/OSF.IO/W3B4Z

Carbon Dioxide Removals and Negative Emission Technologies

We need them all – and fast!

No relevant IPCC scenario without huge amount of NET!

NET means really longterm storage of the Carbon, not usage alone

Wide variety of technologies available with different Readiness Levels and impacts exist

We will need a mix of them and therefore we will need to investigate them all

To meet or come just close to the needed amounts of NET, all technologies will need growth rates even higher compared to PV in the last 10 years

So we need to speed up NOW……

Setting the Scene

Tiemo Wölken

Member of the European Parliament

Fraunhofer

Expert Presentation I: Politics, society and negative emission technologies – a scenario and climate policy analysis

Dr. Vicki Duscha

Coordinator Business Unit Climate Policy,
Fraunhofer Institute for Systems and Innovation Research ISI

Fraunhofer

Politics, society and negative emission technologies

NET options and potentials

Category	CDR method	Mitigation Potential (Gt CO_2/a)	Cost ($/t CO_2)	Status (TRL)
Land-based biological	Soil carbon sequestration in croplands and grasslands	0,6-9,3	45-100	8-9
Land-based biological	Peatland and coastal wetland restoration	0,5-2,1	No data	8-9
Land-based biological	Agroforestry	0,3-9,4	No data	8-9
Land-based biological	Improved forest management	0,1-2,1	No data	8-9
Land-based biological	Afforestation/ reforestation	0,5-10	0-240	8-9
Land-based biological	Biochar	0,3-6,6	10-345	6-7
Chemical	DACCS	5-40	100-300	6
Land-based biological	BECCS	0,5-11	15-400	5-6
Geochemical	Enhanced weathering	2-4	50-200	3-4
Ocean-based biological	Blue carbon management in coastal ecosystems	<1	No data	2-3
Ocean-based biological	Ocean fertilisation	1-3	50-500	1-3
Geochemical	Ocean alkalinity enhancement	1-100	40-260	1-2

Contribute to mitigation pathways in IAMs

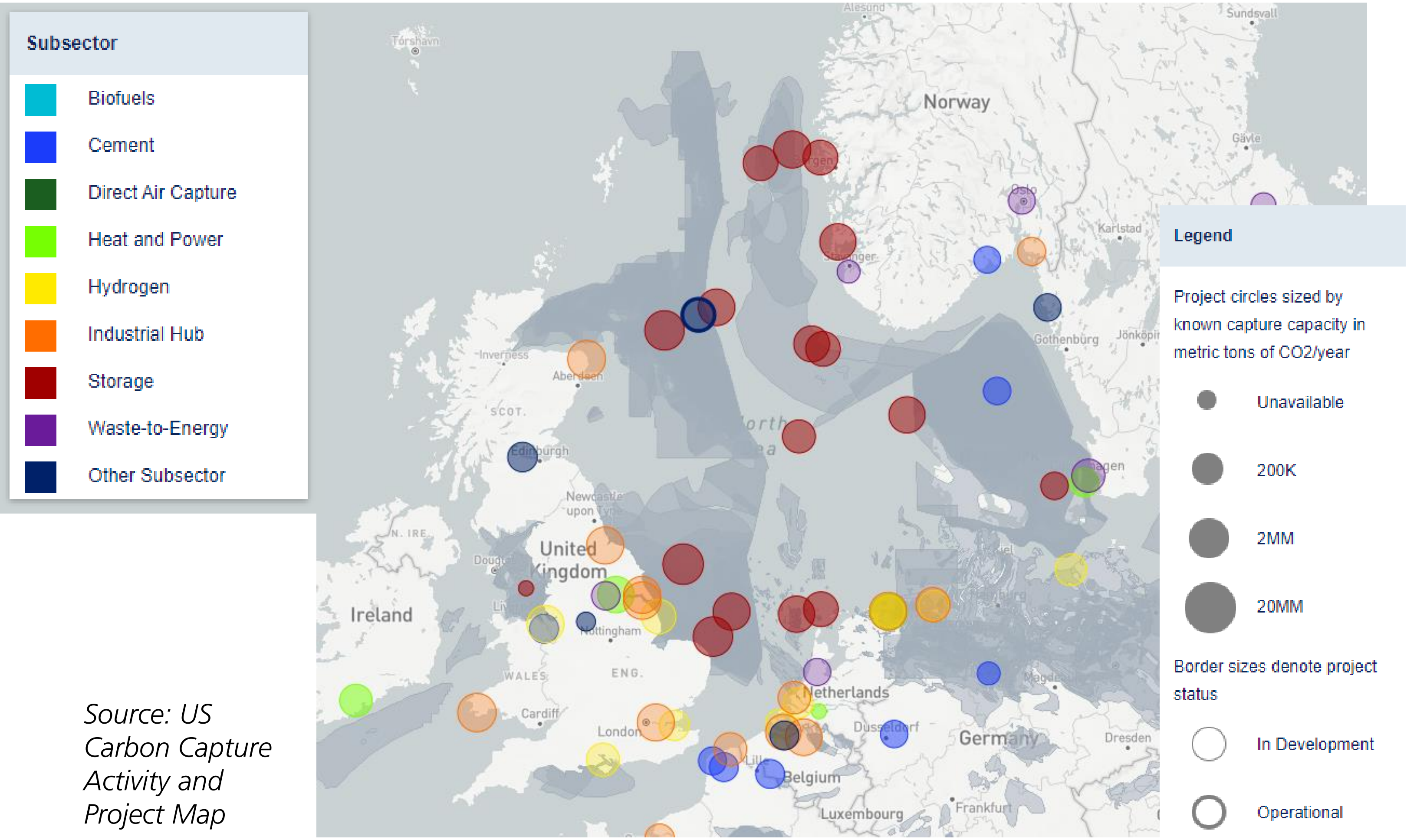
Source: based on IPCC, AR 6, WG III report

Restricted

Fraunhofer

Politics, society and negative emission technologies

Storage (and CCS) activities in the EU



Source: US Carbon Capture Activity and Project Map

Storage project	Injection capacity (Mt/a)	Begin of storage
Aramis (NL)	5	
L-10 Area (NL)	5-8	2026
Porthos (NL)	2.5	Final investment decision is currently being prepared/ Construction meant to start in early 2024
Athos (NL)		Stopped
Northern Lights (NO)	1.5-5	2025
Smeaheia (NO)	20	
Luna (NO)	5	
Scottish Cluster (UK)	*12*	*In development*
Northern Endurance Partnership (UK)	27	Mid 2020
Viking CCS (UK)	10	2030
Hewett Storage Site (UK)	20	2027
Bifrost (DK)	3-16	2027
Greensand (DK)	8	2025/26
Stenlille (DK)	10	2025

Fraunhofer

Politics, society and negative emission technologies

EU regulatory framework

climate neutrality by 2050
interim targets (55% reduction below 1990 levels by 2030)

- EU ETS targets
- ESR targets
- LULUCF sector

ETS Directive
includes transport and geological storage

Innovation Fund
support for CCUS projects

CCS Directive (2012)
geological storage of CO_2

London Protocol
cross-border transport of CO_2

Carbon Removal Certification Framework (CRCF)

Development of Methodologies

Net-zero industry act

Industrial carbon management strategy

Fraunhofer

Politics, society and negative emission technologies

EU regulatory framework – what's missing

- Strategy for CCUS (on the EU level, on MS level?)
- Targets for (permanent) negative emissions/ industrial carbon removals? targets for CCS injection capacity? trajectories/ interim targets?
- Clear definitions (CCU, biogenic carbon, atmospheric carbon, carbon dioxide removal, permanent storage, non-permanent storage, hard-to-abate sectors, hierarchy for different mitigation options?...)
- Standards for captured and transported carbon (content of CO_2 stream, pressure, ...)
- EU-wide infrastructure planning/ optimization
- Dealing with London Protocol issues
- International cooperation? (EEA, UK, others?)

- In the long-term: viable business models for CCU, CCS, carbon dioxide removal
  - use of negative emission certificates under the EU ETS/ ESR for compliance?
  - handling of CCU under the EU ETS
- Support for infrastructure build up

Fraunhofer

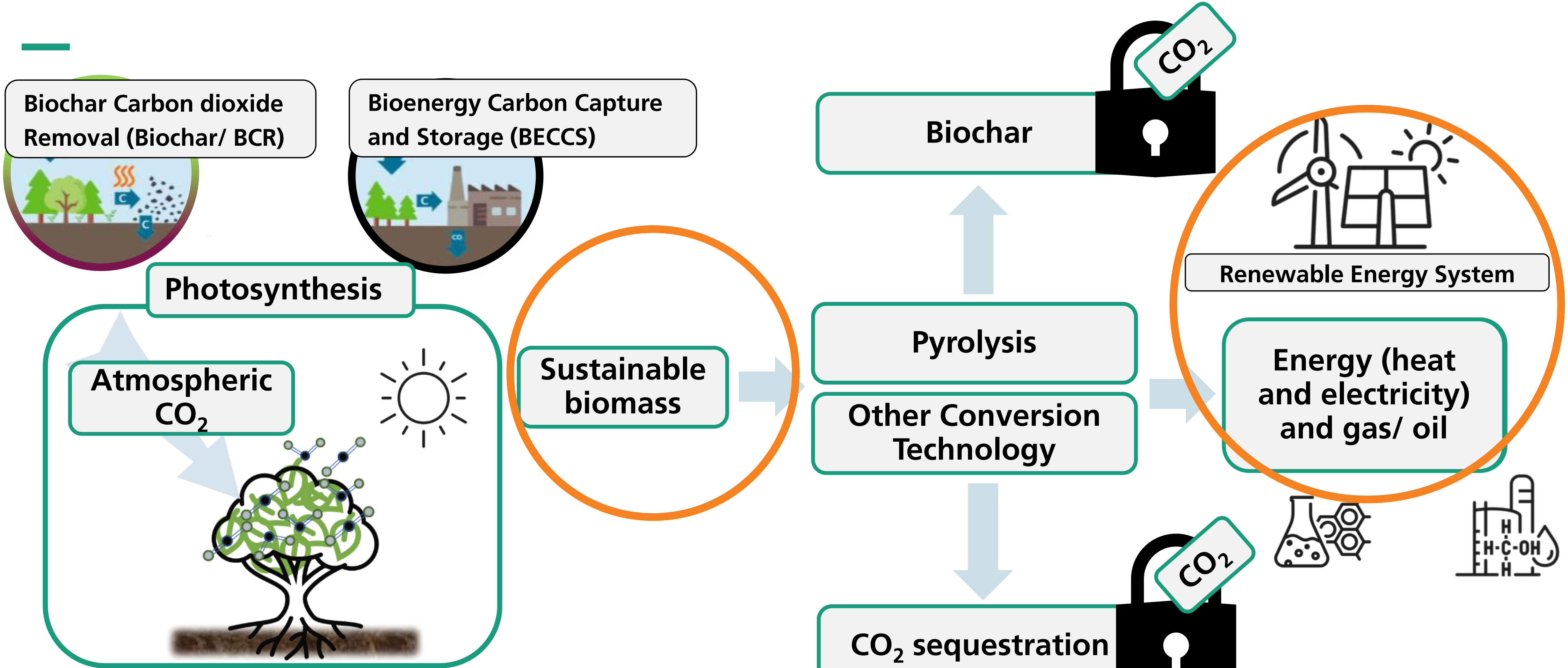
Expert Presentation II: Life cycle analysis of biochar, BECCS and DACCS and their role in future renewable energy systems

Dr. Saskia Kühnhold-Pospischil

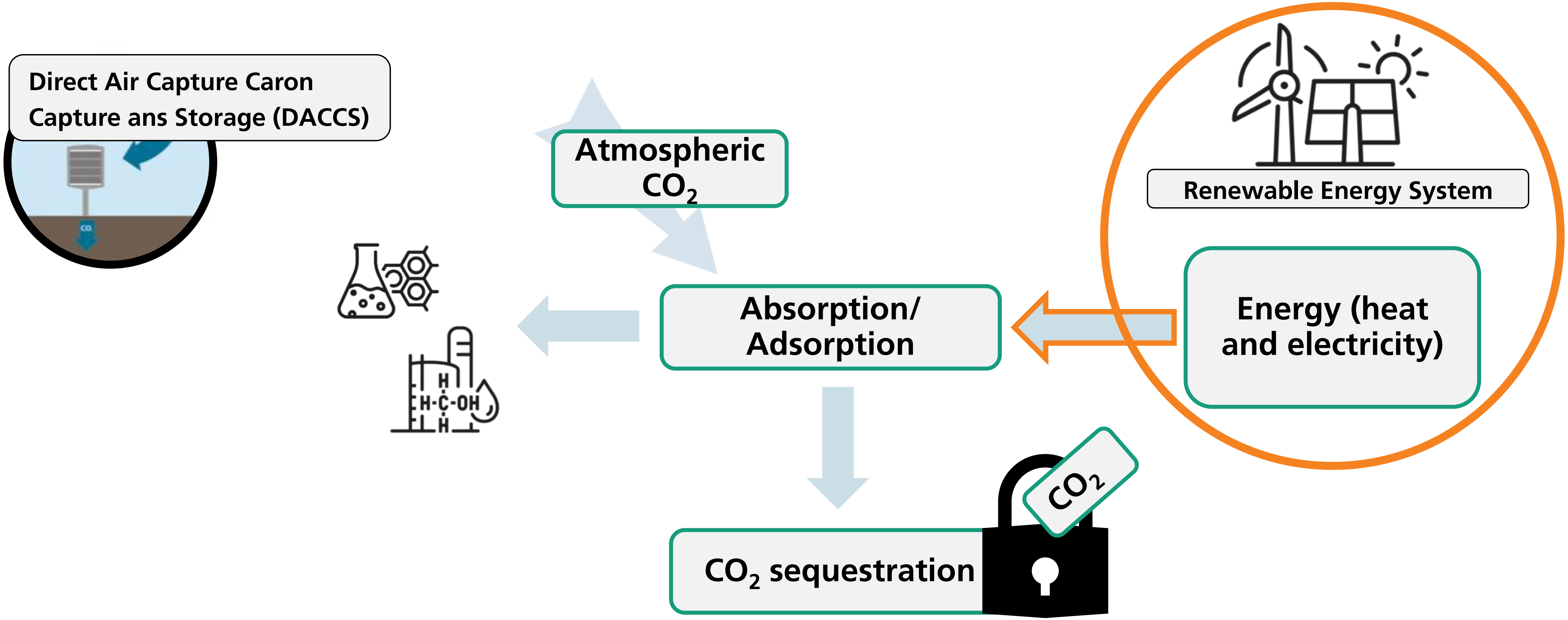
Science Advisor to the Institute Director
Fraunhofer Institute for Solar Energy Systems ISE

Fraunhofer

Negative Emission Technologies will be part of renewable energy systems



Negative Emission Technologies will be part of renewable energy systems

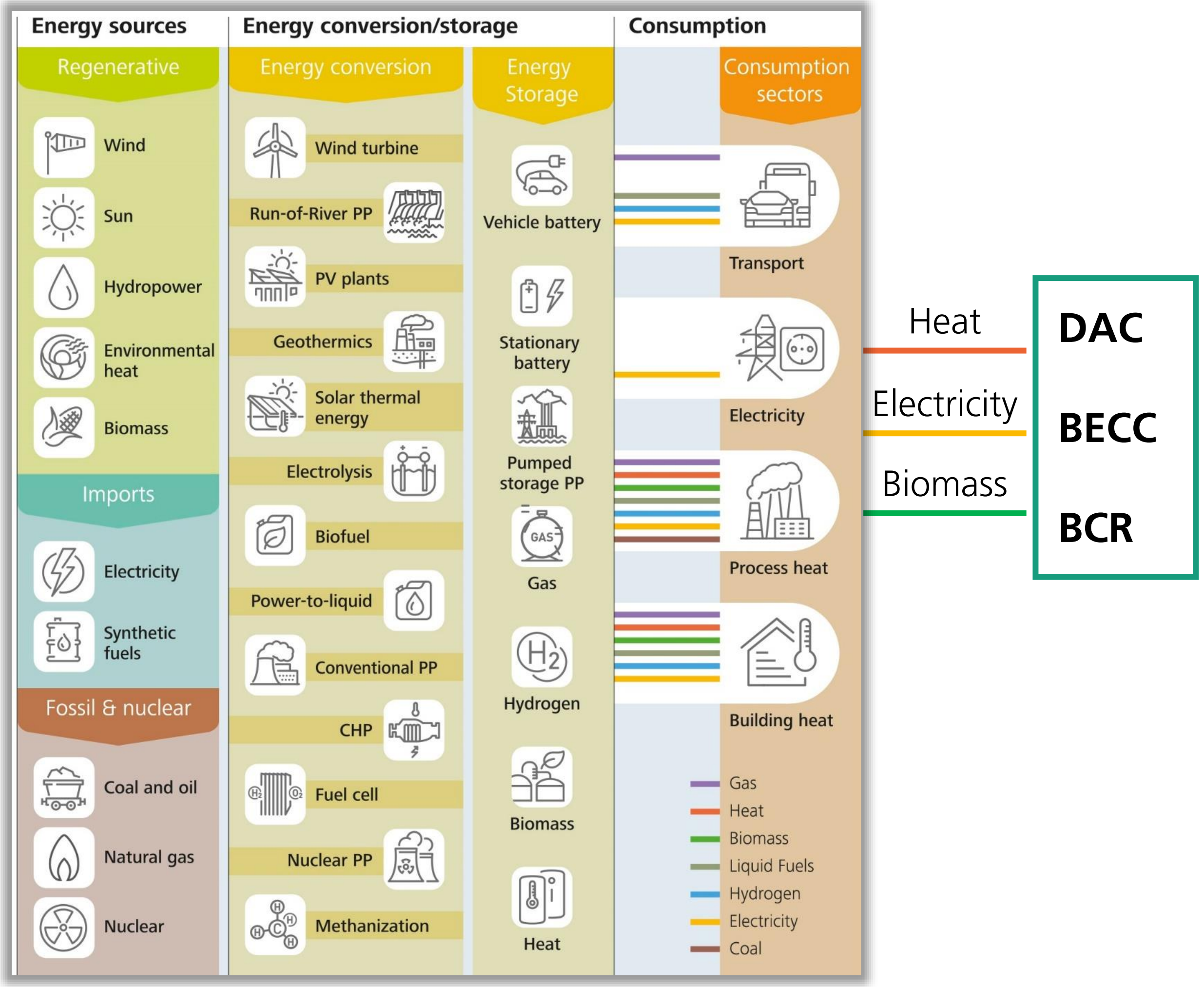


Negative Emission Technologies in renewable energy systems

A system analysis approach with the REMod model

NET development depends on different factors:

- Techno-economic development of NETs
- Availability of green electricity
- Availability of biomass
- Availability of CO_2-Infrastructure
- Regulatory framework for negative emissions
- Demand for CCU
- …



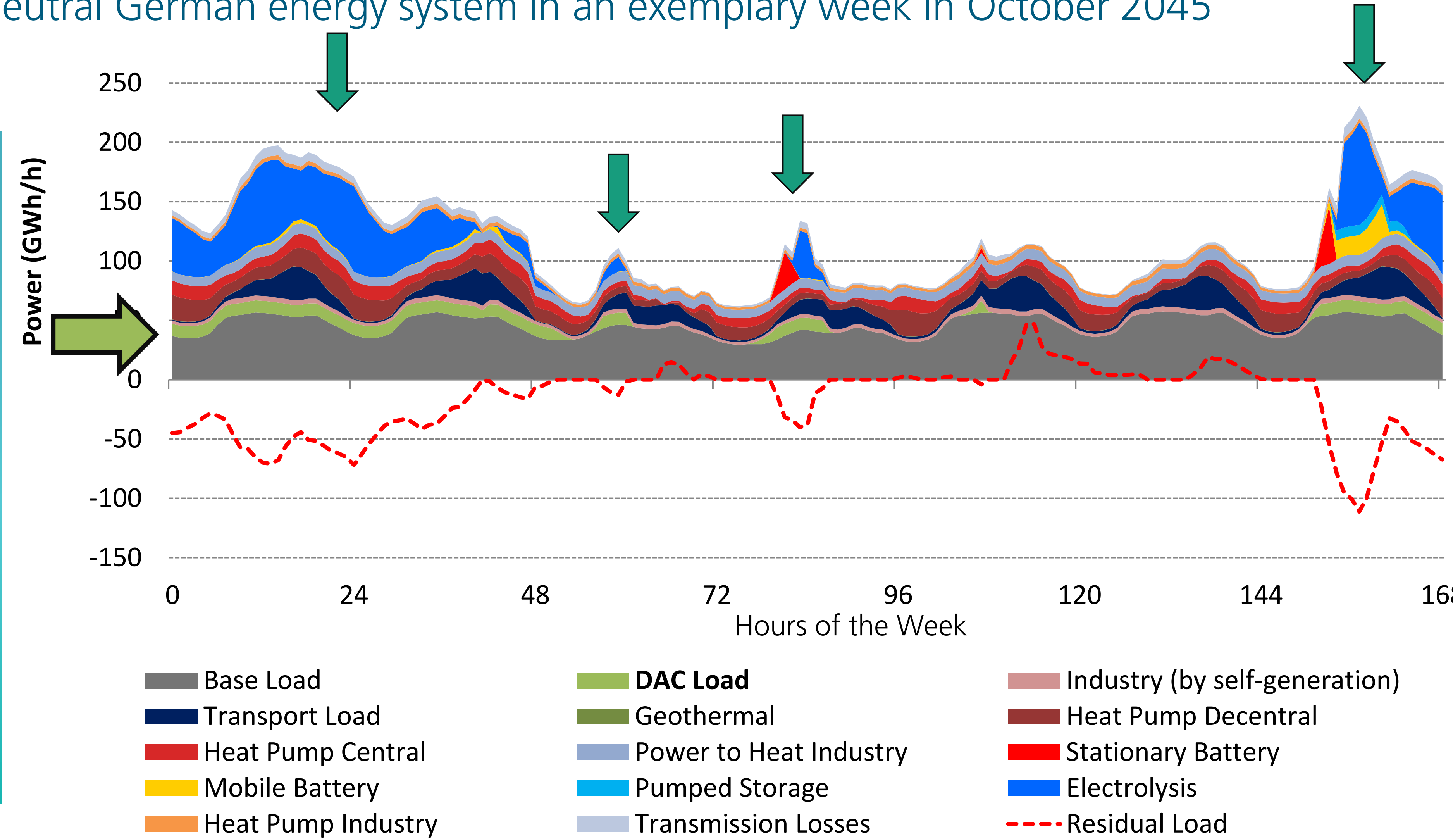
REMod: https://www.ise.fraunhofer.de/en/publications/studies/paths-to-a-climate-neutral-energy-system.html

DAC – potentially providing negative emissions and flexibility

Electricity use in a CO_2-neutral German energy system in an exemplary week in October 2045

Electrolysis and DAC provide flexibility to use excess renewable electricity

Economic evaluation depends on uncertain cost assumptions and VRE availability



  Restricted

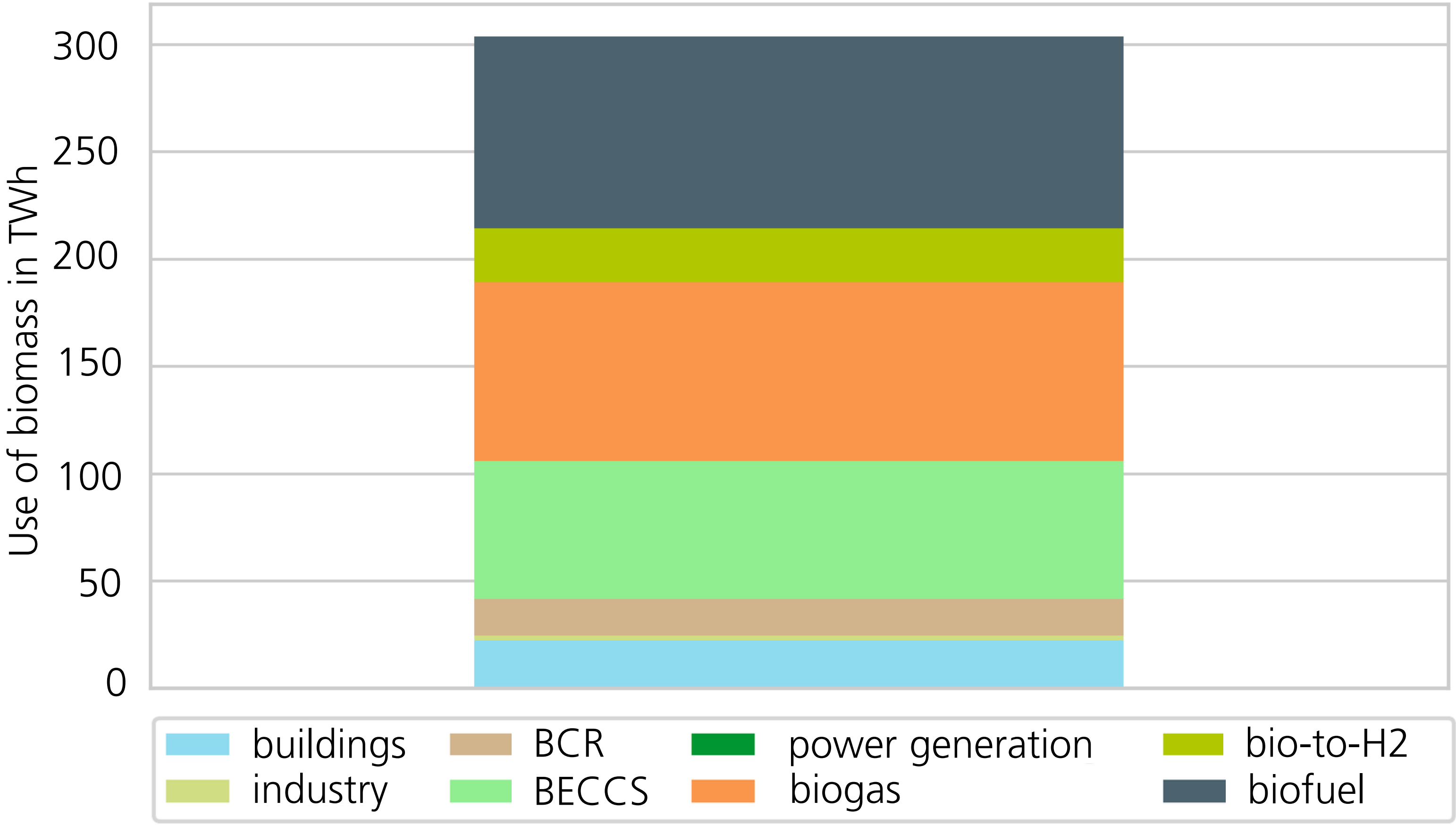
Fraunhofer

Biomass-based NETs in a competition for the use of limited biomass

Exemplary use of biomass in a CO_2-neutral German energy system in 2045

Biomass based NETs are part of a limited sustainable biomass competition.

Standards for evaluating sustainability of biomass and accounting of biomass related GHG emissions are central.



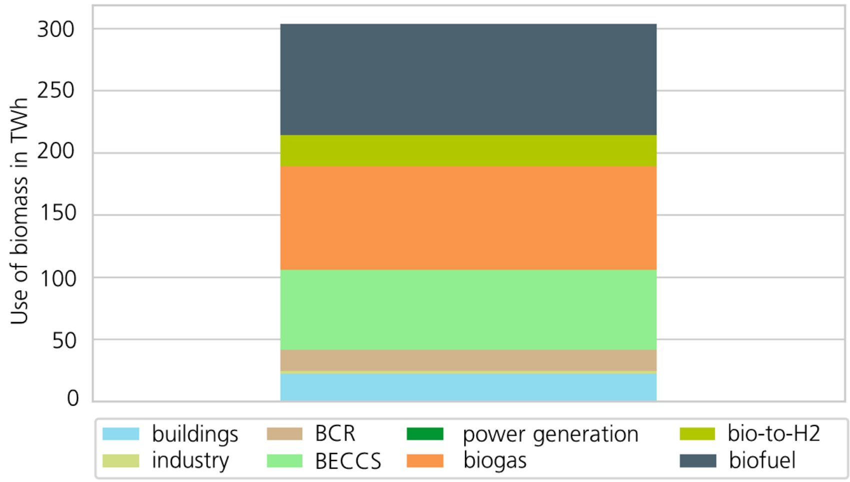
Biomass-based NETs in a competition for the use of limited biomass

Exemplary use of biomass in a CO_2-neutral German energy system in 2045

Biomass is a valuable, limited resource!

→ **Smart** and **efficient** use of biomass is needed
→ **Cascade** use/ **Circular** Economy
→ Use of **residual biomass** for BCR e.g.

An estimation from the European Biochar Industry Consortium:
“In order to achieve 100 megatons CO_2 by 2040, 19% of the European biomass would be required.”



  Restricted

Fraunhofer

Life Cycle Assessment of BCR, BECCS and DACCS

Goal: Through LCA analyses, BCR, BECCS and DACCS can be evaluated in terms of their respective footprints and other categories.

Assumptions:

BECCS:

Grass/ maize silage →
Anaerobic digestion →
Biogas (amino washing) →
Bio methane and CO_2 sink due to sequestration

BCR:

Wood based biomass →
Pyrolysis →
Biochar sink due to soil application

DACCS:

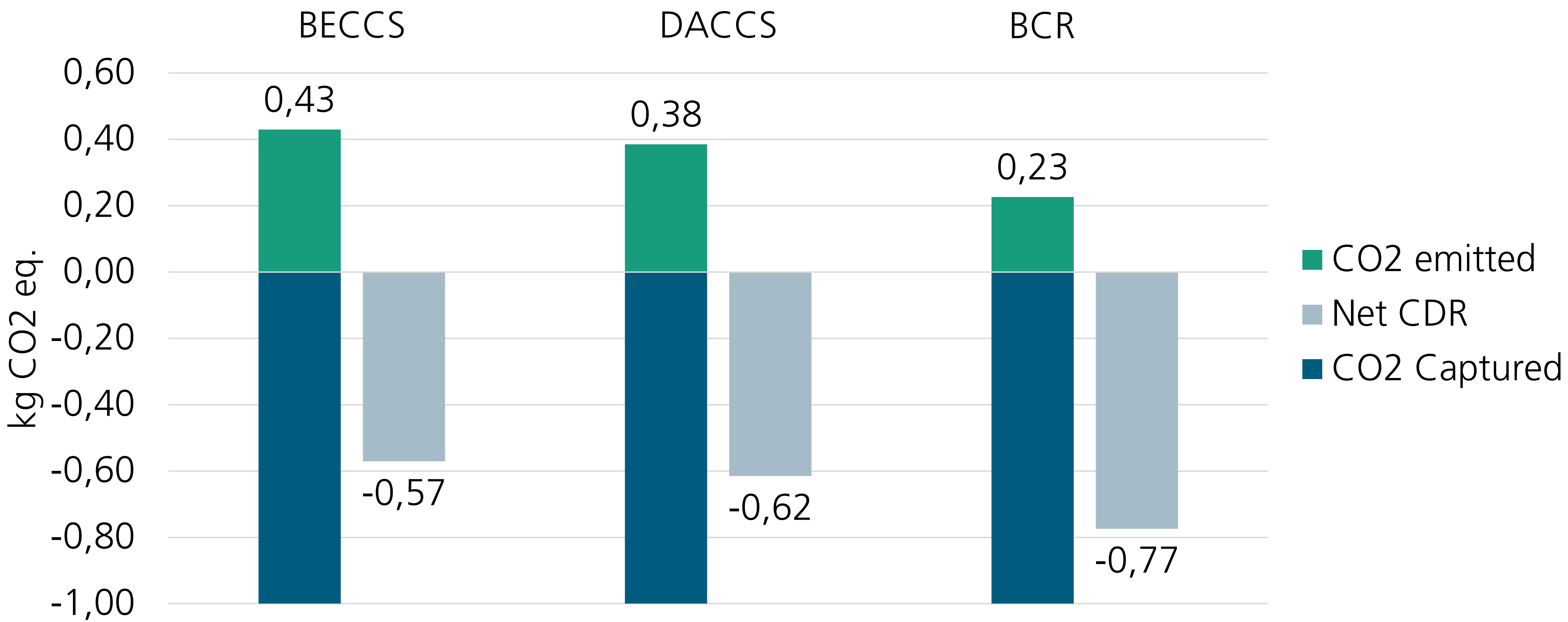
Ventilation →
Polyethyleneimine sorbent →
Heating →
CO_2 sink due to sequestration

  Restricted

Fraunhofer

Results for 1 kg of CO_2 captured and stored

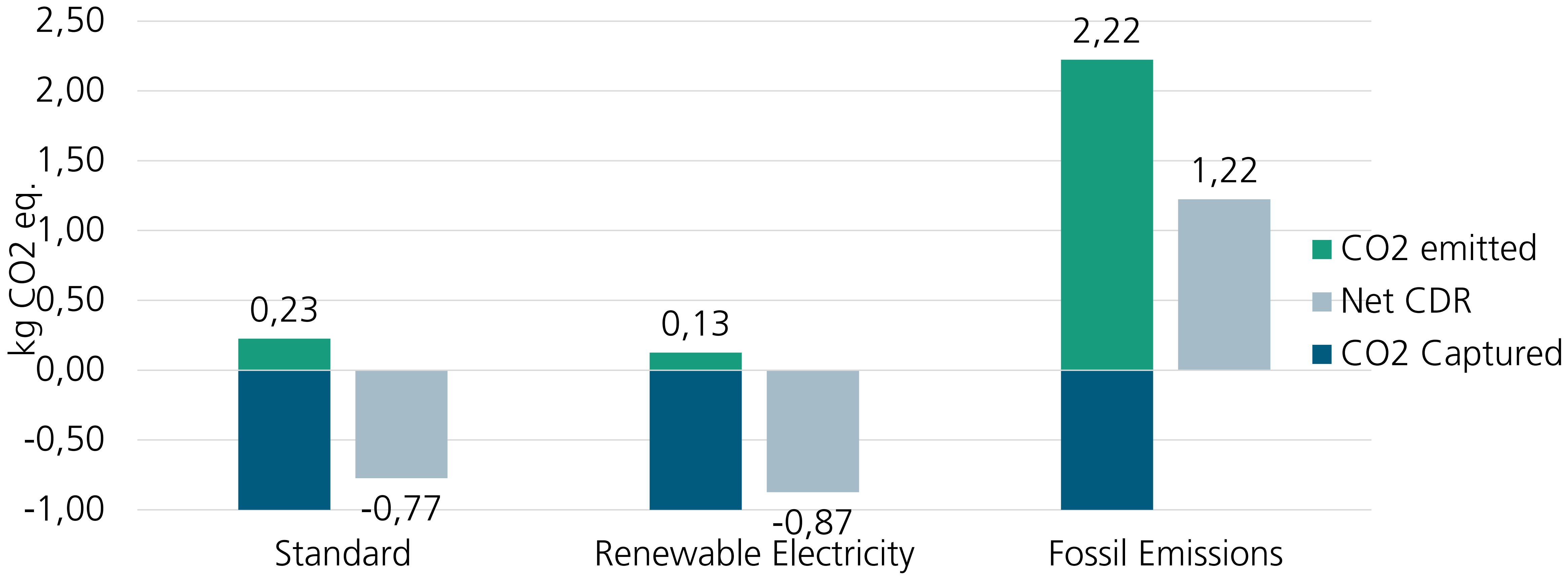
Comparison – Carbon Footprint



Fraunhofer

Results for 1 kg of CO_2 captured and stored

Sensitivity Analysis of BCR – Carbon Footprint



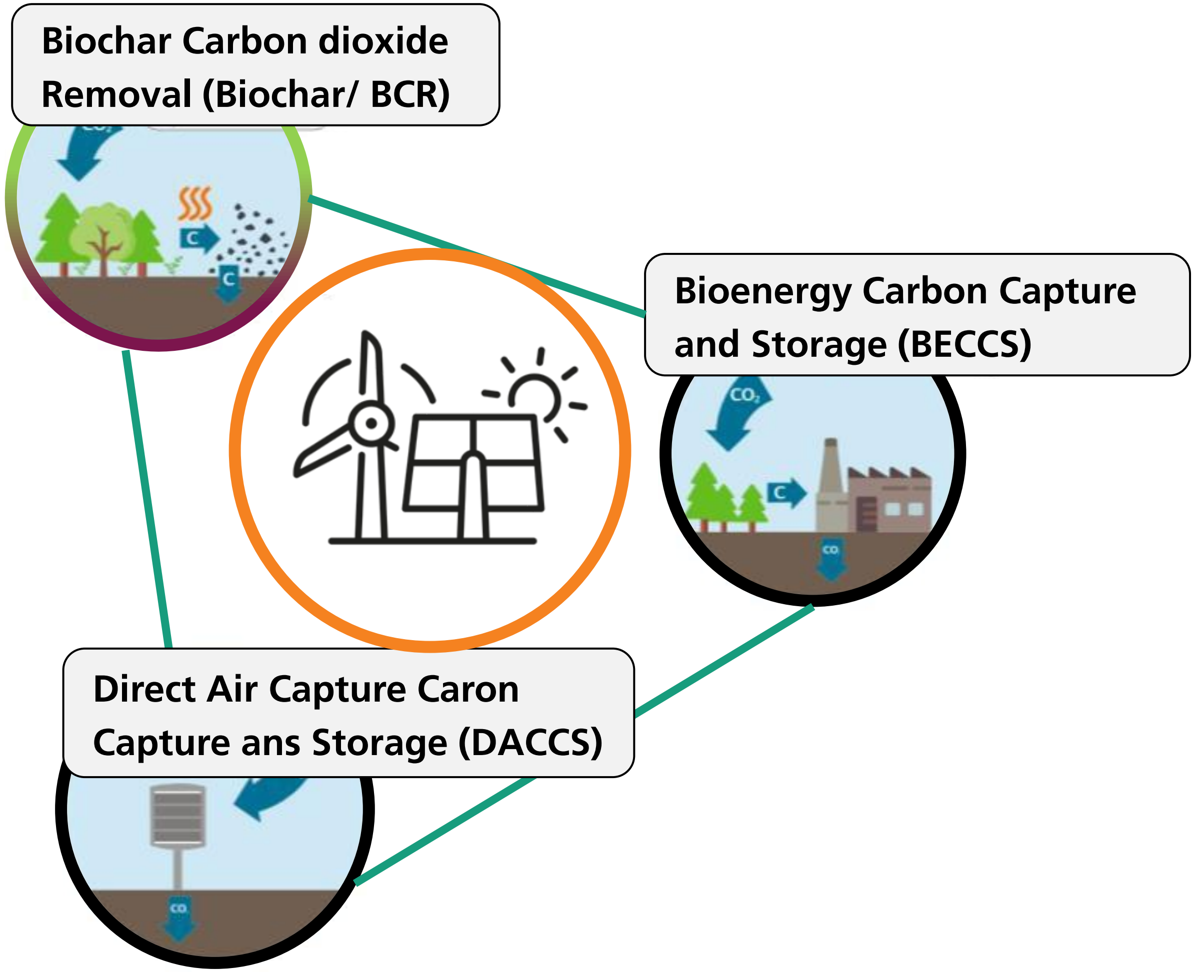
Fraunhofer

Take aways from this talk

1 **Systemic approach**
Negative emissions technologies as part of renewable energies.

2 **Sustainable biomass** is a valuable and limited resource. Strong governance is important and **smart use**.

3 The **entire value chain** must be considered to estimate the **final CO_2 sink capacity** of each NET technology.



Expert Presentation III: Carbon management for climate neutrality - BECCS and PyCCS as key technologies to valorize biogenic residues and waste

Martin Meiller

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT

  Restricted Fraunhofer

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT

Fraunhofer UMSICHT

Carbon management for climate neutrality – BECCS and PyCCS as key technologies to valorize on biogenic residues and waste

Martin Meiller, Robert Daschner, Christoph Glasner, Christopher Kick

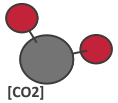
September 27, 2023 | Brussels | Fraunhofer Twin Transition Series

What is BECCS and PyCCS?

Overview and importance

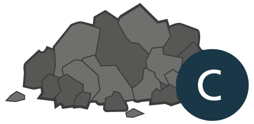
- **B**io**e**nergy **C**arbon **C**apture and **S**torage **(BECCS)**
- **B**io**e**nergy **C**arbon **C**apture and **U**tilization **(BECCU)**

→ CO_2



- **Py**rogenic **C**arbon **C**apture and **S**torage **(PyCCS)**
- **Py**rogenic **C**arbon **C**apture and **U**tilization **(PyCCU)**
- **B**iochar **C**arbon **R**emoval Technology **(BCR)**

→ C



BECCS Ecosystem

BECCS Ecosystem

An overview about the BECCS Ecosystem…

Biomass → Conversion Technology → Carbon Capture → Storage / Utilization

Bioenergy is very complex

- Large variety of biomass, biogenic residues and wastes
- Large variety of conversion technologies
- Large variety of products
- Large variety of Carbon Capture technologies
- Large variety of options to utilize and store C or CO_2

Fraunhofer

BECCS Ecosystem

Biomass and biogenic residues

Biomass → Conversion Technology → Carbon Capture → Storage / Utilization

- Plants and plant components
- Waste and waste by-products (from plant and animal origin)
- Residual wood and waste from woodworking, forestry
- Landscape conservation material

Fraunhofer

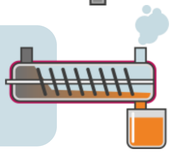
BECCS Ecosystem

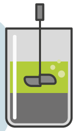
Conversions technologies

Biomass → **Conversion Technology** → Carbon Capture → Storage / Utilization

Combustion 

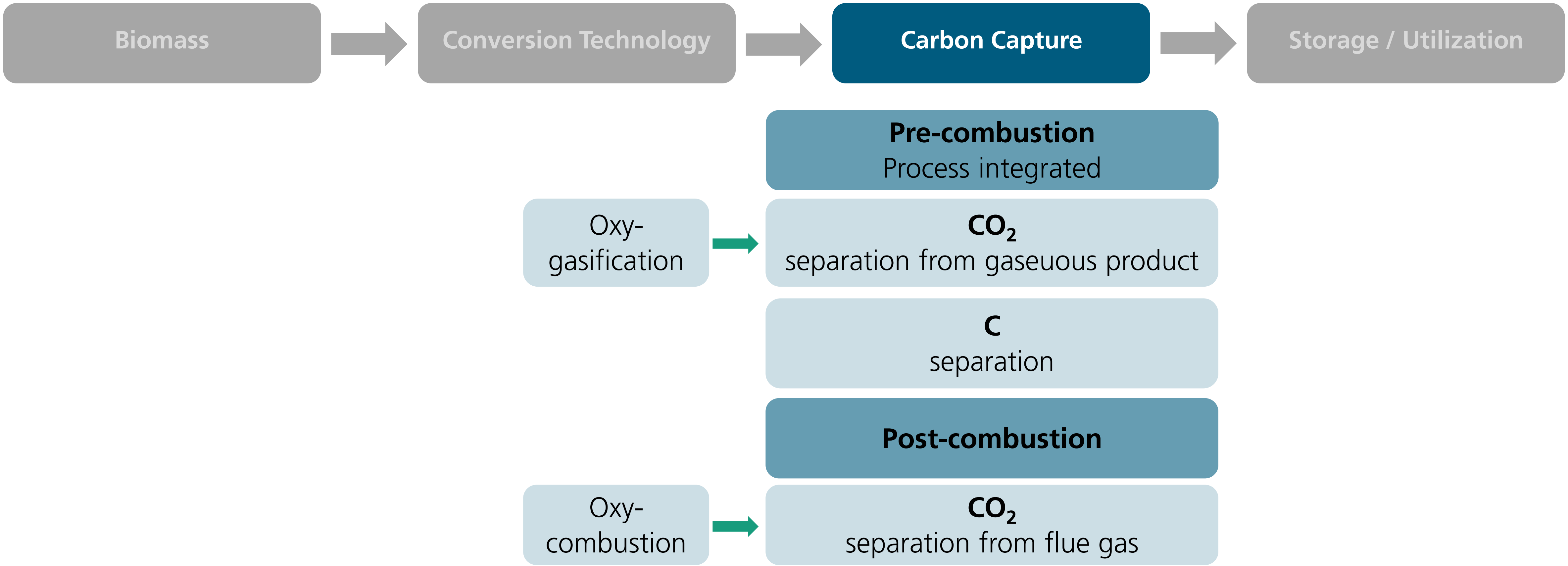
Gasification 

Pyrolysis 

Fermentation 

...

BECCS Ecosystem
Carbon Capture



Fraunhofer

BECCS Ecosystem

Utilization and Storage

Biomass → Conversion Technology → Carbon Capture → **Storage / Utilization**

CO_2

Conversion ←

→ **Non-conversion** (direct use)

Conversion:

Fuels
- Methane
- Methanol
- Gasoline/Diesel

Chemicals
- Chemical inter-mediates
- Monomers, Polymers

Building materials
- Aggregates
- Cement
- Concrete

Non-conversion (direct use):

Plant nutrition
- Greenhouses
- Algae cultivation
- Urea, Fertilizer

Enhanced Oil/ Gas Recovery
- CO_2-injection

Production Auxiliary
- Food, Beverages
- Technical gas
  - Dry cleaning
  - Refrigeration
  - Welding, …

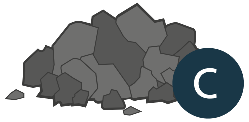
Source: Modified acc. to IEA 2021

BECCS Ecosystem

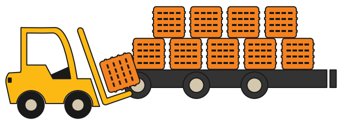
Utilization and Storage

Biomass → Conversion Technology → Carbon Capture → **Storage / Utilization**

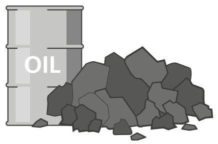
- Biochar
- Methane-Pyrolysis
- …



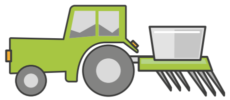
Building materials
- Concrete
- Asphalt

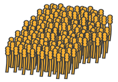


Geological storage



Soil amendment





…

BECCS & PyCCS: Most advanced pathways so far…

Market relevant activities

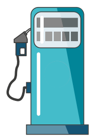
Bioethanol | Biomethane | Combustion & MEA | PyCCS / Biochar

Starch / Cellulose
from corn, sugar beet, wheat

↓ + Enzymes

Glucose

↓ Fermentation



Ethanol + CO_2

- Most important BECCS application in operation
- Worldwide about 2 Mt CO_2 /a captured and stored (EOR & geological)
- CO_2 removed after fermentation step in high concentrated gas
- Process chain Bioethanol + EOR
- 1. Generation Biofuel

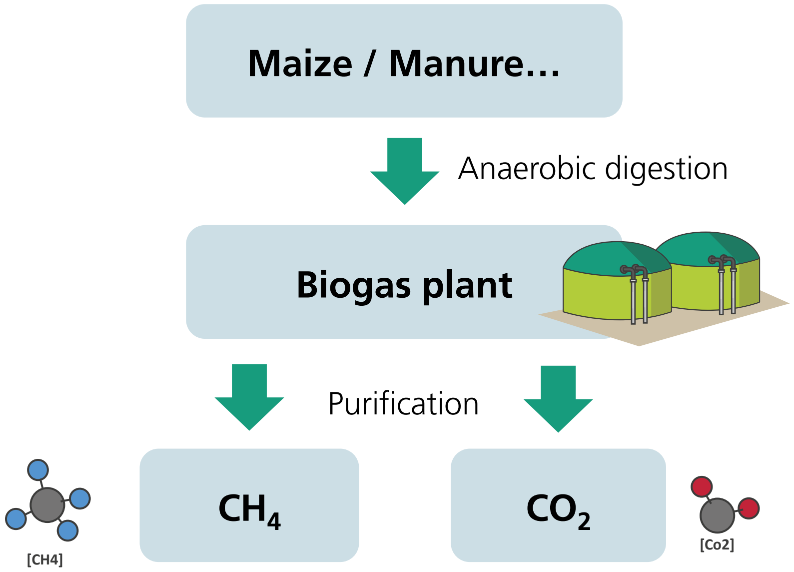
Status:
Technology approved and commercially available

Shabaz et al. 2021
IEA 2022

BECCS & PyCCS

Most advanced pathways so far…

Bioethanol | **Biomethane** | Combustion & MEA | PyCCS / Biochar



- 20,000 biogas plants in Europe, about 9,000 in Germany
- 1,000 plants in Europe upgrade to biomethane, about 220 in Germany
- 3 billion m³ of biomethane
- REPowerEU aims at 30 billion m³ of biomethane by 2030

Status:
Technology approved and commercially available

Ifeu 2022

BECCS & PyCCS

Most advanced pathways so far…

Bioethanol | Biomethane | **Combustion & CarbonCapture** | PyCCS / Biochar

Biomass / Waste

↓

Combustion

↓

Flue gas

↓

Carbon Capture → CO_2

	Ørsted Kalundborg Hub (Denmark)	AVR Duiven (NL)	Twence Hengelo (NL)
Fuel	Wood chips, Straw	Municipal solid waste	Municipal solid waste
Status	Under construction	Operational	Operational
CO_2 captured (t/y)	430,000	60,000	100,000
Removal target (%)	N.A.	90	N.A.
CO_2-Utilization	Geological storage	Greenhouse	Greenhouse

Fraunhofer

BECCS & PyCCS

Most advanced pathways so far…

Bioethanol | Biomethane | **Combustion & CarbonCapture** | PyCCS / Biochar

Biomass / Waste

↓

Combustion

↓

Flue gas

↓

Carbon Capture → CO_2

- Most activities in WtE-sector large scale demonstration + first application
- MEA (Monoethanolamine) most developed carbon capture technology
- Research focus: Increase efficiency of carbon capture

- Almonst 500 WtE-plants treating about 100 Mt of waste in Europe

Status:
- Technology commercially available (especially MEA)
- First commercial projects and demonstration projects on-going, many more in design or construction phase
- R&D required to increase efficiency and strengthen applicability

Fraunhofer

BECCS & PyCCS

Most advanced pathways so far…

Bioethanol | Biomethane | Combustion & CarbonCapture | **PyCCS / Biochar**

Biomass / Waste

↓

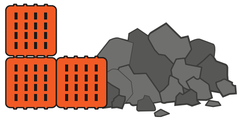
Pyrolysis

↓ ↓

Gas / Oil | **C**

↓

Energy, Products & Fuel



- Potential of pyrogenic carbon capture and storage to remove 30% of the projected 800 billion tons of CO_2eq*
- Markets and prices:
  - 1,000 €/t coal (not carbon) (as of 07/2023)
  - Certificates: Biochar and Carbon C-sink certificates

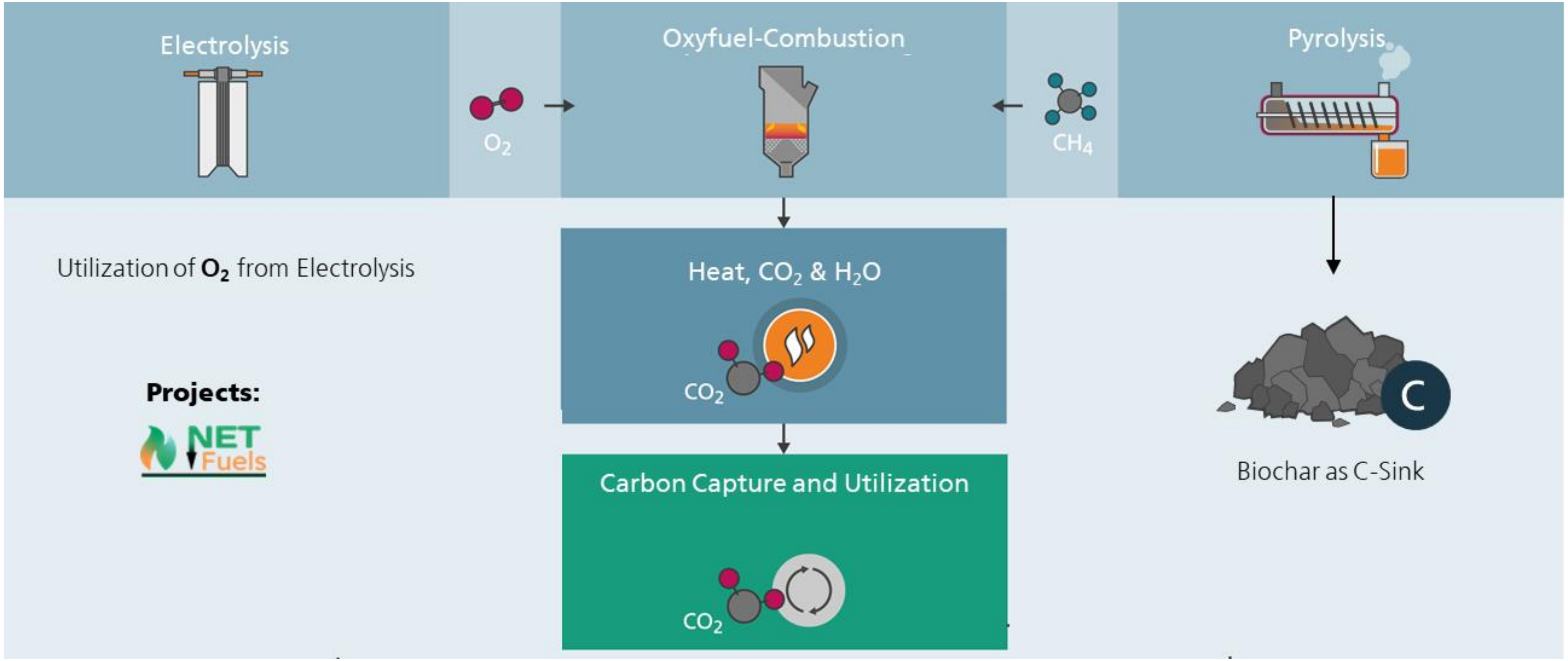
Status:

- Decentral technology
- Technology commercially available, but many small companies
- C-sink certificates in private markets organized

*Schmidt HP, Hagemann N, 400.000 Pyrolyseanlagen zur Rettung des Klimas - Notwendigkeit und Grenzen des exponentiellen Wachstums von Klimatechnologien, Ithaka-Journal 2021, Arbaz, Switzerland, ISSN 1663-0521, pp. 436-442, www.ithaka-journal.net/

Our vision

Efficient combination of BECCS/U and PyCCS/U



  Restricted Fraunhofer

Conclusion and Outlook

Conclusion

- Huge complexity of Bioenergy
- High Technological Readiness Level of BECCS-Ecosystem
- BECCS Ecosystem as a potential „lubricant for cross-sectoral system transitions"

Market entry barriers

- Regulatory insecurity in biomass utilization

BECCS

- (Pollutants) emissions regulations → Based on concentrations

PyCCS

- Application of biochar in soils and different products

Summary of all Expert Presenations

Four key points

NET technology development

- A great variety of NETs exist with permanent sink potentials
- R&D funding and support for first-of-its-kind projects is needed

Sustainable value chain of NETs

- The whole NET value chain need to be considered
- Sustainable biomass is a valuable and limited resource → smart use
- MRVs need to be established

NET Framework

- Regulatory framework is needed for fast NET development
- Harmonized EU-wide infrastructure planning can help uptake of NET
- Sink standards are needed to ensure the sink quality

NET as part of Renewable Energy Systems

- NETs need to be considered as part of renewable energy systems → NETs need biomass, heat and/ or produce heat and/ or electricity

Fraunhofer

Contact information

Peter Schossig
Fraunhofer Institute for Solar Energy Systems ISE

peter.schossig@ise.fraunhofer.de

www.ise.fraunhofer.de/en.html

Vicki Duscha
Fraunhofer Institute for Systems and Innovation Research ISI

vicki.duscha@isi.fraunhofer.de

www.isi.fraunhofer.de/en.html

Saskia Kühnhold-Pospischil
Fraunhofer Institute for Solar Energy Systems ISE

saskia.kuehnhold-pospischil@ise.fraunhofer.de

www.ise.fraunhofer.de/en.html

Martin Meiller
Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT

martin.meiller@umsicht.fraunhofer.de

www.umsicht.fraunhofer.de/en.html

Fraunhofer

Fraunhofer-Gesellschaft

Contact

Katrin Mögele
Fraunhofer EU Office

katrin.moegele@zv.fraunhofer.de

For more information on the Fraunhofer Twin Transition Series:
s.fhg.de/TwinTransition