Séminaire CCTS,
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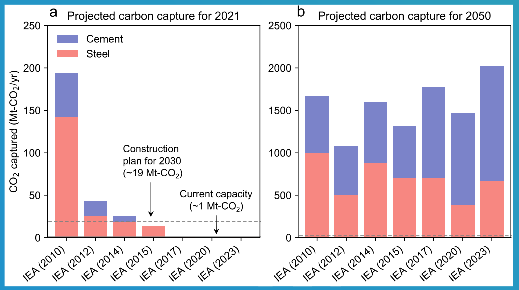
Paris France

Carbon Capture and Storage (CCTS) – How a “Low-Carbon” Innovation Can Fail 2.0



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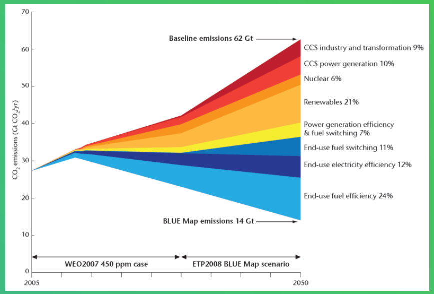

Introduction: “je n’y changerai pas une note …”

How a “Low Carbon” Innovation Can Fail— Tales from a “Lost Decade” for Carbon Capture, Transport, and Sequestration (CCTS)

CHRISTIAN VON HIRSCHHAUSEN,[a] JOHANNES HEROLD,[a] and PAO-YU OEI[a]

ABSTRACT

This paper analyzes the discrepancy between the high hopes placed in Carbon Capture, Transport, and Storage (CCTS) and the meager results that have been observed in reality, and advances several explanations for what we call a “lost decade” for CCTS. We trace the origins of the high hopes placed in this technology by industry and policymakers alike, and show how the large number of demonstration projects required for a breakthrough did not follow. We then identify possible explanations for the “lost decade”, such as incumbent resistance to structural change, wrong technology choices, over-optimistic cost estimates, a premature focus on energy projects instead of industry, and the underestimation of transport and storage issues. We conclude it is likely that we have to live for quite some time with a cognitive dissonance in which top-down models continue to place hope in the CCTS-technology by reducing its expected fixed and variable costs, and bottom-up researchers continue to count failed pilot projects.

Keywords: CCTS, Innovation, Technology policy, Low-carbon energy transformation

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IAEE
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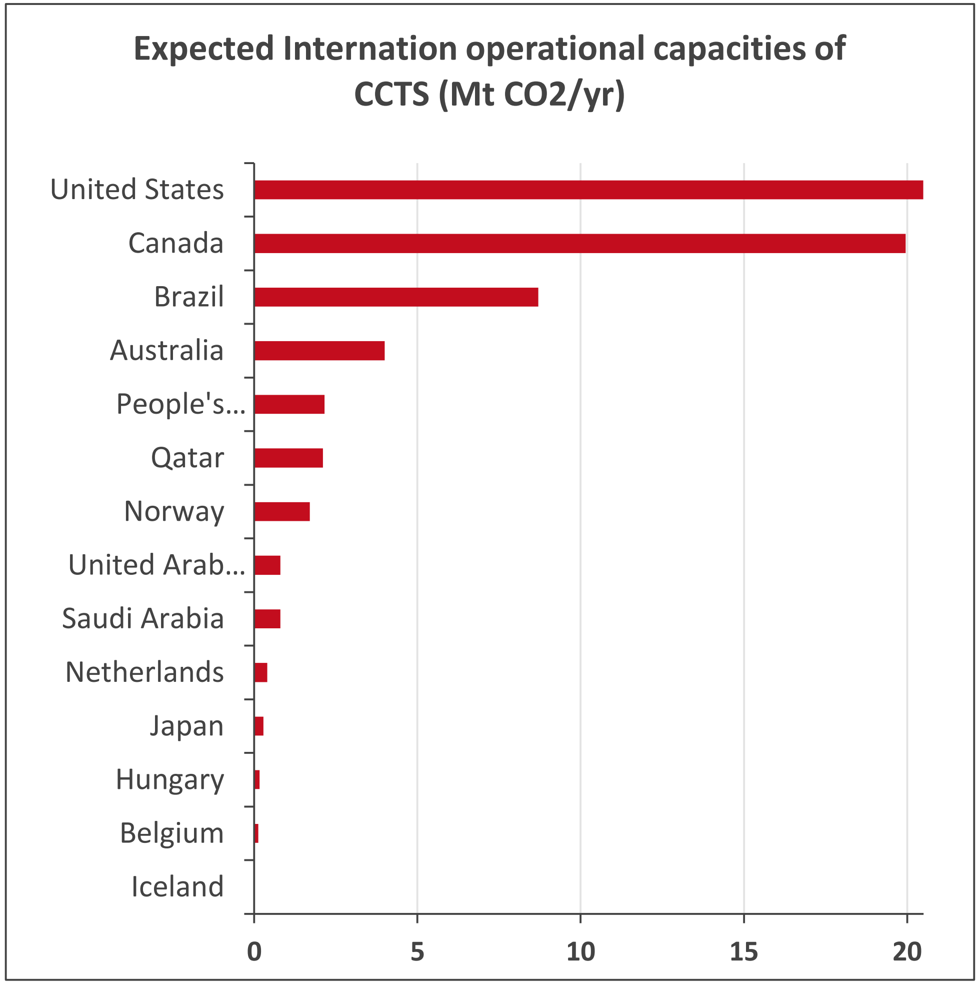
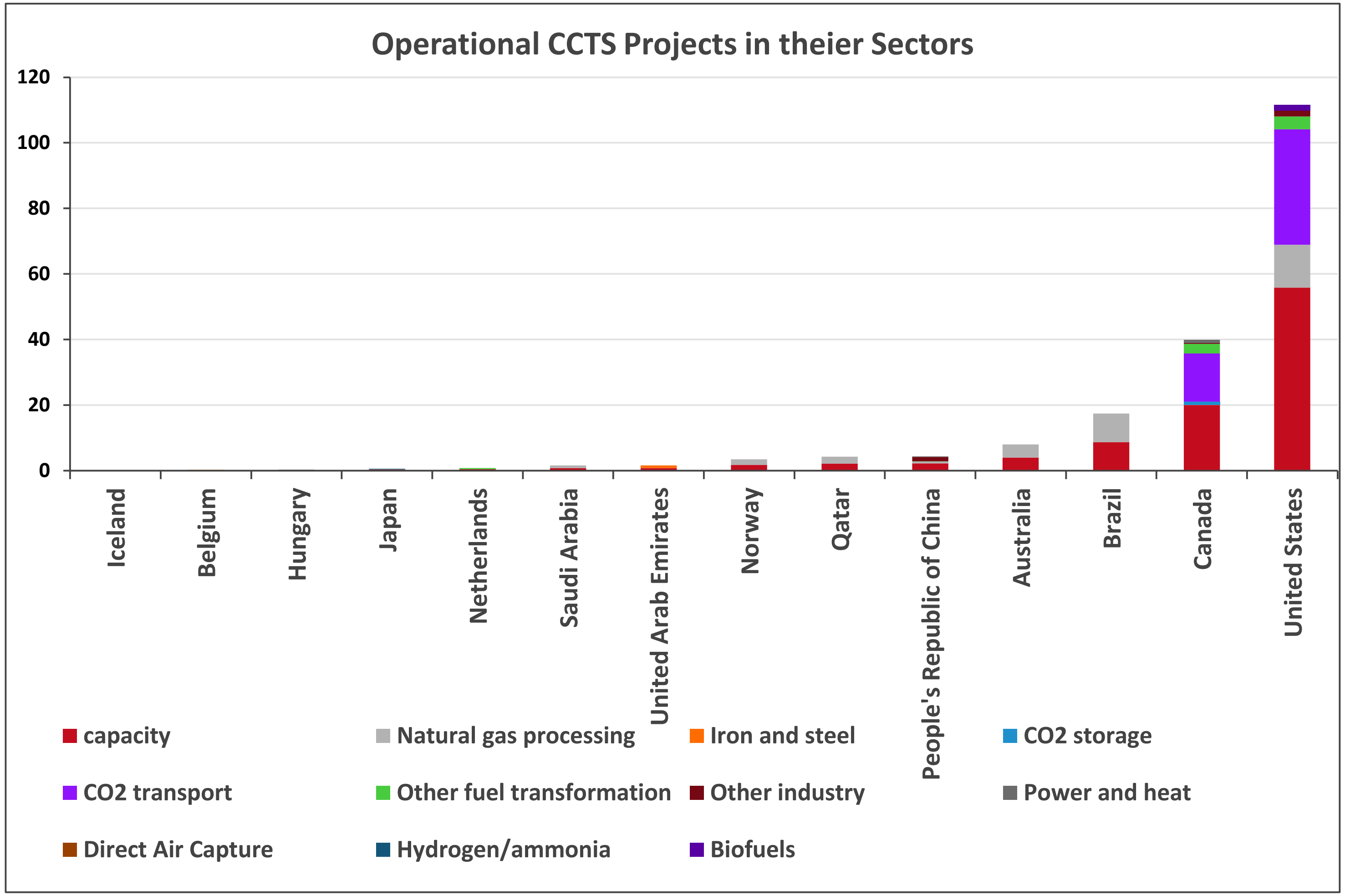
https://www.jstor.org/stable/26189495

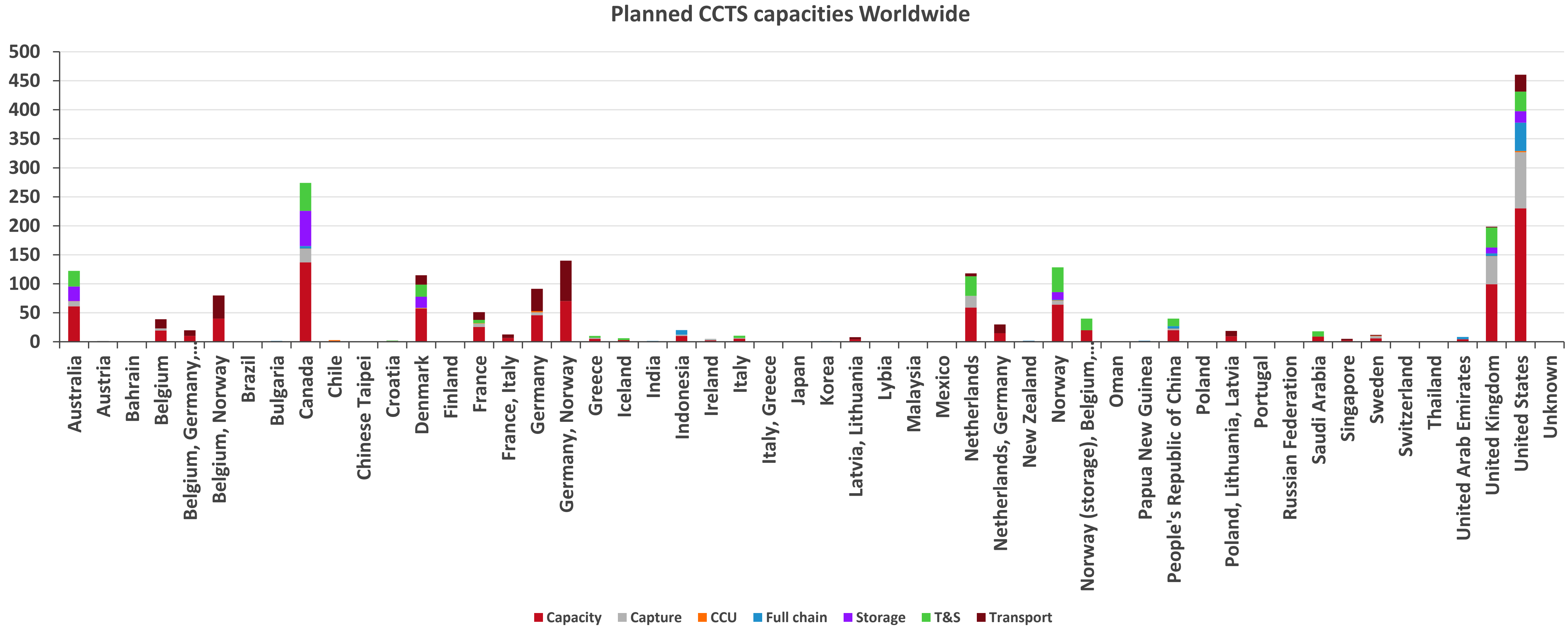
IEAs current Status Quo for CCTS Projects





Source: Own Analysis based on IEA (2023), CCUS Database

IEAs current Status Quo for CCTS Projects: Planned Projects



Source: Own Analysis based on IEA (2023), CCUS Database

This talk in 5 minutes:
5 theses on CCTS and the “carbon circular economy”

1. **The objective of the socio-ecological-technical transformation (“transition”)**

The objective of the socio-ecological-technical transformation (sometimes called “transition”, or “transition énergétique”) is a fossil –free (and fissil-free???) energy system with a fair sharing of costs and benefits, and a combination of central and decentral networks and infrastructure (Christian von Hirschhausen et al. 2018).

2. **Vision of “techno-fixes”**

The dream of simple “techno-fixes” is a constant within the transformation process (Braunger and Hauenstein 2020), be it the “plutonium economy” (Christian von Hirschhausen 2022; C. V. Hirschhausen et al. 2023), the “hydrogen economy”, or … “the carbon recycling economy” (Minx et al. 2018; Fuss et al. 2018). These visions may become true, but it is highly uncertain. They must be disentangled with respect to their origins, their socio-ecological-technical plausibility, and their potential to contribute to the energy transformation

3. **Energy system analysis with and without CCTS**

There are energy system models that require CCTS for the transformation (IEA 2022; IPCC 2005; 2023), and others that do not (Jacobsen 2020; Luderer et al. 2021; Auer et al. 2020)

4. **Significant system challenges to CCTS remain**

According to our research trajectory, the latter (without CCTS) are more consistent with a sustainable transformation: The dream of the carbon recycling economy has not delivered for the last three decades, most of those who promote it currently benefit from the fossil system, and lots of technical and institutional obstacles are unresolved.

5. **Our assessment: CCTS is unlikely to diffuse at scale**

It is unlikely that innovations in CCTS (i.e. proof of concept, individual pilots) in the power sector or industry diffuse industry-wide, and that CCTS will contribute significantly to decarbonization in the next three decades.

Agenda

1. Introduction

2. “Macro”-approach: Techno-historic analysis of energy system scenarios
    - Overview of CCTS since the 1990s
    - The vision of the “Circular carbon CCTS-economy” in 2,000 scenarios in IPPC 6th Assessment Report

3. “Micro” approach: System good analysis
    - Technical system
    - Organizational models

4. Conclusions: 5 theses on CCTS and the “carbon circular economy”

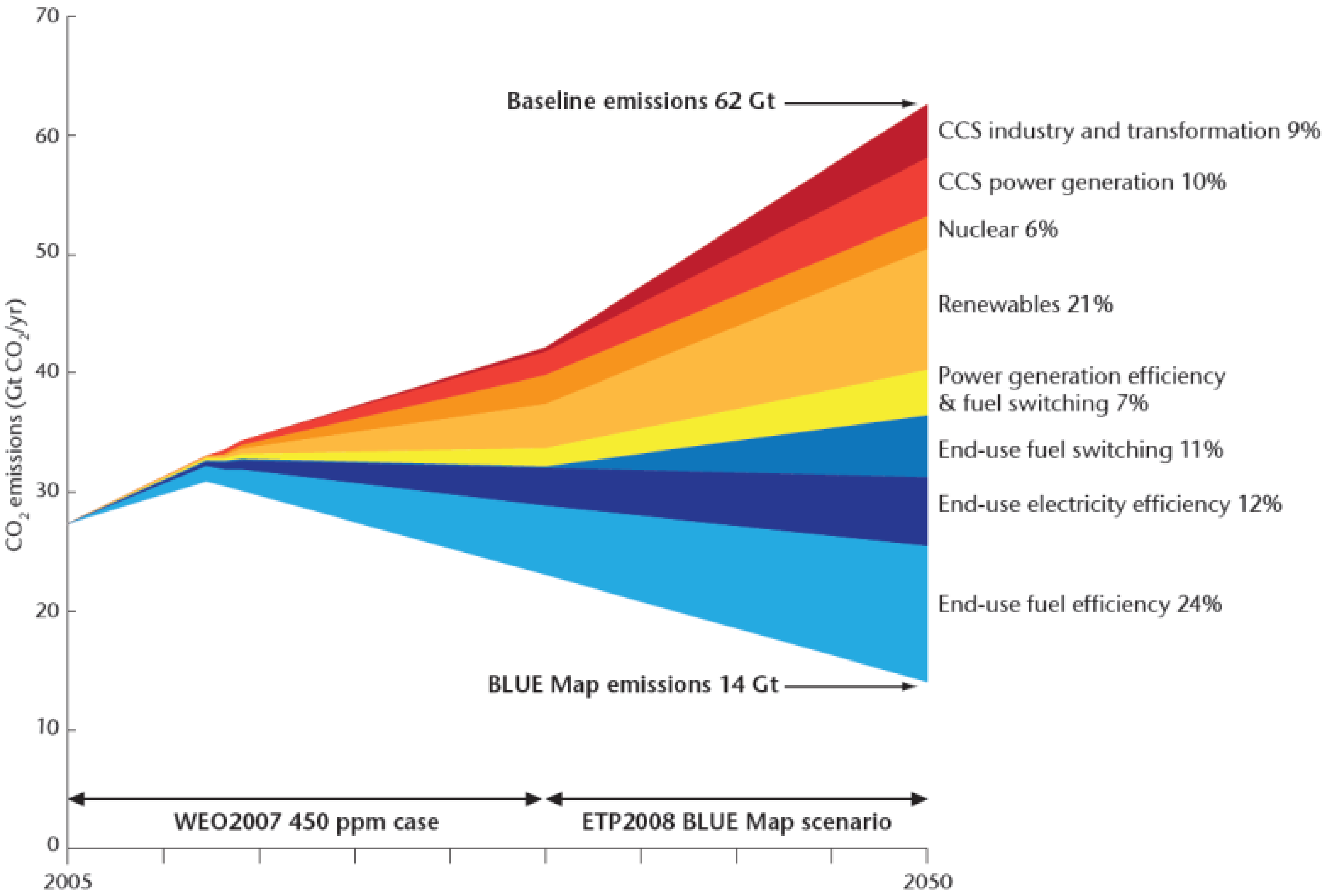
“Macro”-approach: Techno-historic analysis of energy system scenarios

- Overview of CCTS since the 1990s
- The vision of the “Circular carbon CCTS-economy” in 2,000 scenarios in IPPC 6th Assessment Report

Overview of CCTS since the 1990s

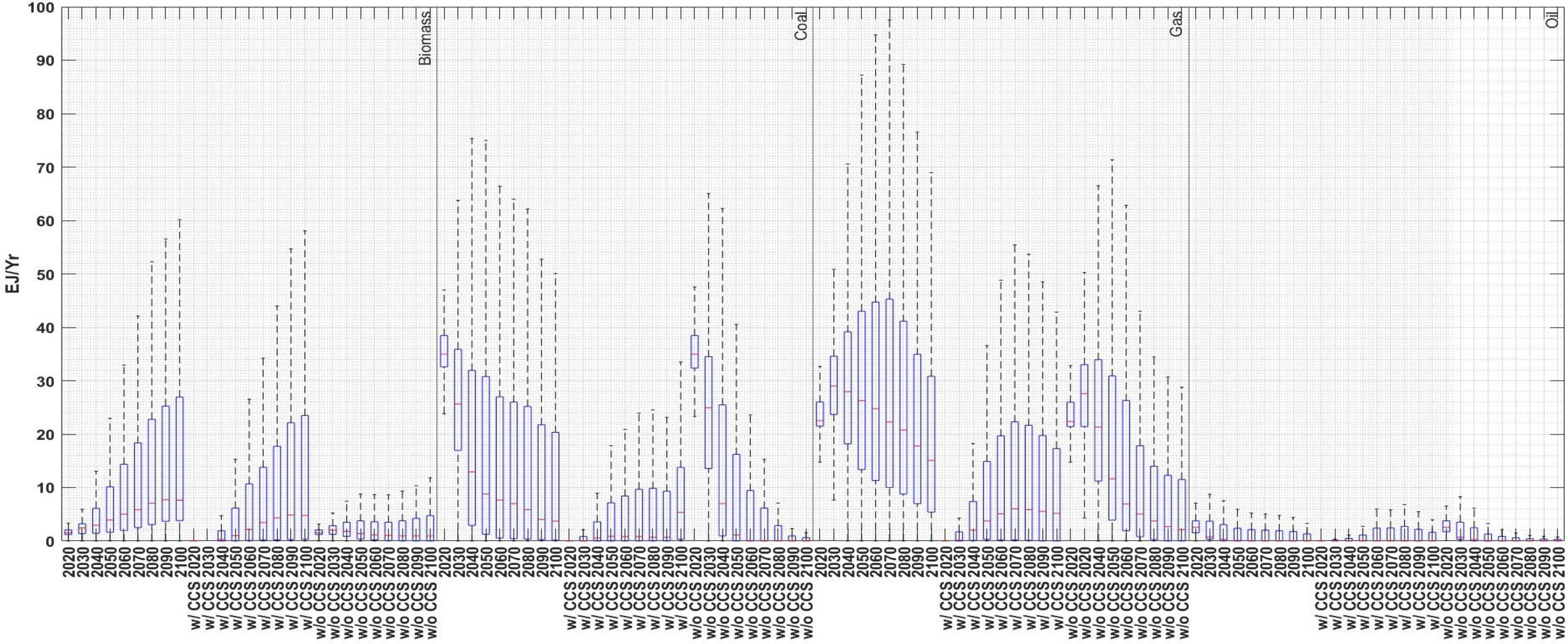
	"Clean coal"	"Clean gas" (oil)	"Clean fossil industry"	References
1) 1990-2000s	**X**	**(X)**		(IPCC 2005; Jaccard 2006; C. Hirschhausen, Herold, and Oei 2012)
2) 2010s	**X**	**X**	**(X)**	(Stern 2017; 2019a; 2019b; Christian von Hirschhausen, Praeger, and Kemfert 2020)
3) 2020s		**X**	**X**	(Watari et al. 2022; Global CCS Institute 2022)

IEA Technology Roadmap Carbon Capture and Storage (2009)



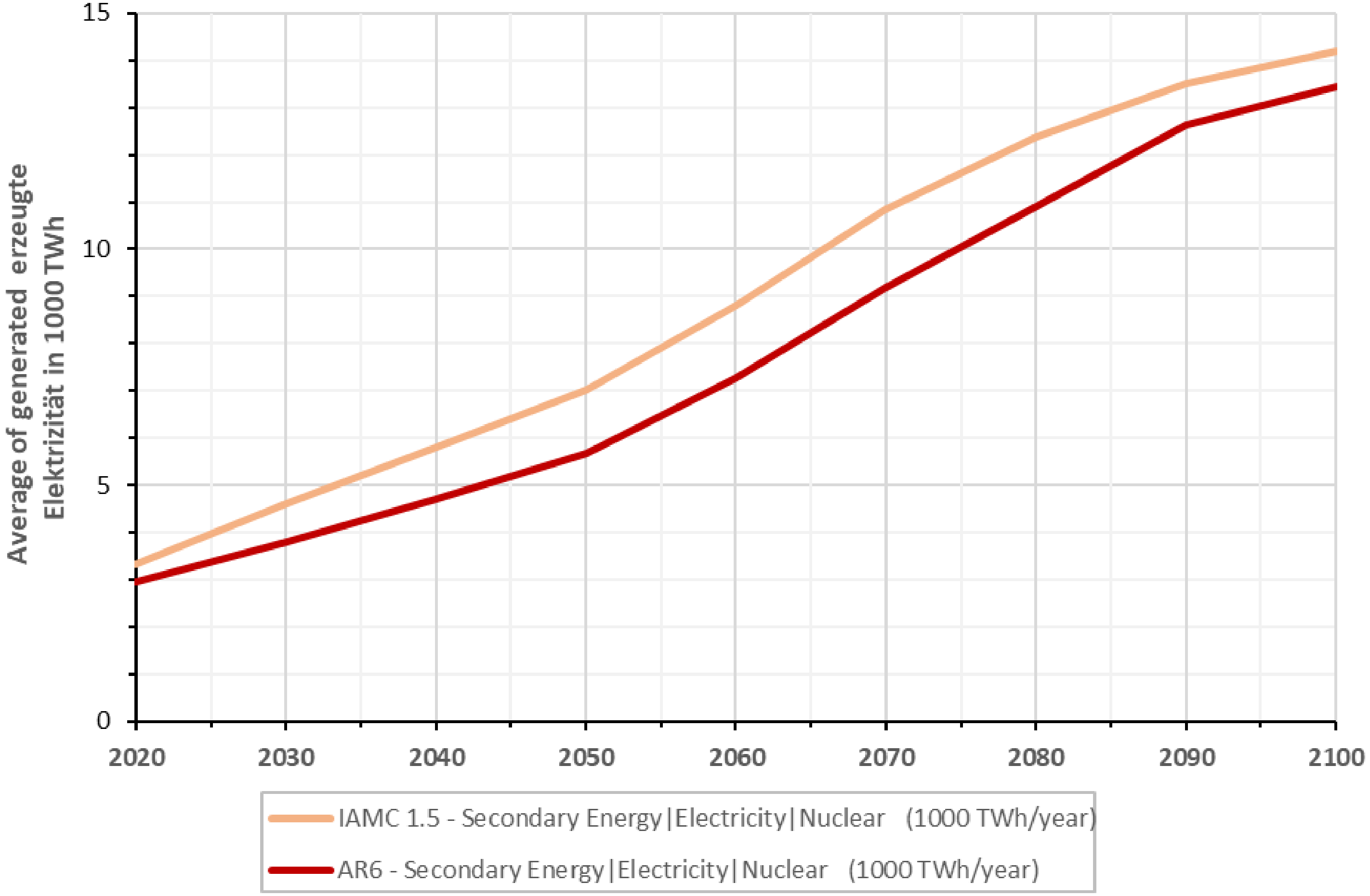
Source: https://nachhaltigwirtschaften.at/de/iea/publikationen/iea-technology-roadmap-carbon-capture-and-storage-2009.php

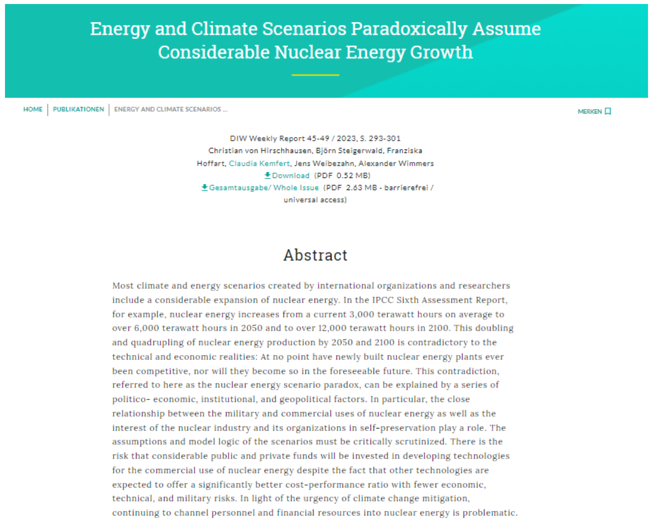
The vision of the "Circular carbon CCTS-economy" in 2,000 scenarios in IPPC 6th Assessment Report: Electricity with and without CCTS



Source: Steigerwald, Weibezahn, Slowik et.al. 2023 based on Byers et.al. 2022

The vision of the "Plutonium breeder economy" in 2,000 scenarios in IPPC 1.5 and 6th Assessment Report: Electricity from nuclear power





Energy and Climate Scenarios Paradoxically Assume Considerable Nuclear Energy Growth

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DIW Weekly Report 45-49 / 2023, S. 293-301
Christian von Hirschhausen, Björn Steigerwald, Franziska Hoffart, Claudia Kemfert, Jens Weibezahn, Alexander Wimmers
Download (PDF 0.52 MB)
Gesamtausgabe/ Whole Issue (PDF 2.63 MB - barrierefrei / universal access)

Abstract

Most climate and energy scenarios created by international organizations and researchers include a considerable expansion of nuclear energy. In the IPCC Sixth Assessment Report, for example, nuclear energy increases from a current 3,000 terawatt hours on average to over 6,000 terawatt hours in 2050 and to over 12,000 terawatt hours in 2100. This doubling and quadrupling of nuclear energy production by 2050 and 2100 is contradictory to the technical and economic realities: At no point have newly built nuclear energy plants ever been competitive, nor will they become so in the foreseeable future. This contradiction, referred to here as the nuclear energy scenario paradox, can be explained by a series of politico- economic, institutional, and geopolitical factors. In particular, the close relationship between the military and commercial uses of nuclear energy as well as the interest of the nuclear industry and its organizations in self-preservation play a role. The assumptions and model logic of the scenarios must be critically scrutinized. There is the risk that considerable public and private funds will be invested in developing technologies for the commercial use of nuclear energy despite the fact that other technologies are expected to offer a significantly better cost-performance ratio with fewer economic, technical, and military risks. In light of the urgency of climate change mitigation, continuing to channel personnel and financial resources into nuclear energy is problematic.

https://doi.org/10.18723/diw_dwr:2023-45-1

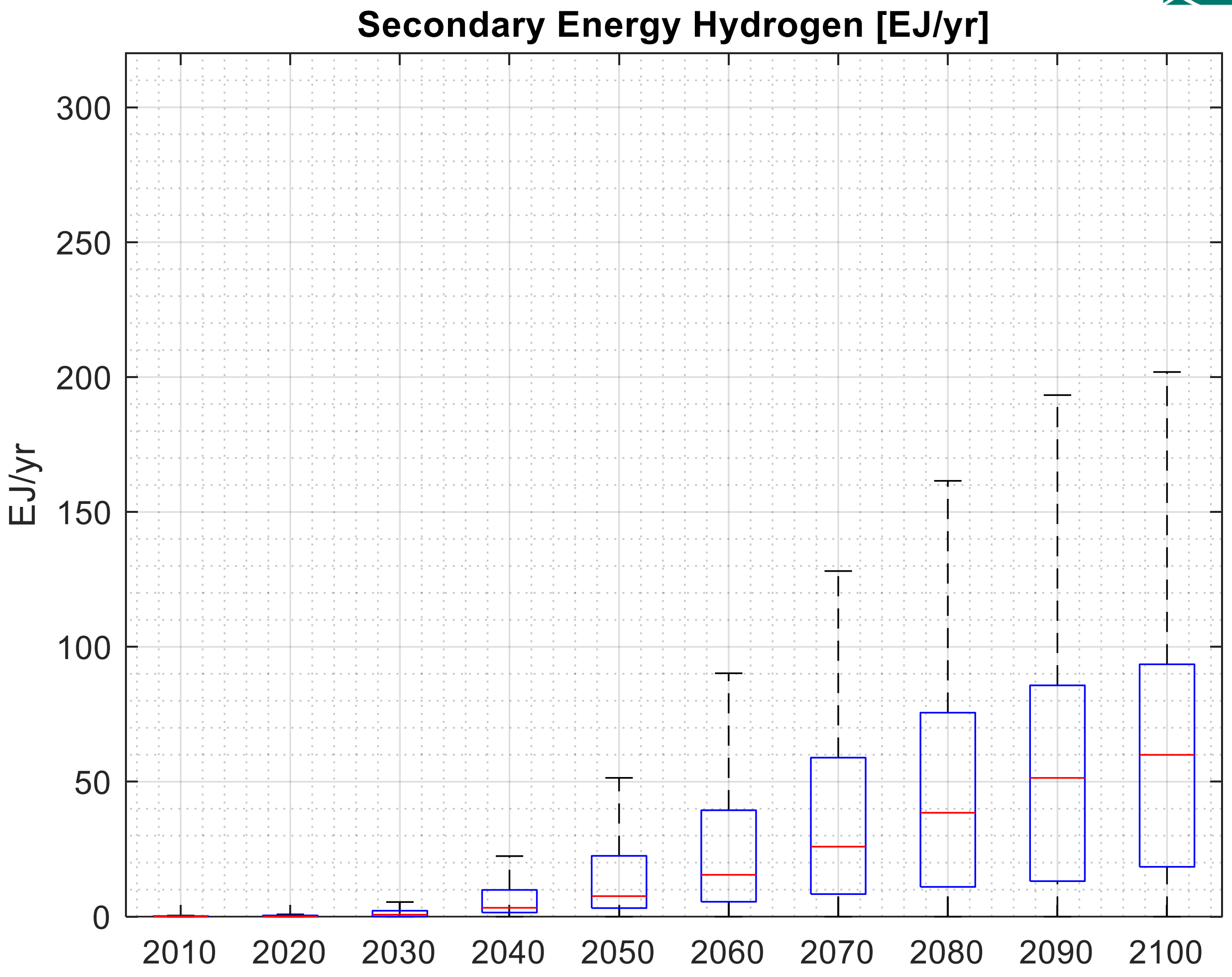
Source: Steigerwald, Weibezahn, Slowik et.al. 2023 based on Byers et.al. 2022

The vision of the "Hydrogen economy" in IPPC 6th Assessment Report

Statistical development between 2010 and 2100

Year	2010	2020	2030	2040	2050
Scenario count	934	771	896	978	1013
Min [EJ/yr]	10,850	1,360	1,003	1,003	1,104
Max [EJ/yr]	10,850	10,990	35,759	77,891	150,332
Median [EJ/yr]	0,098	0,014	0,719	3,268	7,591
Average [EJ/yr]	0,194	0,323	1,893	7,506	16,612
Standard Deviation [EJ/yr]	0,473	0,507	2,090	7,431	15,794

Year	2060	2070	2080	2090	2100
Scenario count	1027	1026	1027	1028	1029
Min [EJ/yr]	1,200	1,035	1,001	1,072	1,174
Max [EJ/yr]	129,447	164,183	231,455	288,493	316,933
Median [EJ/yr]	15,492	25,937	38,499	51,414	59,961
Average [EJ/yr]	26,528	37,324	47,981	58,268	66,714
Standard Deviation [EJ/yr]	22,924	29,835	36,702	43,484	49,597



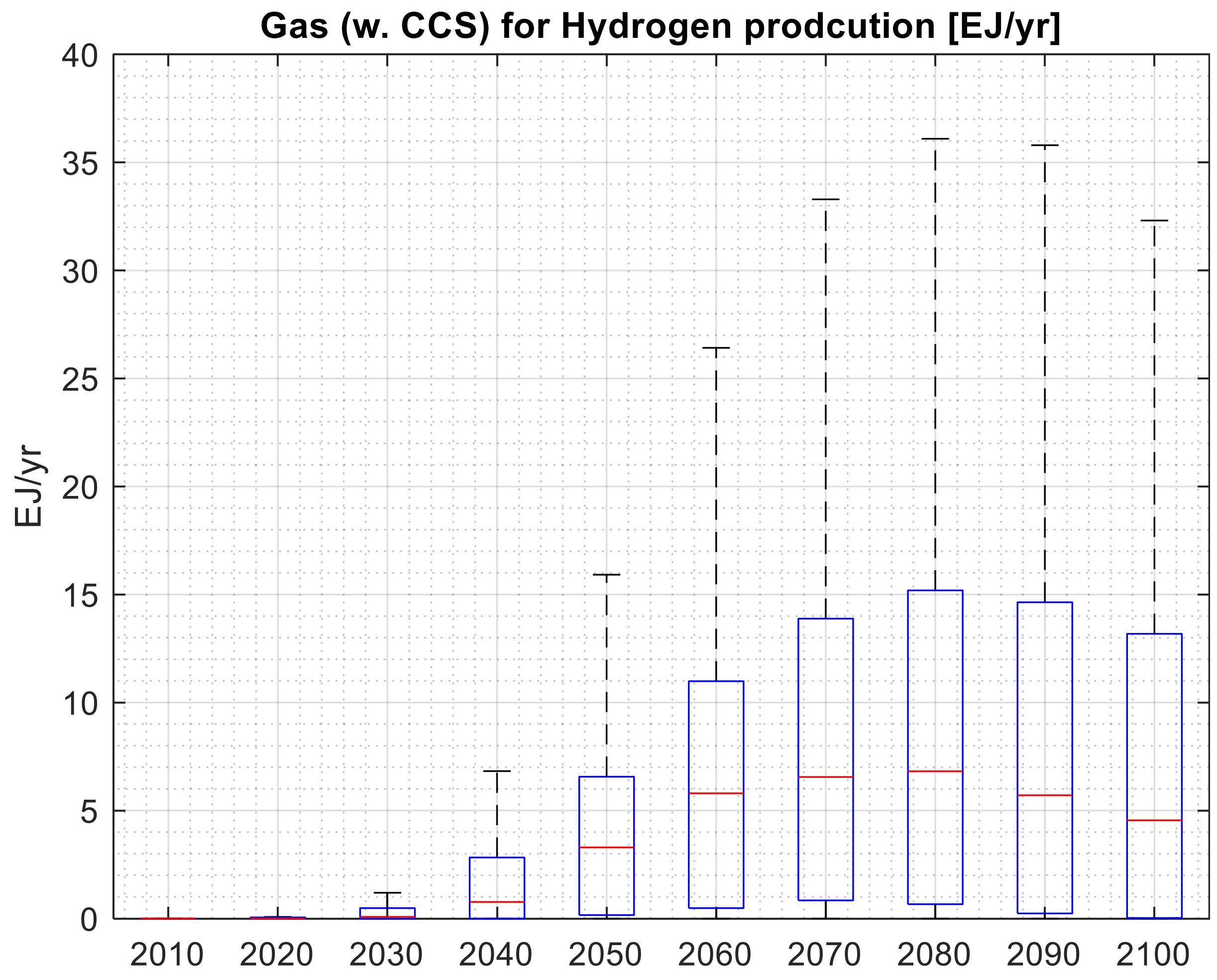
Source: Steigerwald, Weibezahn, Slowik et.al. 2023 based on Byers et.al. 2022

The vision of the "Hydrogen economy" (with CCTS) in IPPC 6th Assessment Report: Electricity with CCTS

Statistical development between 2010 and 2100

Year	2010	2020	2030	2040	2050
Scenario count	159	372	460	529	550
Min [EJ/yr]	0,000	0,000	1,018	1,035	1,010
Max [EJ/yr]	0,000	0,194	5,581	22,532	57,379
Median [EJ/yr]	0,000	0,000	0,079	0,769	3,292
Average [EJ/yr]	0,000	0,061	0,431	2,061	4,896
Standard Deviation [EJ/yr]	0,000	0,053	0,586	2,158	4,678

Year	2060	2070	2080	2090	2100
Scenario count	579	595	576	552	534
Min [EJ/yr]	1,031	1,013	1,024	1,006	1,014
Max [EJ/yr]	84,957	104,191	117,397	121,265	119,539
Median [EJ/yr]	5,798	6,551	6,817	5,707	4,549
Average [EJ/yr]	8,629	11,341	12,507	12,795	12,249
Standard Deviation [EJ/yr]	8,569	12,438	14,250	15,019	15,038



Source: Steigerwald, Weibezahn, Slowik et.al. 2023 based on Byers et.al. 2022

“Micro” approach: System good analysis Overview of CCTS since the 1990s

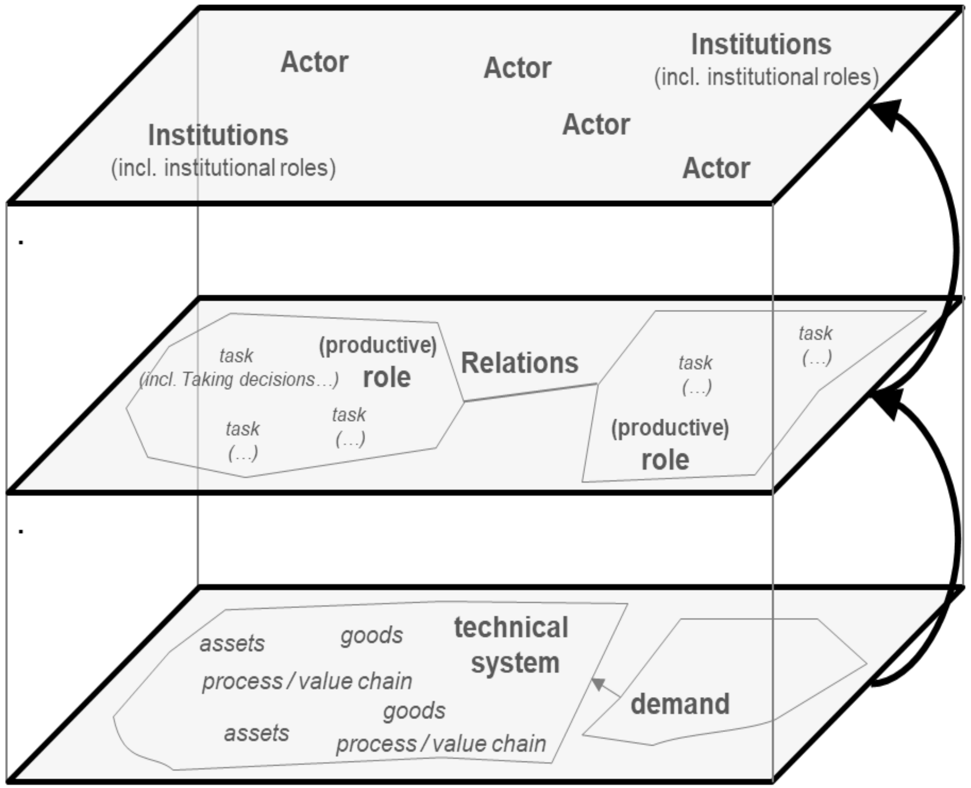
- Technical system
- Organizational models

Derivation of organizational model
Bringing it together: technical system, actors and institutions

REMINDER: Organizational models represent the institutional design that enables the offering of system goods

- What interests do the actors have (profit versus common good maximization)?
- What resources do the actors have (know-how, capacities, infrastructure, ...)?

→ **Derive options for the provision of a system good**



Source: Based on (Beckers, Gizzi, and Jäkel 2012)

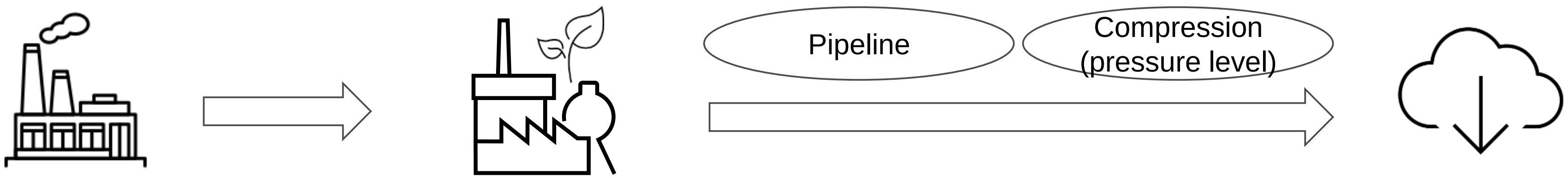
Overview of the technical system of carbon capture, transport and storage (simplified overview)

Carbon capture
Industrial process with CO_2 emissions that cannot be mitigated / avoided with current technologies

Flue gas treatment
Additional processing of CO_2 to increase CO_2 share in stream. This compression and treatment requires energy

Transport
Pipeline infrastructure for safely transporting compressed carbon dioxide streams (gaseous or liquid) to storage destinations

Permanent storage
Permanent storage of carbon dioxide using safe, long-term and economically viable storage options



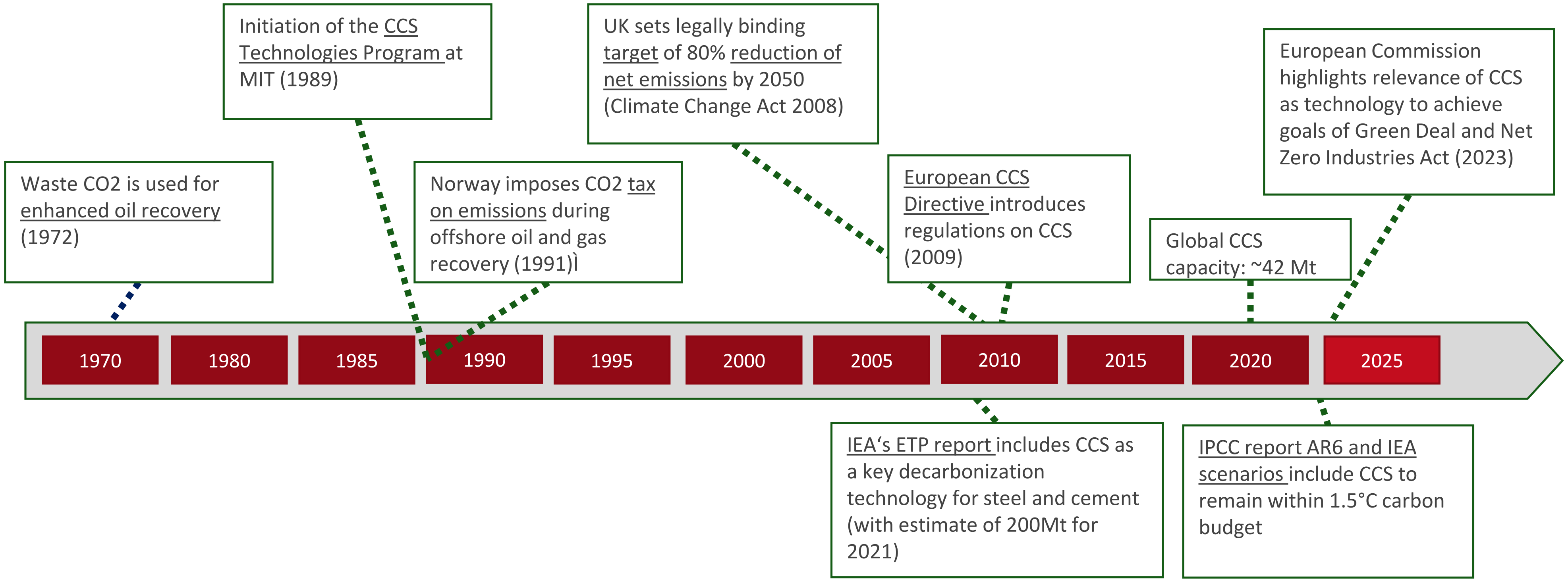
Technical infrastructure and challenges:

1) **Transport infrastructure:** pipelines, compressors, etc
2) **Renewable electricity**: for industrial process, compression, operations
3) **Storage**: near-distance locations for (permanent) storage

Infrastructure policy:

1) **Provision of infrastructure within short amount of time** (and several economic, political and social factors that need to be considered
2) **2) Financing of infrastructure:** definition of the organizational model to finance the infrastructure

Brief overview of milestones of CC(T)S



Status quo: CCTS today

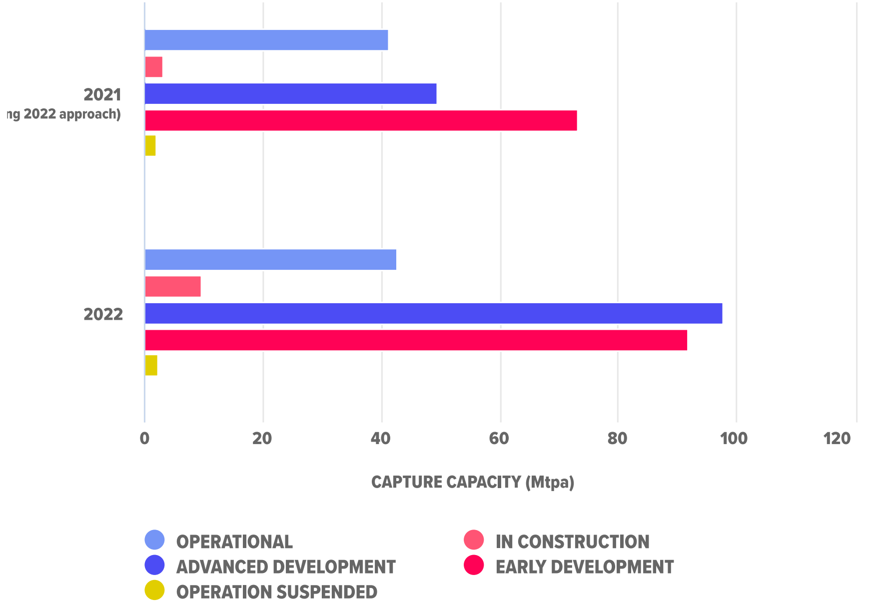


Fig. Capacity of CCS facilities in development (©Global CCS Status Report 2022, Global CCS Institute)

1) **Current application of CCTS:** Power generation, natural gas production and 20% industrial processes (fertiliser, steel, methanol & ethanol)
2) **Significant funding for CCS projects**: over US$12 billion for CCS and related activities in the US; EU Innovation Fund, UK Government CCUS Investor Roadmap
3) **Global capacity of CCTS**: approx. 40 Mt_{CO2} per year (global CO2: ca. 38 Gt_{CO2})

Examples of CCTS in industry

Steel	**Ethanol**	**Fertiliser**
ABU DHABI CCS (PHASE 1 BEING EMIRATES STEEL INDUSTRIES), 0.8 Mt/a	ILLINOIS INDUSTRIAL CARBON CAPTURE AND STORAGE, 1 Mt	ENID FERTILIZER, 0.2 Mt

CCTS deployment in steel and cement production: estimates, status quo and outlook

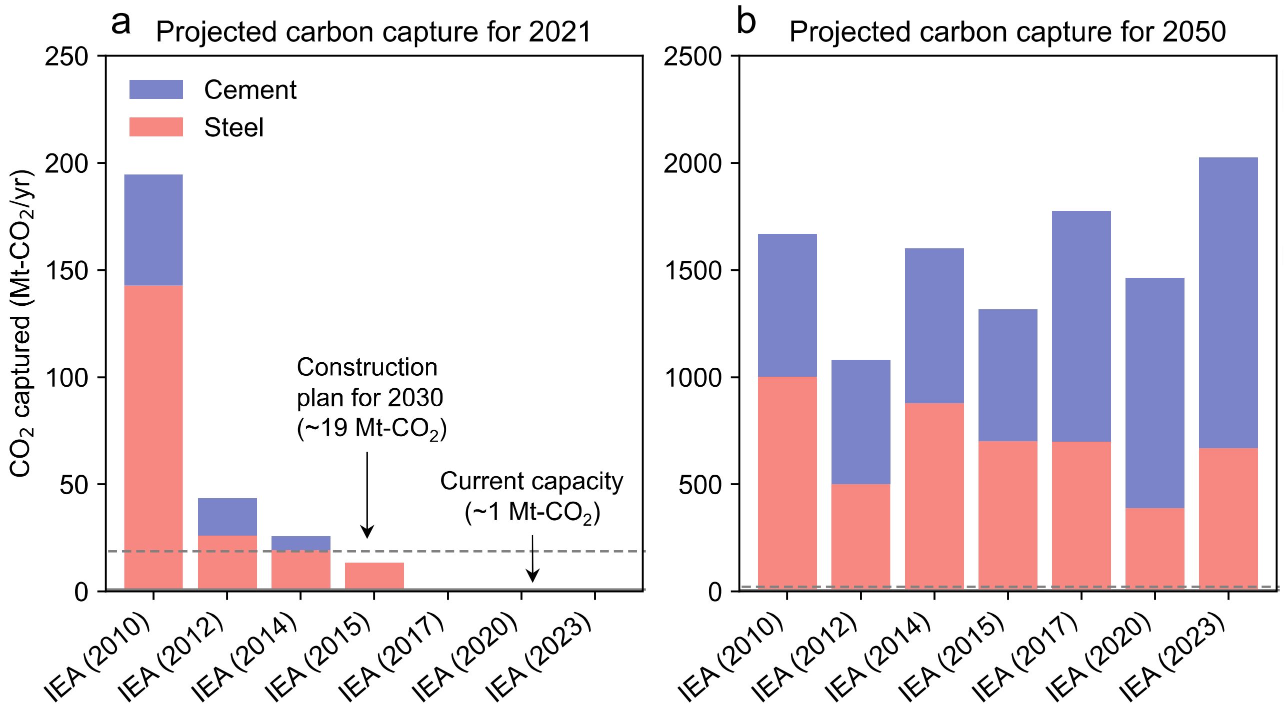


Fig. (a) Carbon capture capacity for 2021 projected by the International Energy Agency (IEA) scenarios (b) Carbon capture capacity for 2050 projected by the IEA scenarios.

1) **Deployment of CCTS** slower than projected: CCTS capacity falls short of the levels that past IEA reports assumed would be deployed by 2021

2) **From 1 Mt to 2000 Mt:** The 2050 CCUS capacity envisaged in the IEA scenarios requires an expansion at a rate that far exceeds current construction plans for steel and cement

Global feasible supply of steel and cement within Paris-compliant carbon budgets by 2050

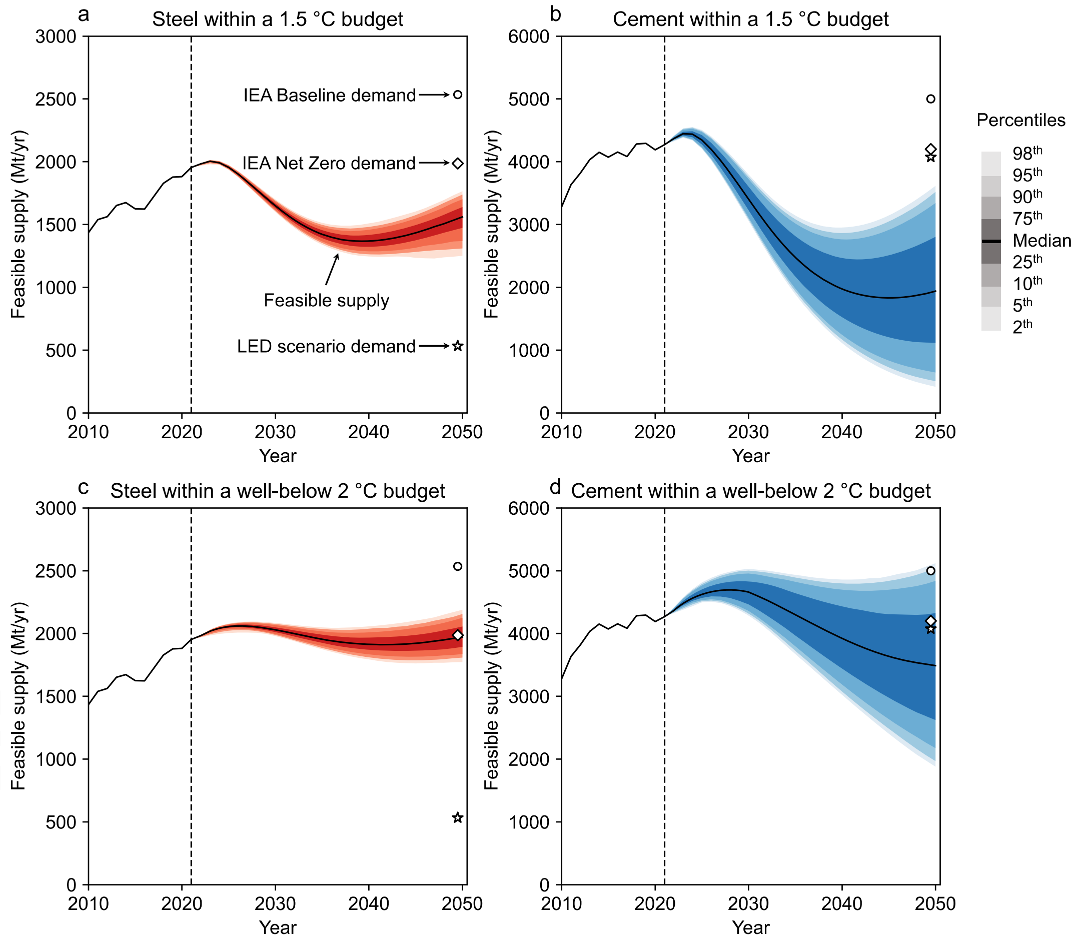


Fig. 2 Global feasible supply of steel and cement within Paris-compliant carbon budgets by 2050. a Steel supply within a 1.5C budget. b Cement supply within a 1.5C budget. c Steel supply within a well-below 2C budget. d Cement supply within a well-below 2C budget. The expected demand data are based on the International Energy Agency (IEA) Baseline scenario (Stated Policies Scenario), the IEA Net Zero scenario, and the Low Energy Demand (LED) scenario.

1) Scenario analysis:
Feasible supply of steel and cement within the 1.5°C budget is likely to fall short of the expected demand: 58–65% for steel and 22–56% for cement (interquartile ranges)

2) Discussion:

- Large uncertainties in deployment rates of CCTS
- Different alternatives for net zero production routes exist (e.g., steel DRI but no cement alternative at scale available yet)
- Differences in available evidence of material demand reduction strategies

Delivering the infrastructure needed for net zero industrial production

- **Technical system: currently installed CCTS capacity is very small** compared with overall CO2 emissions (~0.1 %)
- **Scale-up: little historical evidence** of successful CCTS deployment in energy-intensive industries (one steel, a few fertiliser and chemicals; no cement; etc)
- **Deployment of CCTS significantly slower than projected:** feasible bulk material supply is likely to fall short of global demand
- **Technical system for CCTS** requires system-good approach to appropriately address the complexities of infrastructure delivery and to accelerate it
- **Priorities for infrastructure policy:** scale-up renewable electricity sources, accelerate deployment of alternatives to emissions-intensive processes and use the limited storage / CCTS for hard-to-abate processes

This talk in 5 minutes:
5 theses on CCTS and the “carbon circular economy”

1. **The objective of the socio-ecological-technical transformation (“transition”)**

The objective of the socio-ecological-technical transformation (sometimes called “transition”, or “transition énergétique”) is a fossil –free (and fissil-free???) energy system with a fair sharing of costs and benefits, and a combination of central and decentral networks and infrastructure (Christian von Hirschhausen et al. 2018).

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Literature

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