Functional Technology Foresight: A Case Study on Direct Air Capture and Storage Technology – Methodological Thoughts

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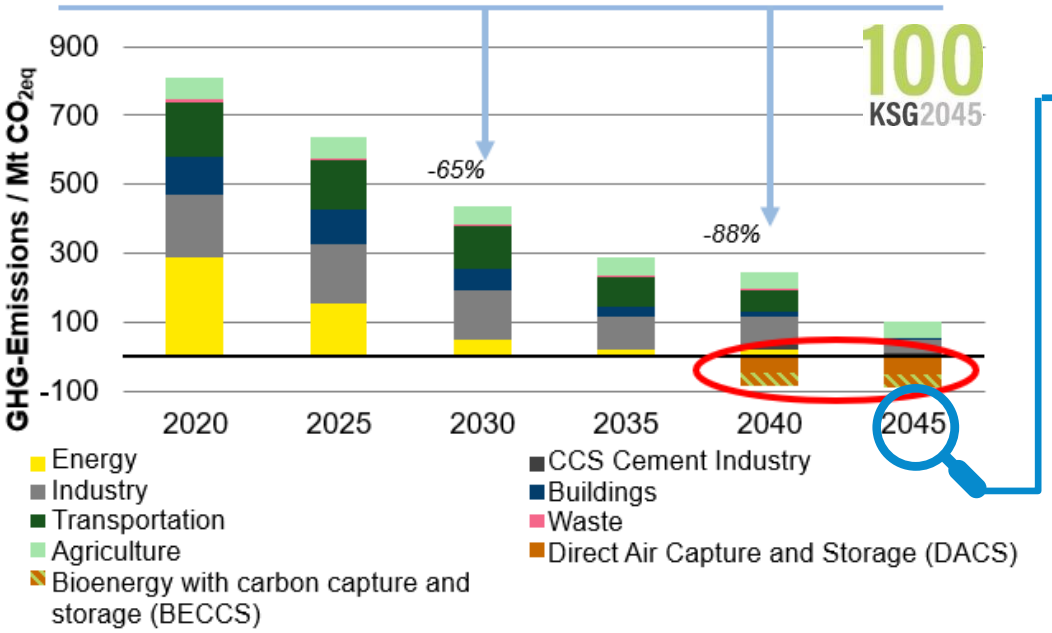
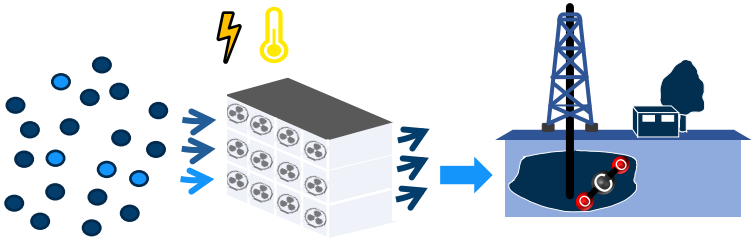
IEK-3: Institute of Techno-economic Systems Analysis

Direct Air Capture and Storage (DACS) is an important negative emission technology with the potential to help mitigating global warming and climate change.

Germany / cost optimized scenario

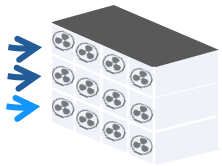


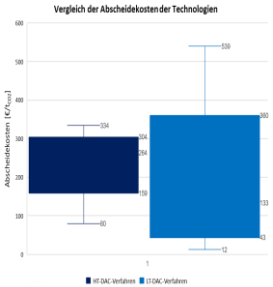
21.8 Mt/a **to be sequestered** in DE @ 2045

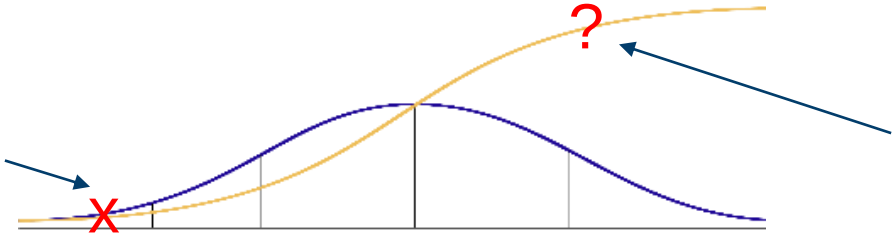


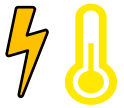
Source: Stolten, D.; Markewitz, P.; Schöb, T.; Kullmann, F.; Kotzur, L. et al. (2021): Strategies for a greenhouse gas neutral energy supply by 2045. Forschungszentrum Jülich GmbH

But, how to model DACS plants in energy systems analysis?

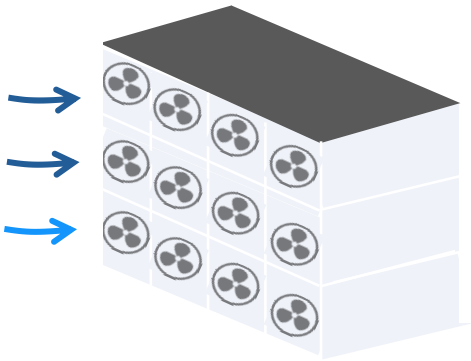








Currently $\sum 19$ *pilot plants globally* $(\sim 10\mathrm{k}\frac{\mathrm{t}}{\mathrm{a}})$



To conduct reasonable systems analysis, the following questions need to be answered in an unbiased way:

- What are characteristics of successful DACS plants?
- In which direction is future DACS plant development heading?
- Which aspects are important to include in systems analysis and in which way?

The Idea Behind Functional Technology Foresight

What are we looking for?

Dominant future technical solutions

Which sources do we have at hand?

Patents ≡ information about inventions that are expected to provide future benefits


Eur J Futures Res (2016) 4: 13
DOI 10.1007/s40309-016-0093-1

ORIGINAL ARTICLE

Functional technology foresight. A novel methodology to identify emerging technologies

Riccardo Apreda [1] · Andrea Bonaccorsi [2] · Felice dell'Orletta [3] · Gualtiero Fantoni [1]

What to look for in patents?

Functional description of the invention which is an abstract, universal description and independent of a technological solution

How to include a high number of existing patents into the assessment?

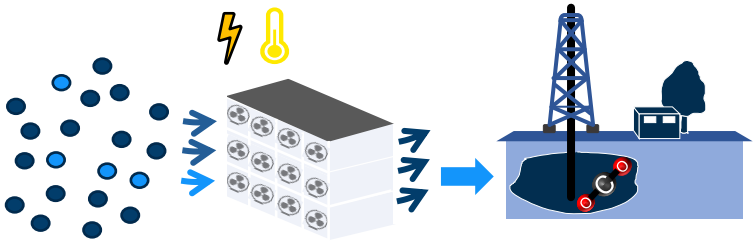
Combining expert knowledge and natural language processing to identify trends within patents

Source: R. Apreda et al: Functional technology foresight. A novel methodology to identify emerging technologies. In: Eur J Futures Res (2016) 4:13

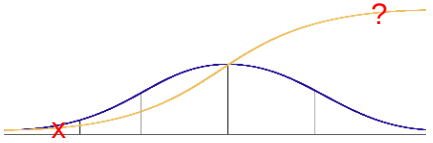
Goals

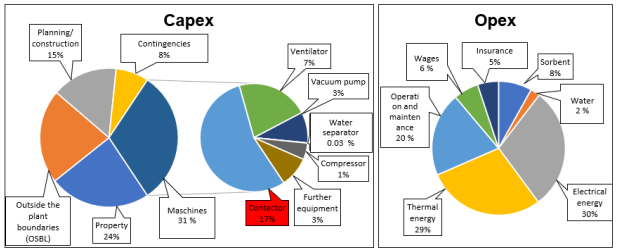
1) Can Functional Technology Foresight be used for assessing technological development for DACS technology?

2) Which adjustments are necessary to strengthen the methodology so that it allows extensive and continuous technology screening and evaluation as an input for systems analysis for emerging technologies?



Ambient air CO_2 capture CO_2 storage





Functional Technology Foresight

1 Definition of object of interest & boundaries of the investigation

2 Conduction of the functional analysis

3 Functional bibliometric analysis on relevant patent groups

Text preparation → Multi-word terminology extraction → Assessing domain relevance → Identification of hot topics

4 Interpretation

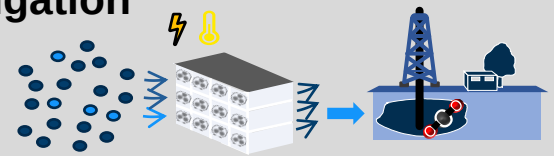
Identification of disruptive innovations

Source: R. Apreda et al: Functional technology foresight. A novel methodology to identify emerging technologies. In: Eur J Futures Res (2016) 4:13

Applying Functional Technology Foresight for DAC(S) Systems Analysis

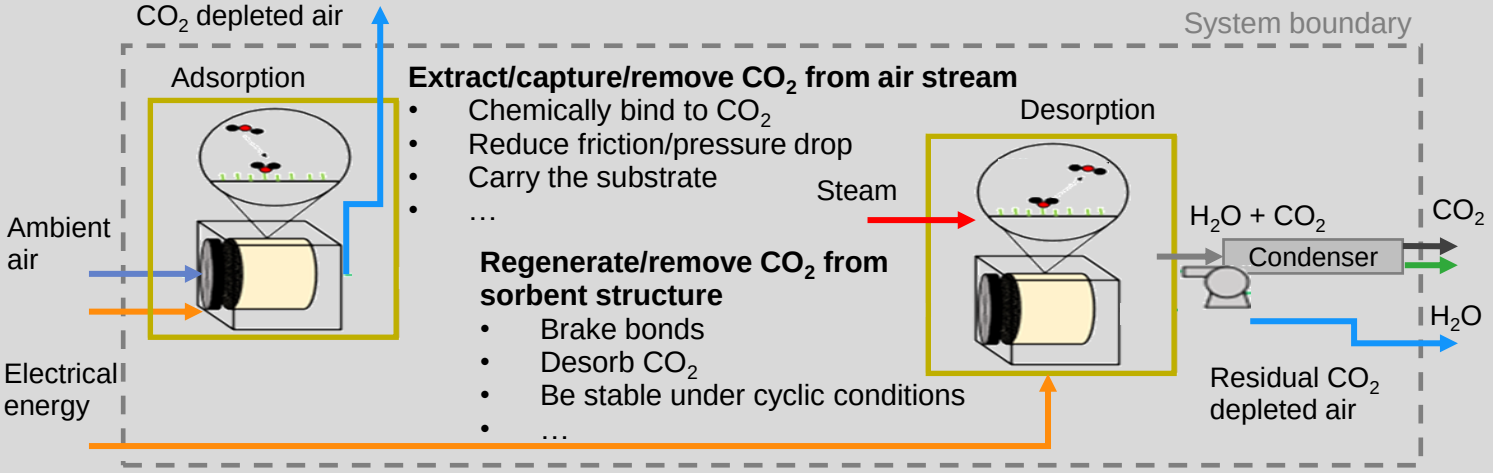
1 Definition of object of interest & boundaries of the investigation

A technical solution that uses energy and chemical processes to extract CO_2 from the ambient air and keeps the CO_2 out of the carbon cycle for a long time.



2 Conduction of the functional analysis (low temperature DAC)

- Level of detail?



Adjusted from McQueen, N., et.al.: A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future

3 Functional bibliometric analysis on relevant patent groups

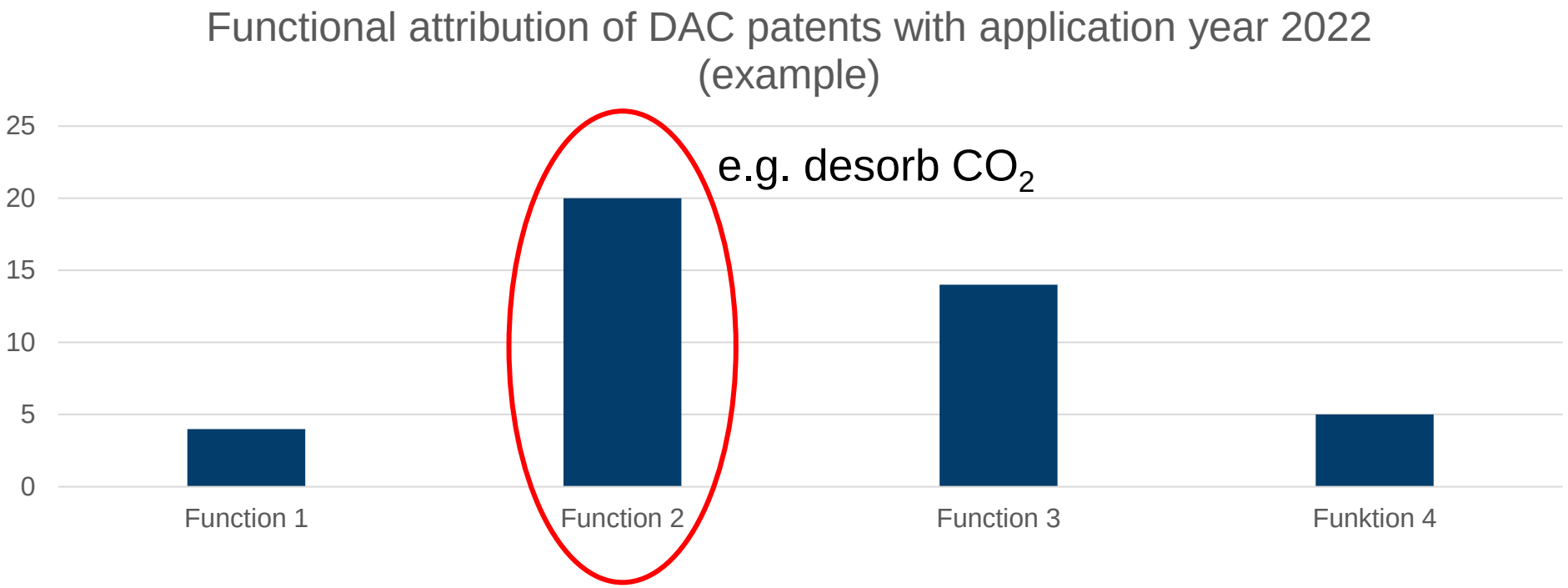
- Extension for identifying incremental innovation e.g. frequency of covering a certain function as a proxy for change & extension for identifying up-scaling effects?

4 Interpretation

Identification of future (dominant) technical solutions

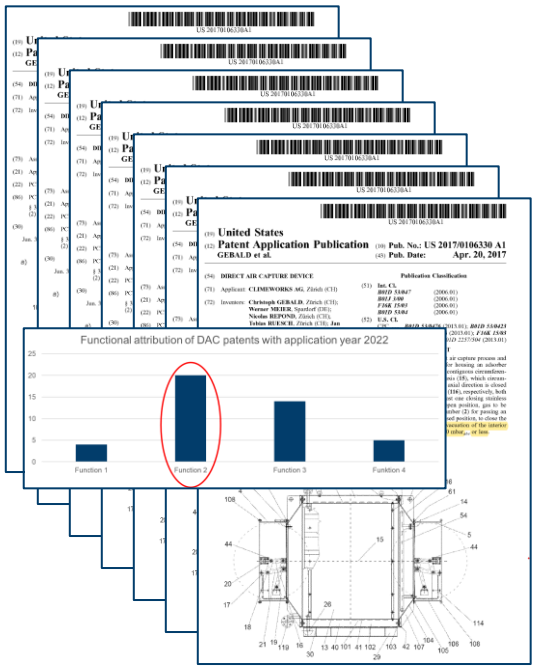
Illustration of a Possible Example for Identifying Incremental Innovations

- DAC patents 2022 EU database (espace.net)
- Occurence of functions → indication for future development (incremental innovation)
- n=43



Possible future changes in technical solutions for realizing function two

How to translate this information into techno-economic parameters?



translate

Year xy

Capex
Opex
Efficiency

Compare to ‚state of the art' with the help of morphological box
+ functional hierarchy

	Option A	Option B	Option C
F1			
F2			
F3			
F4			
F5			
F6			
F7			

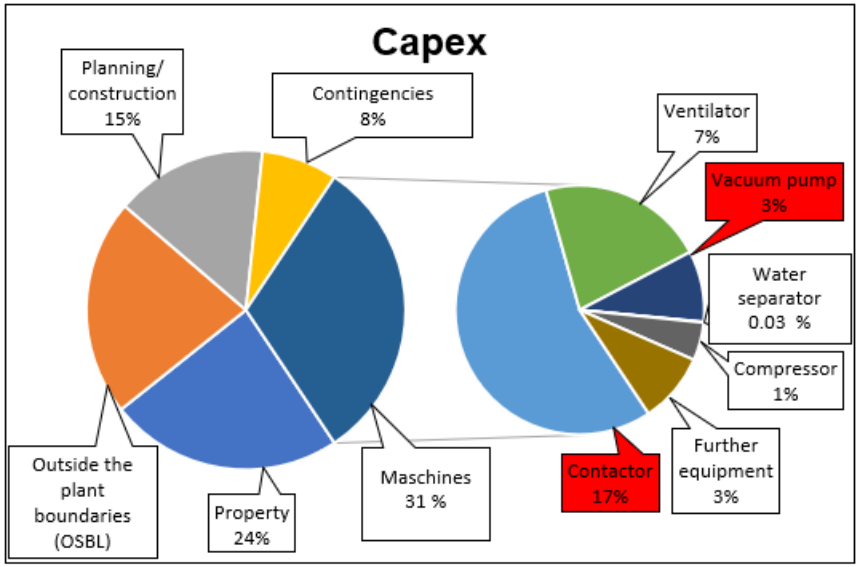
State of the art: Low temperature high temperature

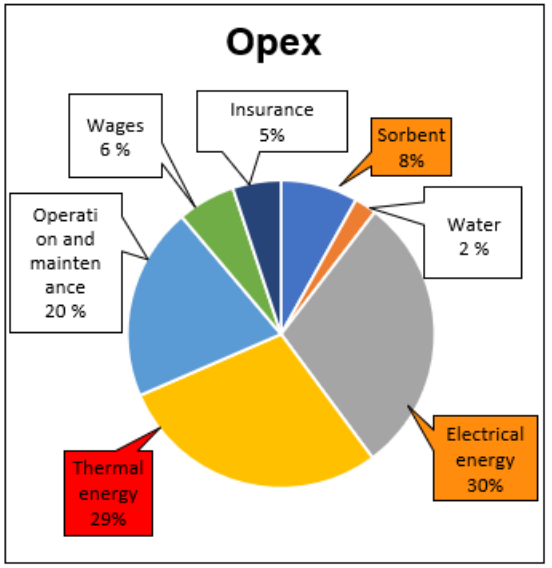
Source: US 2017/0106330 A1

Possible Impact of Changes in Future Technical Solutions for Function Two

Bringing together functions and technical components/technical solutions (example: desorb CO_2)

State of the art: Low temperature DAC

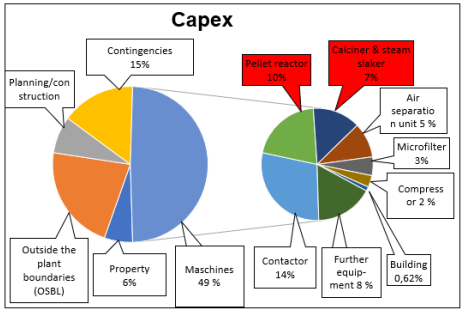


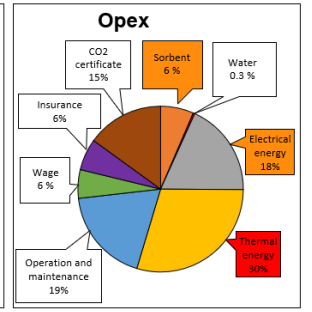


Split up: own calculations based on: [1,8,16,17,18,21]

Split up: own calculations based on: [1-20]

high temperature DAC





Sensitivity analysis based on existing data of state of the art technology

Summary

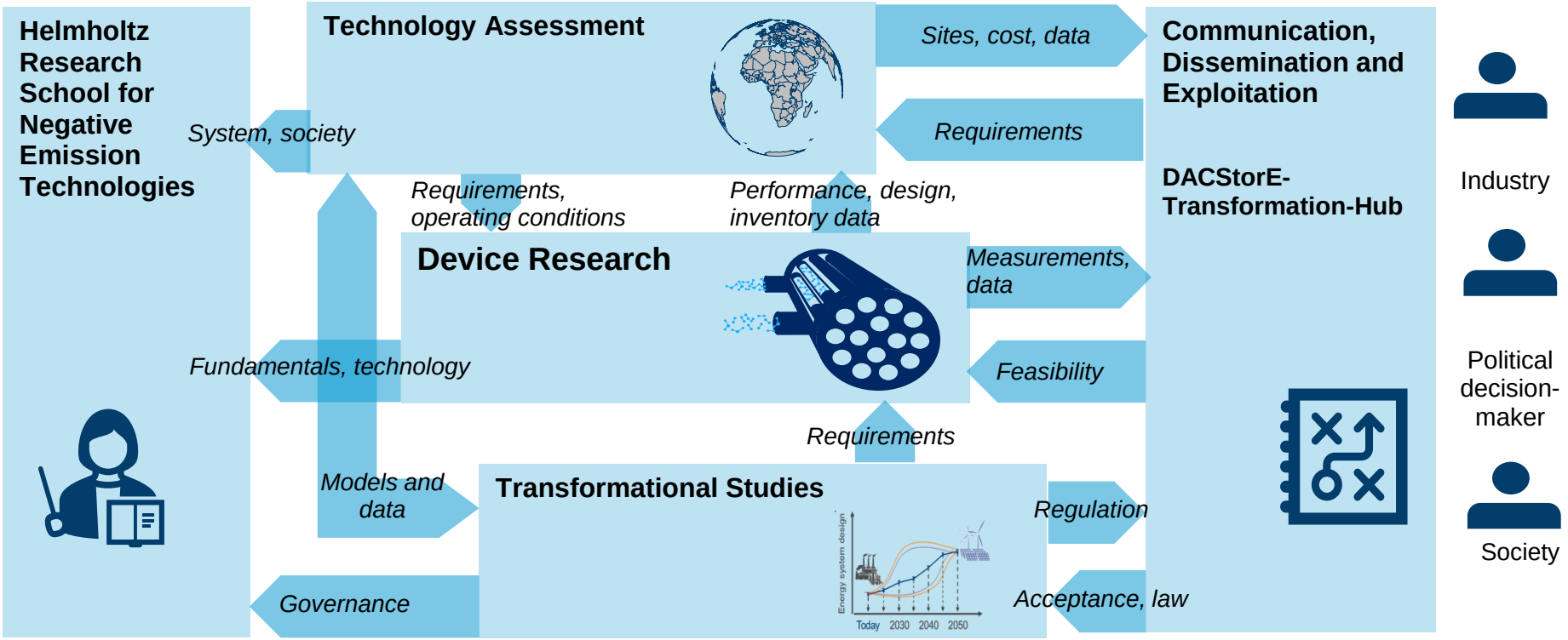
- Direct Air Capture and Storage (DACS) technology can play an important role in mitigating global warming and climate change
- Despite of high uncertainty in techno-economic data especially regarding upscaling this technology needs to be accurately modeled in systems analysis to derive the impact of its broad roll out on the system
- Functional Technology Foresight seems to be a promising method:
  - … which in principle can be applied to DACS technology
  - … which needs extension in terms of including the identification of incremental innovation and upscaling effects
  - … which needs an additional morphological box and information about the functional hierarchy as well as a state-of-the-art techno-economic parameterization in order to translate the methods results into techno-economic parameters

Future Steps

Full scale implementation

- Extend the functional map during an expert workshop
- Conducting functional technology foresight for all relevant patent groups
  - Discuss results with experts
- Translating functional technology foresight results into techno-economic parameters with the introduced approach
- Identifying strength and weaknesses: comparing foresights from 5 years ago with current state of the art of DAC plants
- Extension to transportation and storage of CO_2

Project DACStorE - Boost the Sustainable Ramp-up of DACS Technology



This work was performed as part of the project ‘A Comprehensive Approach to Harnessing the Innovation Potential of Direct Air Capture and Storage for Reaching -Neutrality’ (DACStorE), which is funded by the Initiative and Networking Fund of the Helmholtz Association (grant agreement number KA2-HSC-12).

Thanks a lot for your attention!

For further questions please contact:

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Project DacStorE
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H2 Atlas Africa
go.fzj.de/h2africa

Project Resur
go.fzj.de/resur

References for Split-up Calculations on Slide 10

[1] Lebling, K., et. al.: Direct Air Capture: Assessing Impacts to Enable Responsible Scaling, 2022.; [2] McQueen, N., et. al.: Cost analysis of direct air capture and sequestration coupled to low-carbon thermal energy in the united states. Environmental Science & Technology, 2020. [3] Sabatino, F., et. al.: A comparative energy and costs assessment and optimization for direct air capture technologies. Joule, 2021. [4] Wurzbacher, J., et. al.: Concurrent separation of CO2 and H2O from air by a temperature-vacuum swing adsorption/desorption cycle. Environmental Science & Technology, 2012. [5] Leonzio, G., et. al.: A comparative study of different sorbents in the context of Direct Air Capture (DAC): Evaluation of key performance indicators and comparisons. Applied Sciences, 2022., [6] McQueen, N., et. al.: A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. Progress in Energy, 2021. [7] McQueen, N., et. al.: A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. Progress in Energy, 2021. [8] Sanz-Perez, E., et. al.: Direct capture of co2 from ambient air. Chemical Reviews, 2016. [9] Gebald, C., et. al.: Amine-Based Nanofibrillated Cellulose As Adsorbent for CO2 Capture from Air. Environmental Science & Technology, 2011 [10] Azarabadi, H. & Lackner, K.: A sorbent-focused techno-economic analysis of direct air capture. Applied Energy, 2019. [11] Sinha, A., et. al.: Systems design and economic analysis of direct air capture of CO2 through temperature vacuum swing adsorption using mil-101(cr)-pei-800 and mmen-mg2(dobpdc) MOF adsorbents. Industrial & Engineering Chemistry Research, 2017. [12] Gebald, C., et. al.: Low-Pressure Drop Structure of Particle Adsorbent Bed for Adsorption Gas Separation Process. WO Patent 2014/170184 Al, 23 Oktober 2014. [13] Deutz, S. u. Bardow, A.: Life-cycle assessment of an industrial direct air capture process based on temperature–vacuum swing adsorption. Nature Energy, 2021. [14] Gebald, C., Zimmermann, T. and Tingaut, P: Porous adsorbent structure for adsorption of CO2 from a gas mixture. World Intellectual Property Organization WO 2012/168346 Al, 2012. [15] Beuttler, C., et. al.. The role of direct air capture in mitigation of anthropogenic greenhouse gas emissions. Frontiers in Climate, 2019. [16] Towler, G. u. Sinnott, R.: Chapter 7 - Capital cost estimating. In: Chemical Engineering Design (Third Edition), S. 239-278, Butterworth-Heinemann, 2022. [17] National Academies of Science, Engineering, and Medicine: Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. National Academies Press, Washington, D.C., 2018. [18] Keith, D., et .al.: A Process for Capturing CO2 from the Atmosphere. Joule, 2(8):1573–1594, 2018. [19] Wurzbacher, J. A.: Development of a temperature vacuum swing process for CO2 capture from ambient air, Dissertation, ETH Zürich, 2015. [20] International Energy Agency: Direct Air Capture: A key technology for net zero, 2022. [21] Holmes, G. u. Keith, D.: An air-liquid contactor for large-scale capture of CO2 from air. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2012.