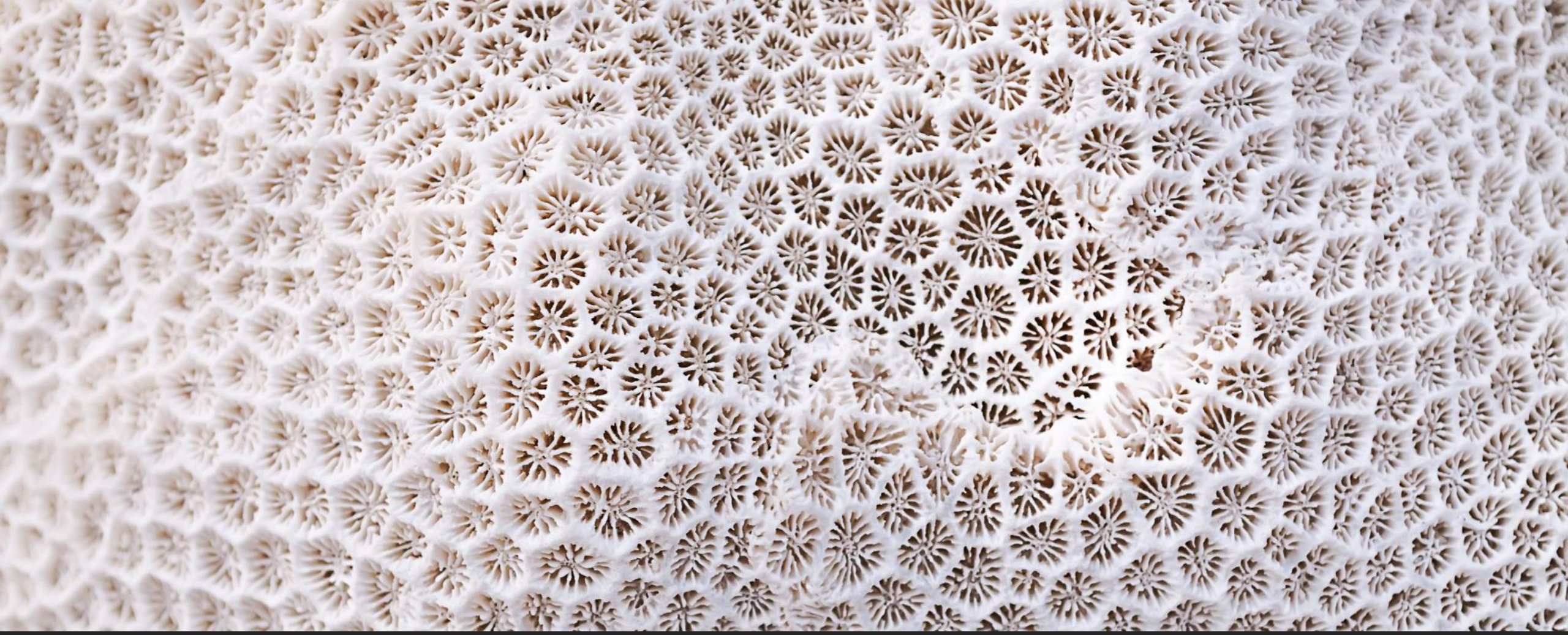


Industrial Carbon Capture and Canada's Energy Transition Trilemma

AN OVERVIEW OF OPPORTUNITIES AND CHALLENGES

FOR UQAM WEBINAR
2023-04-20

Roadmap

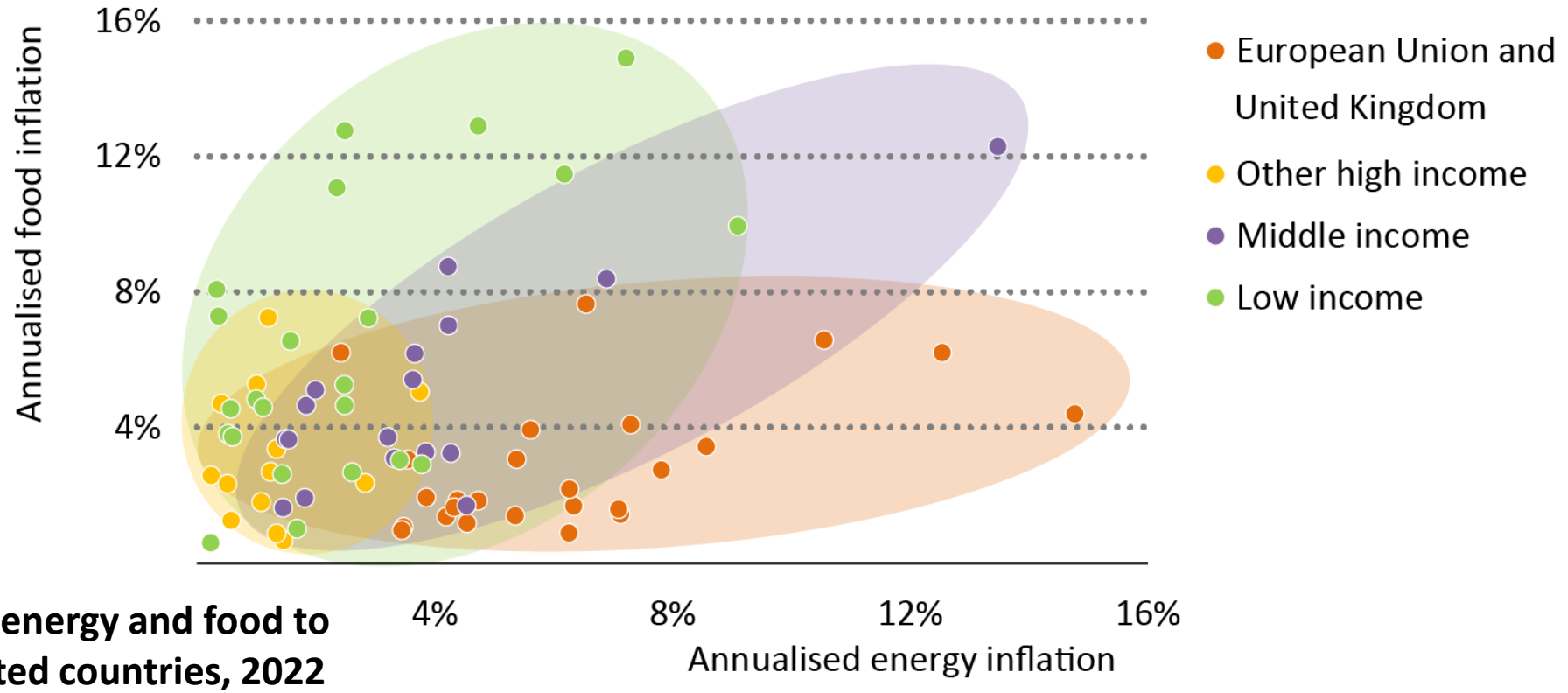
Trilemma – say what?
- Objective: Net zero or bust!

Getting to Net Zero
- Impact: How big is Big?
- Sectors
- What will it take?

High-level overview of CCUS
- How do we capture CO_2?
- Caught it … Now what?

Opportunities for Canada
- Potential
- Are we doing enough?

Trilemma:
Climate + Economy + Social Equity

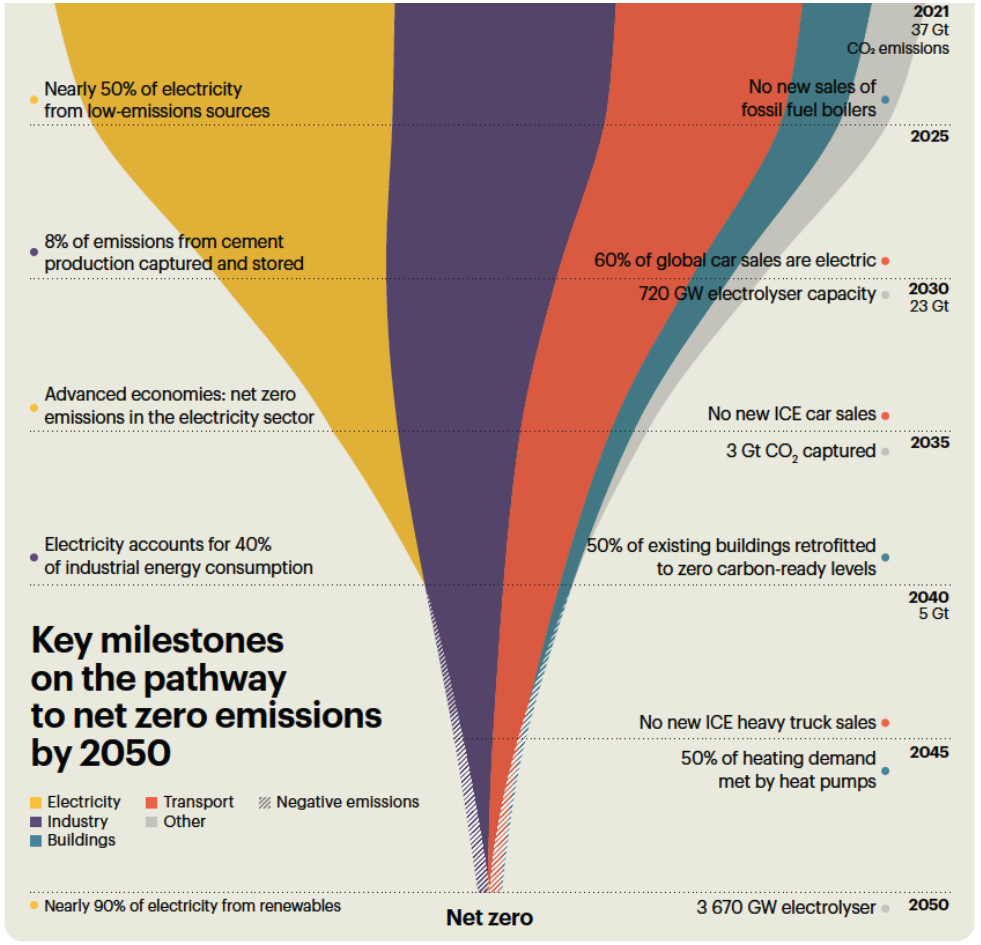


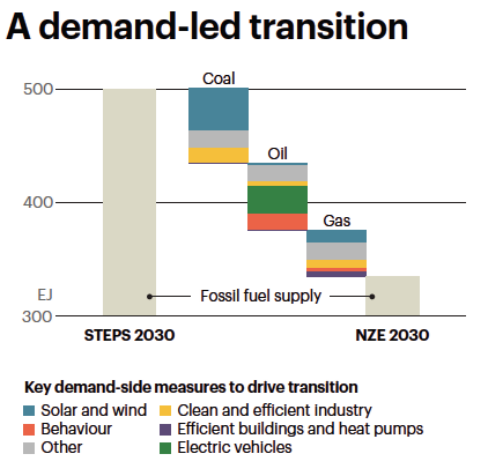
Contributions of energy and food to inflation in selected countries, 2022

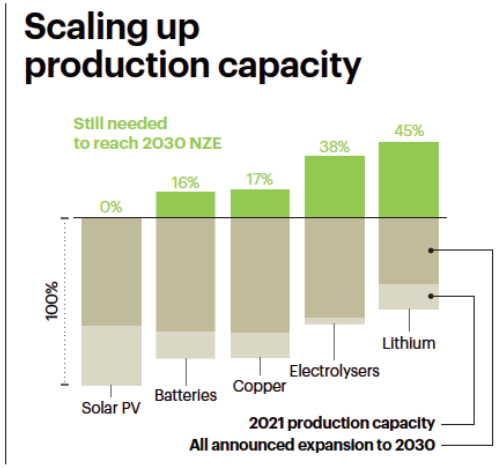
Objective

Net Zero or bust!

Relentless focus on emissions







IEA World Energy Outlook 2022

How big is Big? A Lot bigger than today

To achieve Net-Zero by 2050, CCUS:

- **MUST sequester 6.2 GT CO_2e/year** (International Energy Agency*)
- **Current installed capacity globally: 11.9 MT CO_2e/year** (Global CCS Institute**)
- Need to install on average more than 100 x 2 MT plants per year (every year until 2050) to meet the Net Zero target

We will **need 3,000 to 6,000 large-scale CCUS projects** in operation by 2050

In 2022 we had …

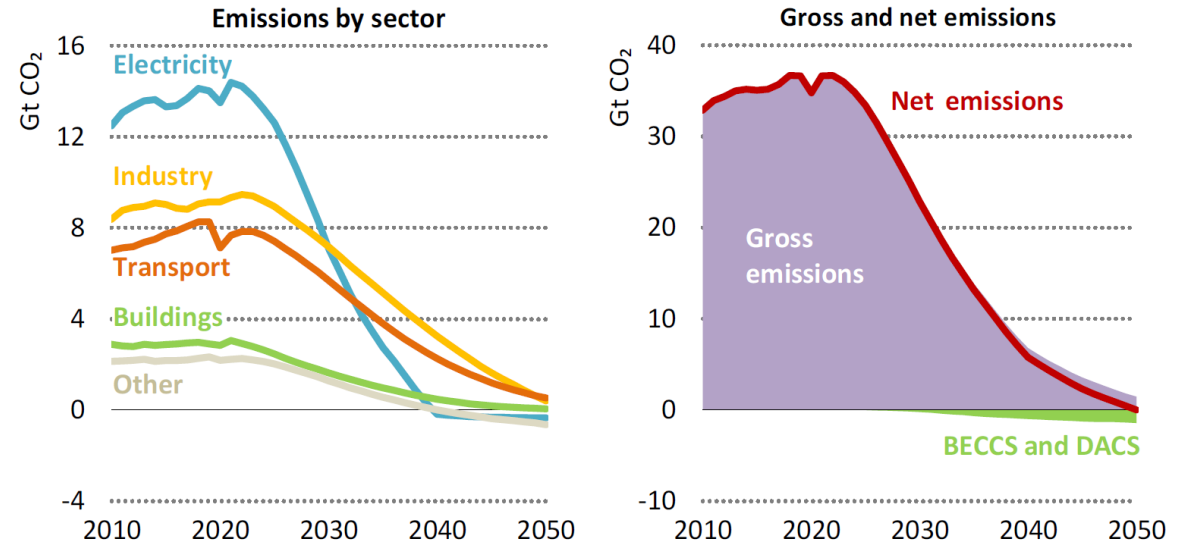
… **30 large-scale CCUS plants** in operation.

* IEA World Energy Outlook 2022

** GCCSI Global Report 2022

Can’t get to Net-zero w/o EVERYTHING

Figure 3.1 ▻ Energy-related CO_2 emissions by sector and gross and net emissions in the NZE Scenario, 2010-2050

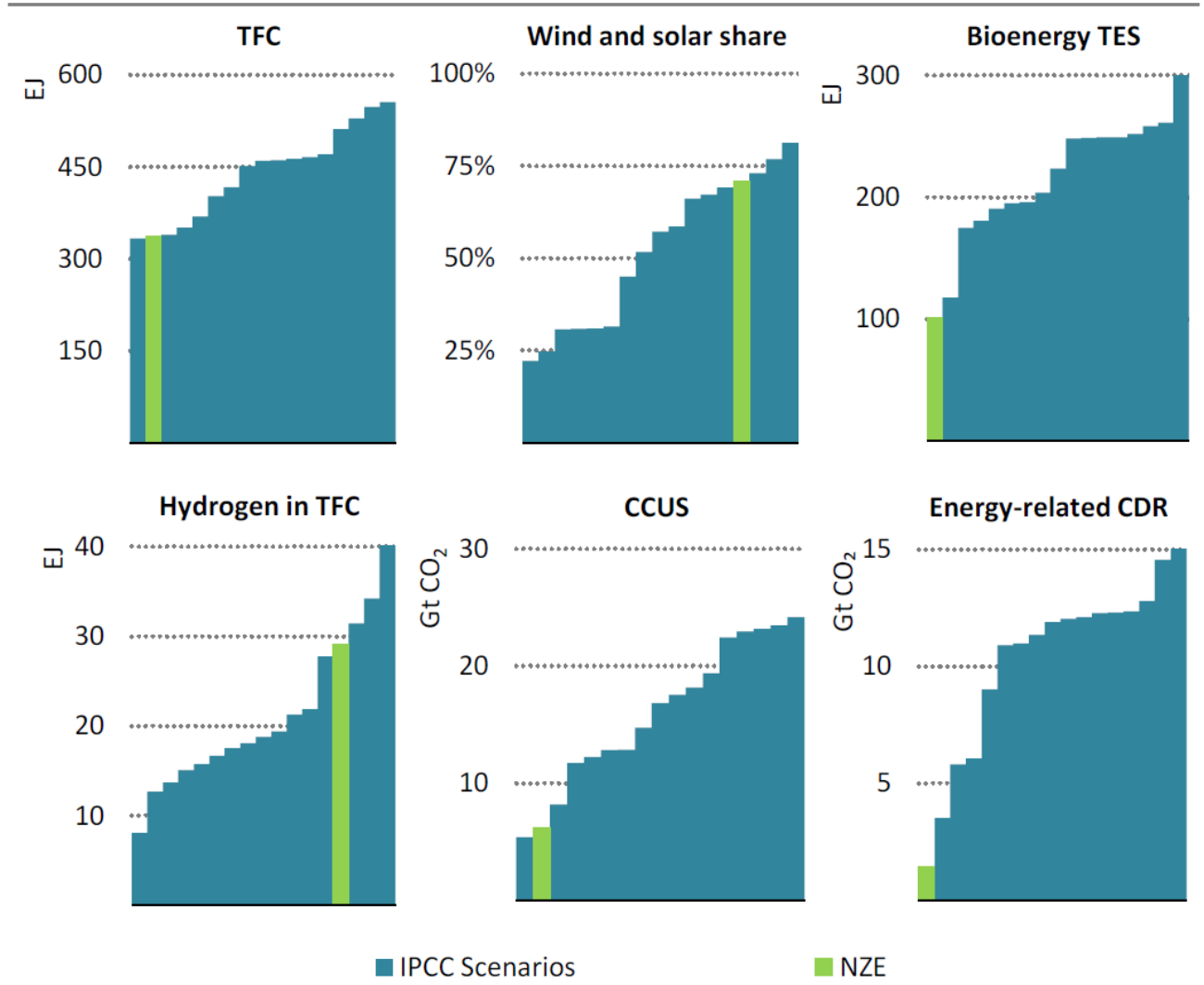


The power sector leads emissions reductions to 2030, but all sectors contribute to the net zero emissions goal, with residual emissions in 2050 balanced by atmospheric removals

Notes: BECCS = bioenergy equipped with CCUS; DACS = direct air capture and storage. Other includes agriculture and other energy transformation sectors.

More than one path to NZ

Key indicators for the selected IPCC scenarios and the IEA NZE Scenario in 2050

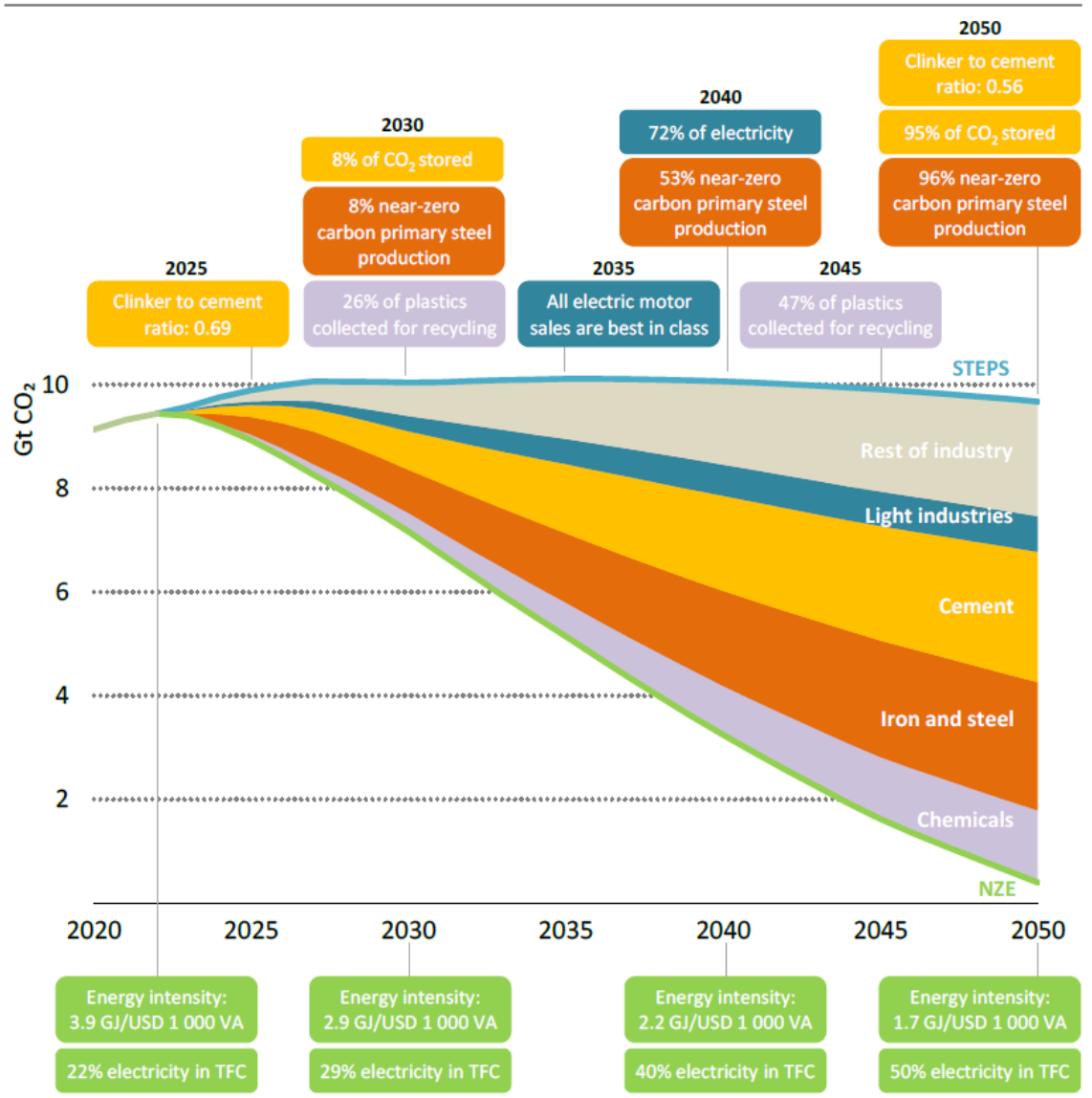


IEA NZE Scenario requires less CCUS and CDR than comparable IPCC scenarios, and it relies more on energy efficiency, renewables and hydrogen

Notes: TFC = total final consumption; TES = total energy supply; CCUS = carbon capture, storage and utilisation; CDR = carbon dioxide removal. IPCC Scenarios refers to the 16 vetted C1 IPCC scenarios that reach net zero energy sector emissions by 2050 (IIASA, 2022).

By Industry

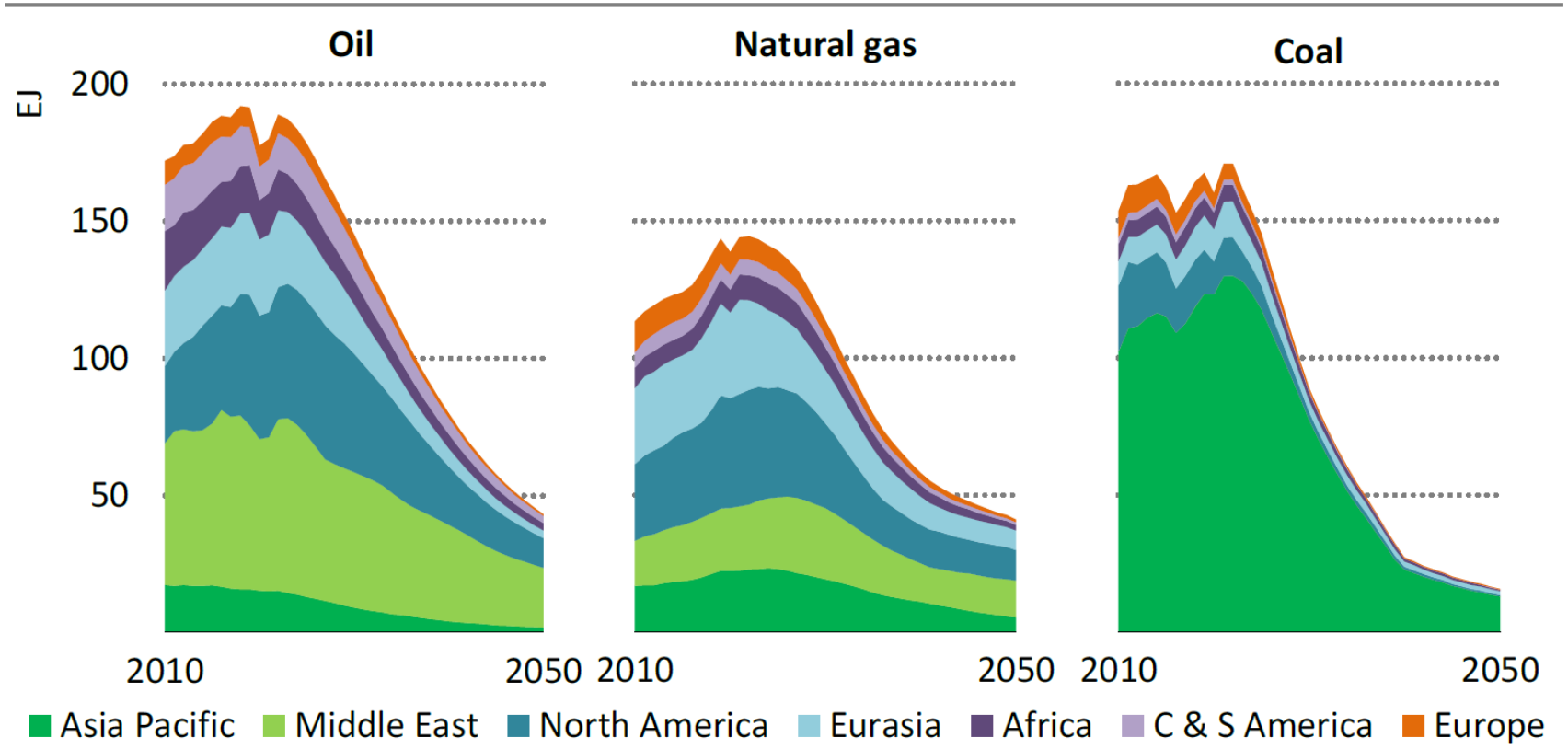
Industry requires a portfolio of technologies … such as energy and material efficiency, electrification, hydrogen and CCUS



Notes: VA = value added; TFC = total final consumption. Innovative routes for iron and steel include hydrogen based and CCUS-based routes.
Milestones in green relate to the whole of the industry sector.

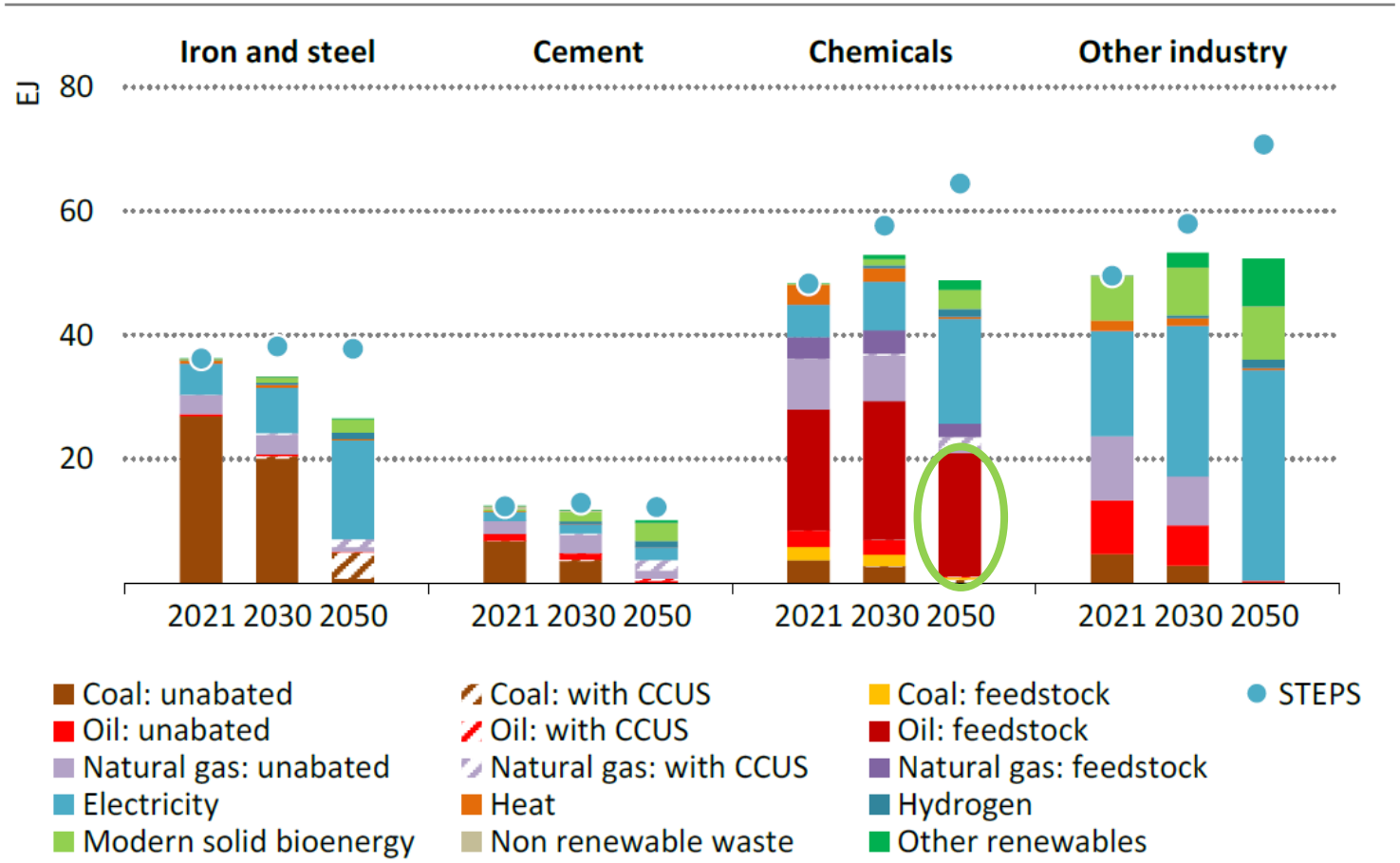
Oil, NG & Coal on the way to NZE?

Declines in demand can be met without approving new long lead time upstream conventional oil and gas projects, new coal mines or mine lifetime extensions

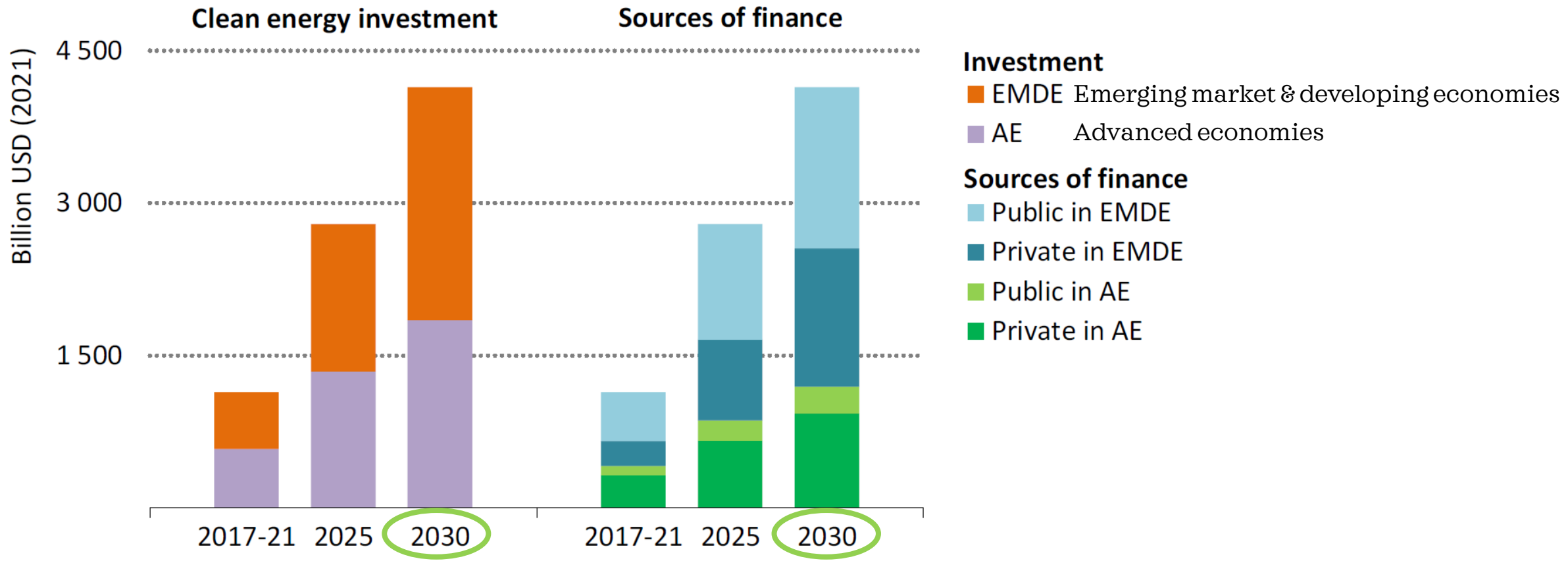


No way to avoid Oil as Feedstock in Chemicals sector

Electricity makes inroads in all industry sub-sectors; in some it is used to produce hydrogen onsite. In 2050, the share of unabated fossil fuels is less than 5%, from around 50% today.



Investment and Sources



Limitations

Where might we hit limits to achieving Net Zero?

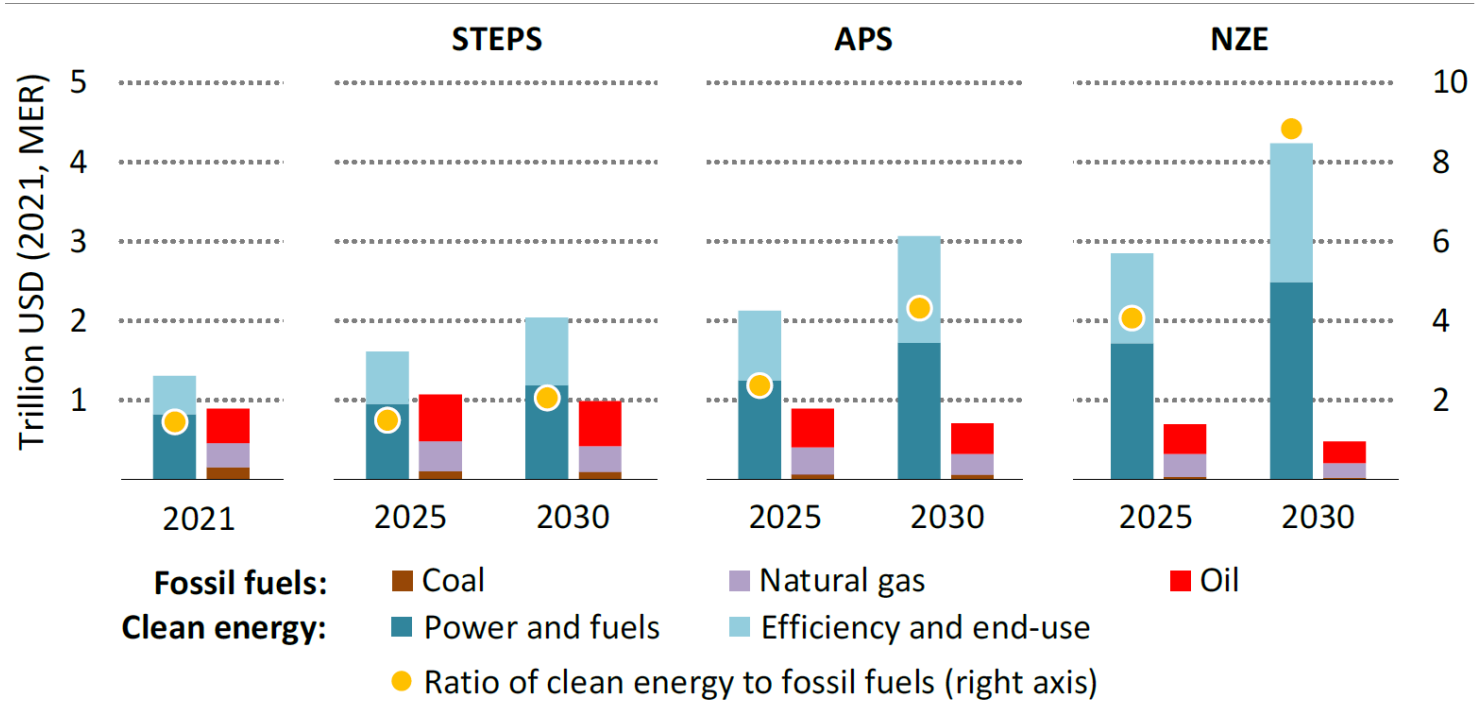
1. Cost-effective transitions require well-functioning markets (see (3), below)
2. Almost every contributing transition technology faces supply-chain limits
    - Geopolitical supply chain risks and challenges
    - Global capacities
3. Uncertainty is the enemy of agility – political polarization causes gridlock

A robust path forward requires:

- Flexibility
- Diversity
- Resilience

Transition

Around USD 9 is invested in clean energy for every USD 1 invested in fossil fuels in 2030 in the NZE Scenario



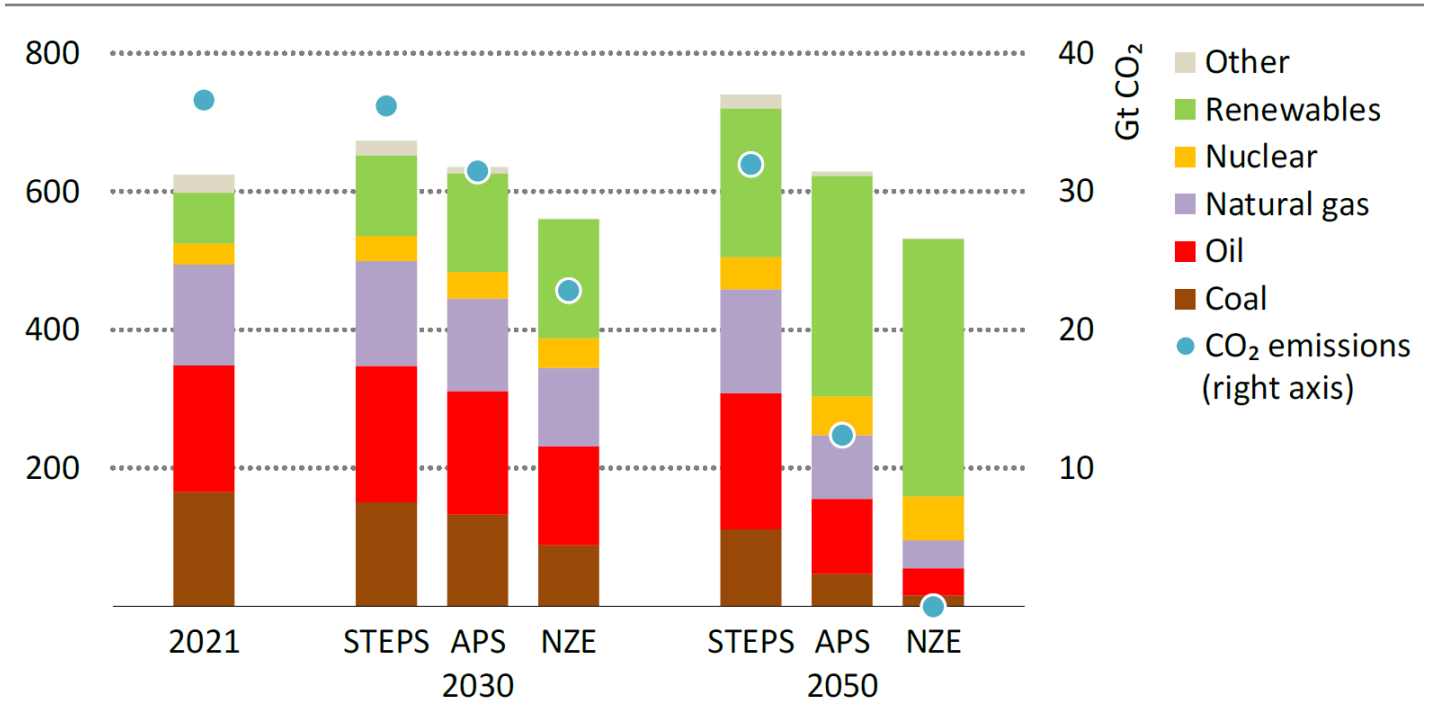
Steps: Stated Policies Scenario
APS: Announced Pledges Scenario

Energy Supply & Emissions

Even in the NZE scenario Oil, Gas & Coal persist in 2050

How?

→ CCUS



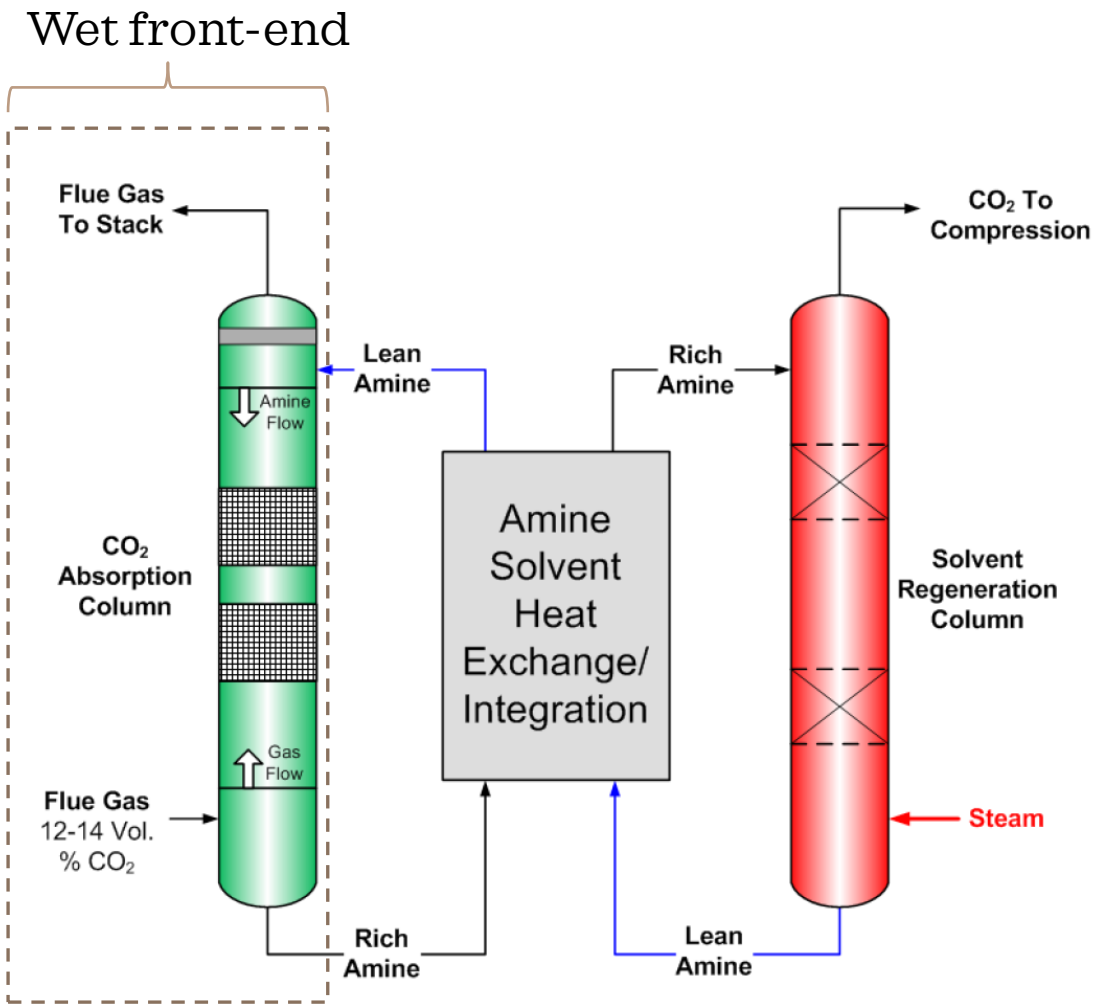
IEA World Energy Outlook 2022

How do we capture CO_2?

Traditional

Source matters

Cost matters



Conventional "Wet" Capture

Old-style amine-based chemistry

Next-generation solvents

Many other types of chemistry

- Absorber column transfers CO_2 from the flue-gas to some liquid "solvent" (including water)

US DoE *Carbon Dioxide Capture Handbook - 2015*

Source Matters

Source	CO_2 concentration	Relative volume	1 ink drop to
Cement plant	20%	1	4 drops water
Coal power	12%	1.7	7 drops water
Ind. Boiler (OTSG)	8%	2.5	10 drops (0.5 ml)
Natural Gas power	4%	5	1 ml water
Air	0.041%	500	~ ¼ cup water

Cost Matters – But it is getting better

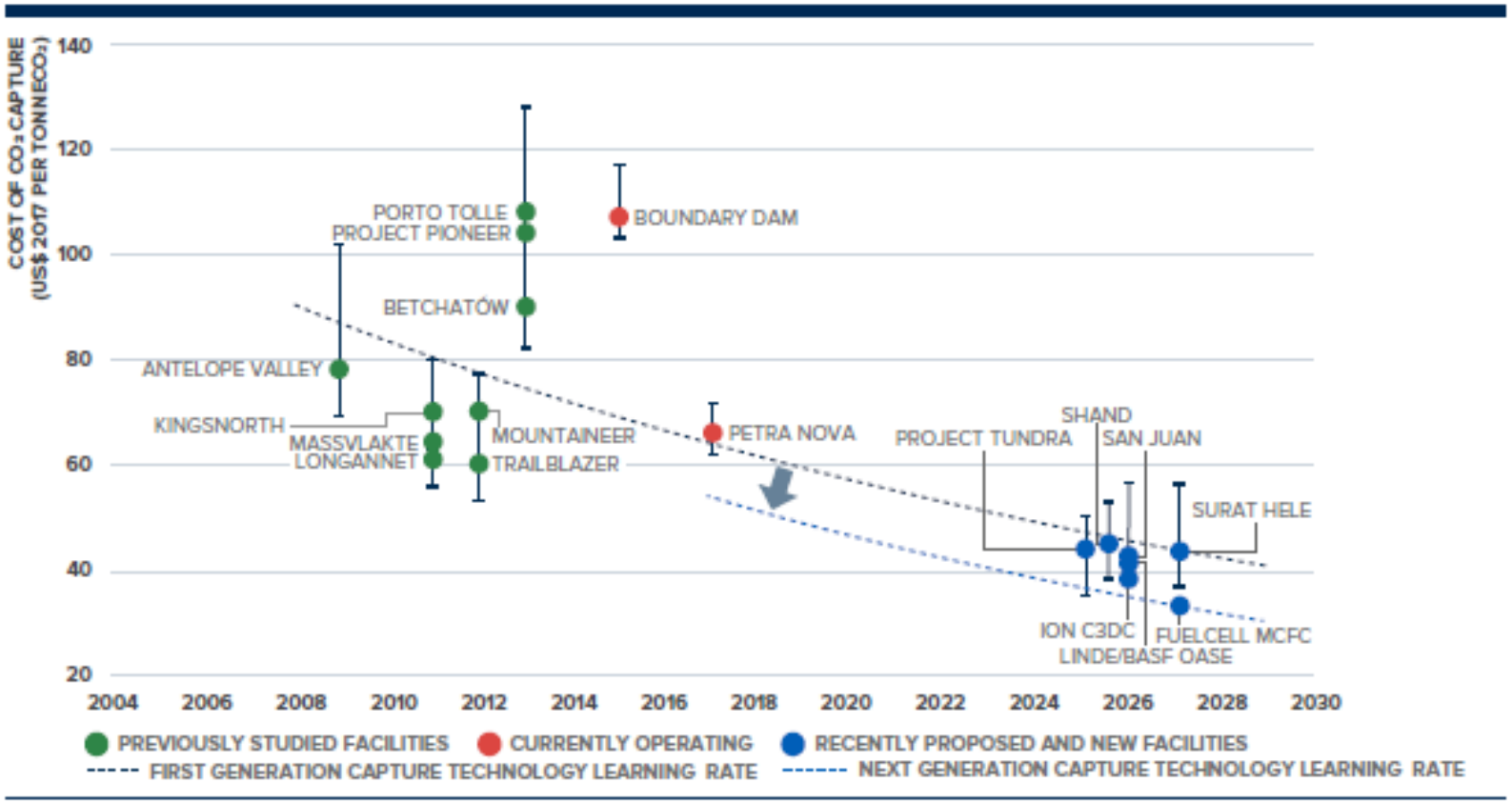


FIGURE 8 LEVELISED COST OF CO_2 CAPTURE FOR LARGE SCALE POST-COMBUSTION FACILITES AT COAL FIRED POWER PLANTS, INCLUDING PREVIOUSLY STUDIED FACILITIES[vii]

Global CCS Institute *Global Status of CCS 2019*

Got it …

NOW WHAT DO I DO WITH IT?

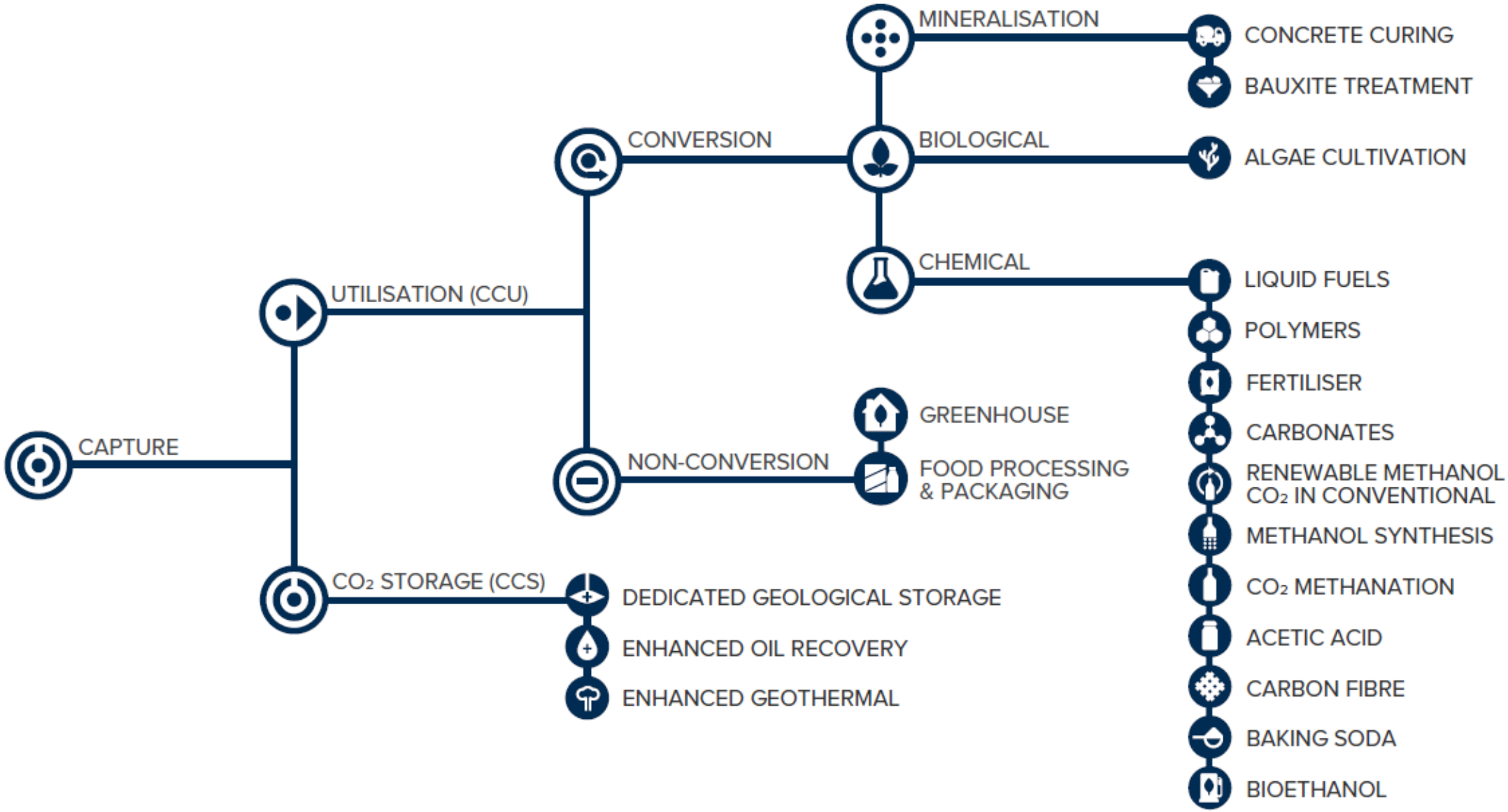
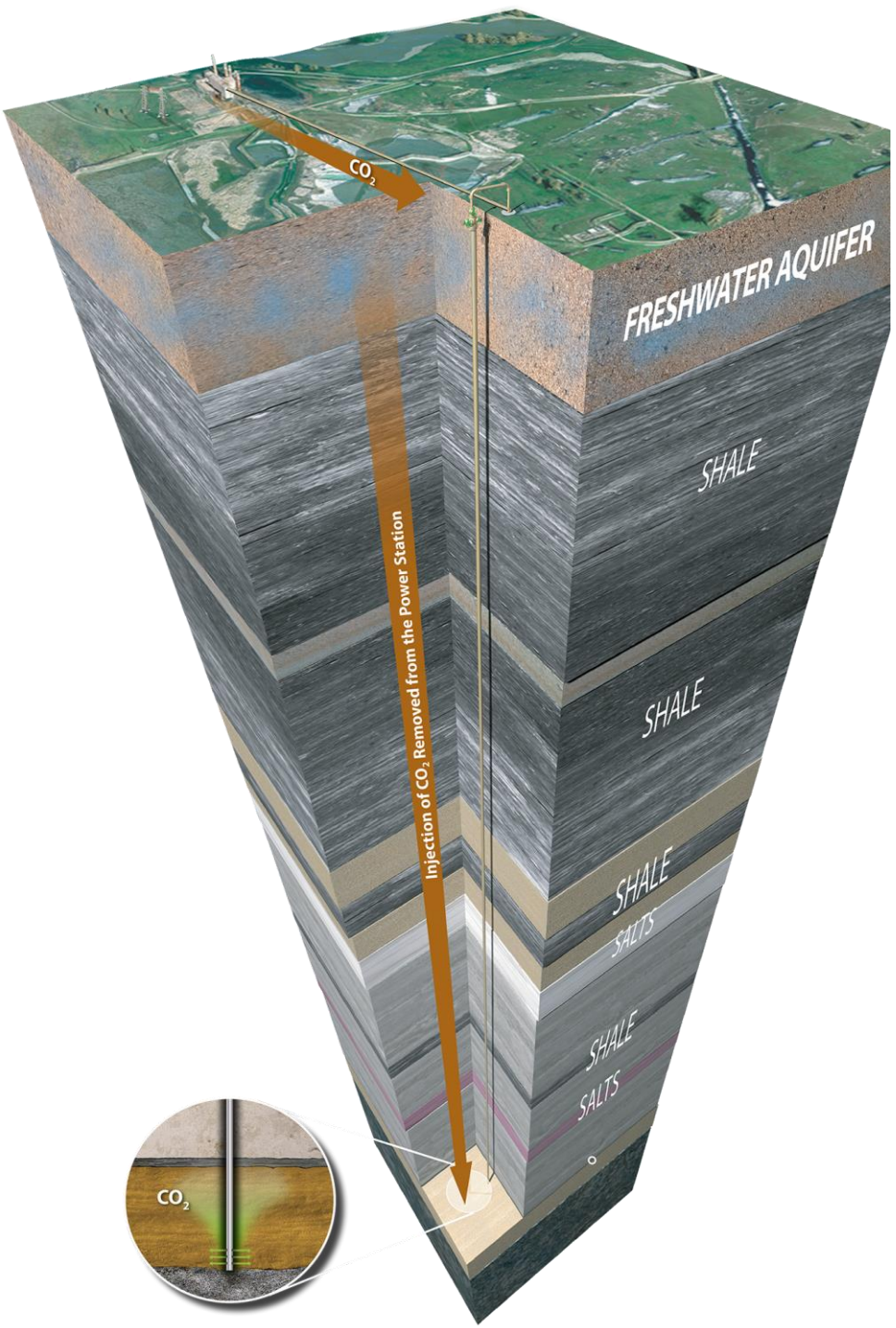


FIGURE 25 UTILISATION AND STORAGE PATHWAYS

Global CCS Institute *Global Status of CCS 2019*

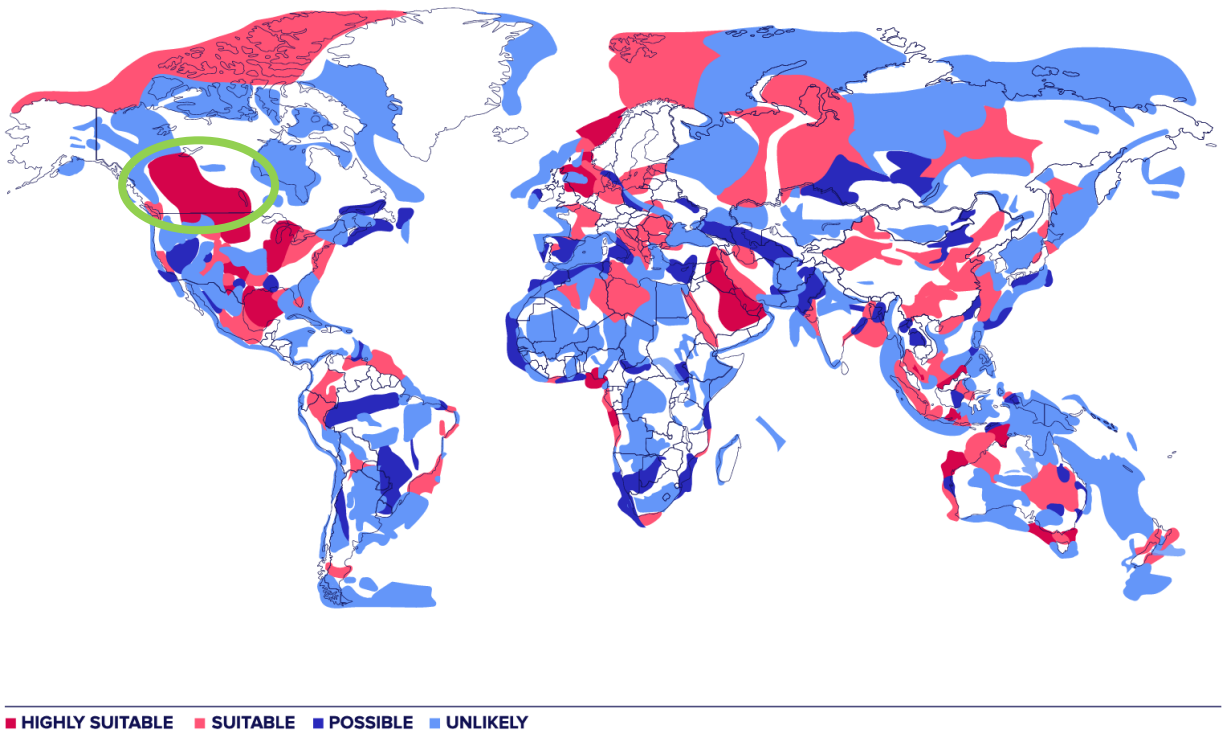


Bury it!
(Put it back where it came from)

"Landfill" model

- Pro
  - Can **scale up fast**
  - Lots of capacity (if you are geologically lucky)
  - **Secure, permanent storage**
- Con
  - Pure cost – no revenue (except regulatory incentives)

We didn't wait until recycling was perfected to start garbage collection.



Global CCS Institute *Global Status of CCS 2022*
Original Source:
Results from Assessment 3 of the CO_2 Storage Resource Catalog: OGCI et al (2022)

Storage Capacity

Canada Emissions:

- 760 MT CO_2e/year (2017)

Geological storage capacity**:

- 200,000 to 430,000 MT CO_2e (VERY conservative) or
- 250 to 500 years' worth of total national emissions (Global CCS Institute)
- May be many times that based on unexplored capacity and new storage methods

**Global CCS Institute *Global Status of CCS 2019*

Why CCUS as a path for Canada?

Transferrable capacity from O&G:

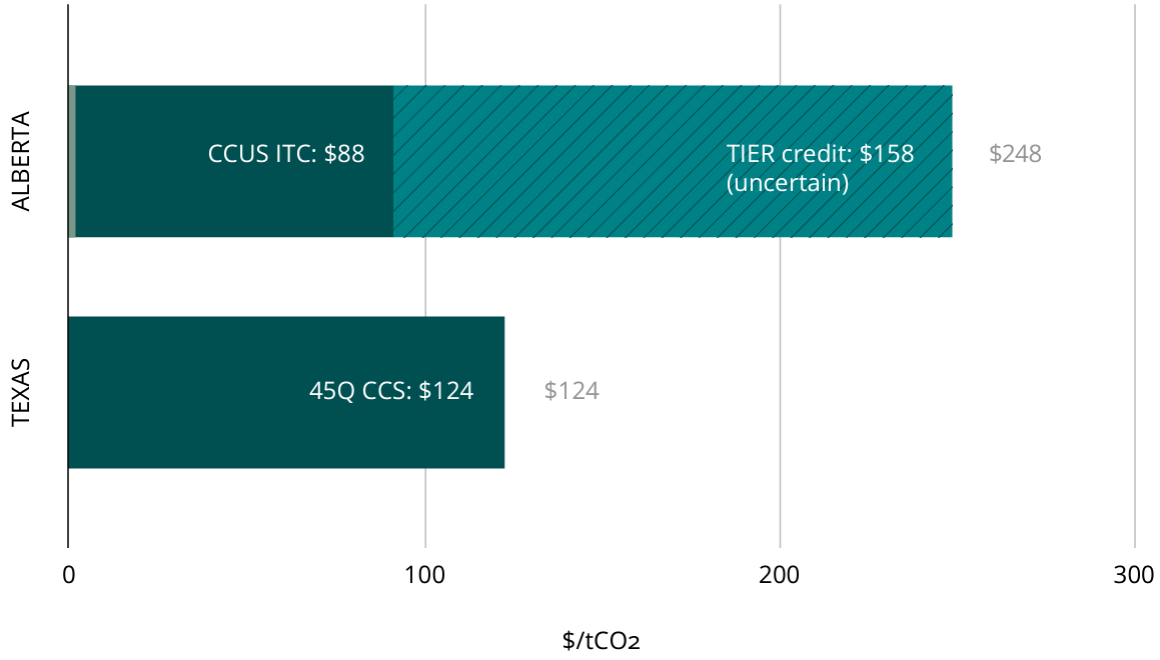
- Engineering – large projects
- Geosciences
- Pipelines
- Drilling, injection
- Seismic, monitoring
- Environmental
- Chemicals production
- Policy & regulatory for CO_2 storage
- Huge geological storage capacity

In the future, chemical production facilities will be located
- Close to feedstocks; AND
- Close to geological storage capacity

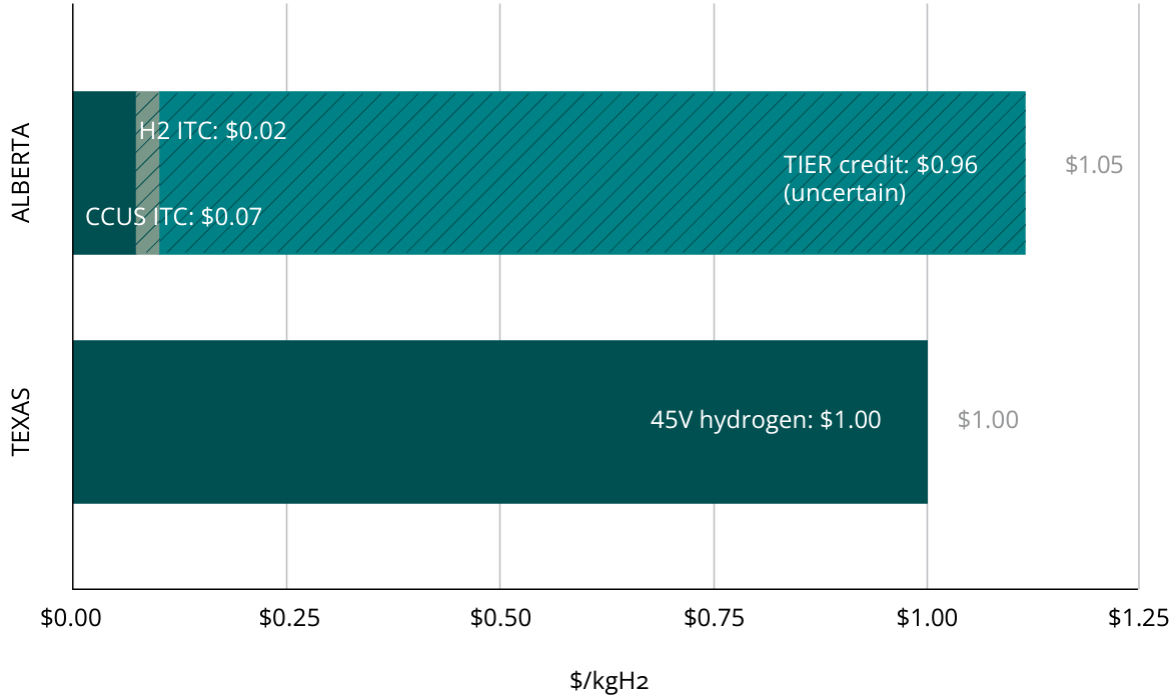
If the policy & economics are right, there is no better place in the world.

Everyone wants to win the energy transition

CCUS

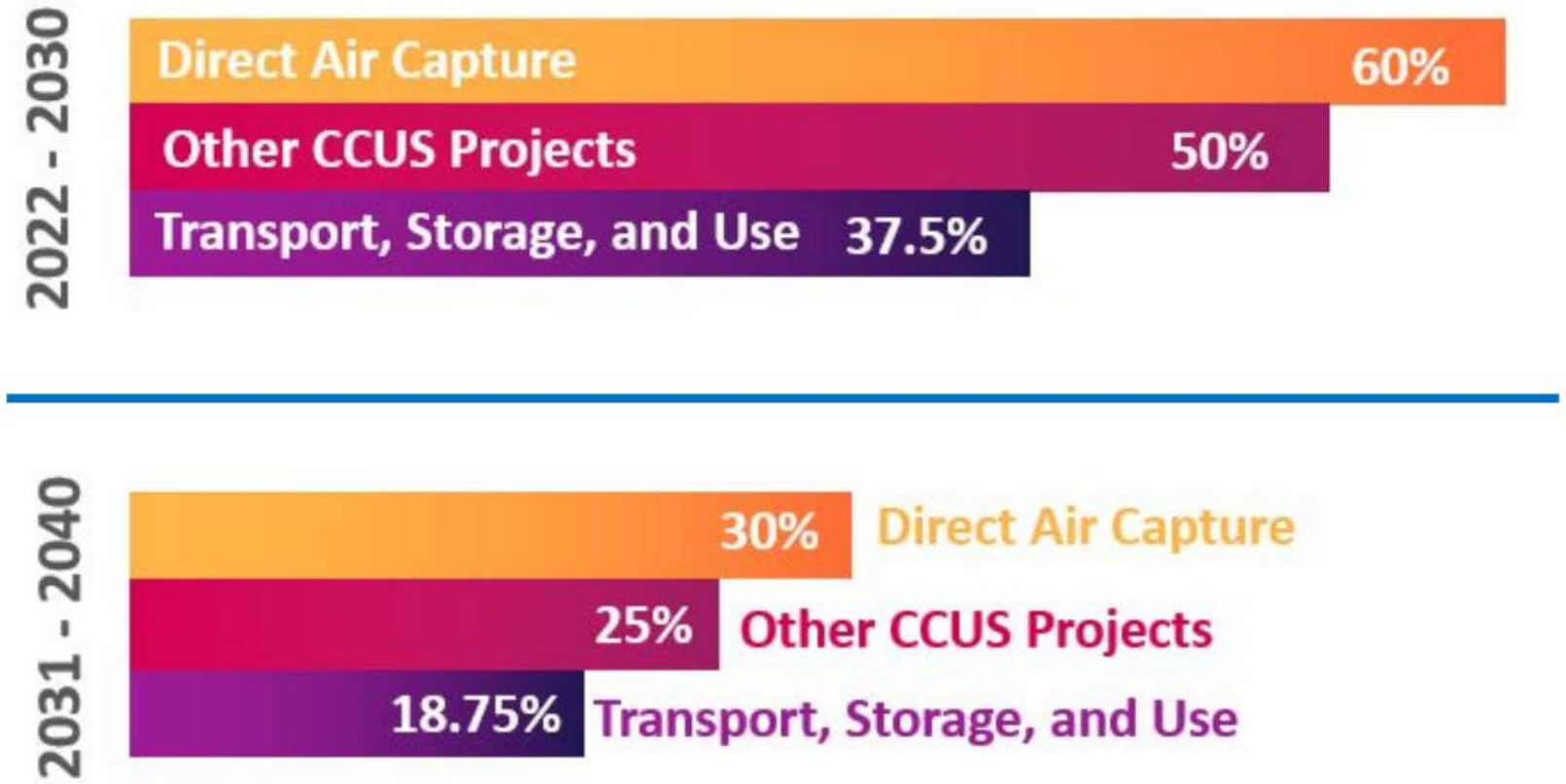


Blue Hydrogen

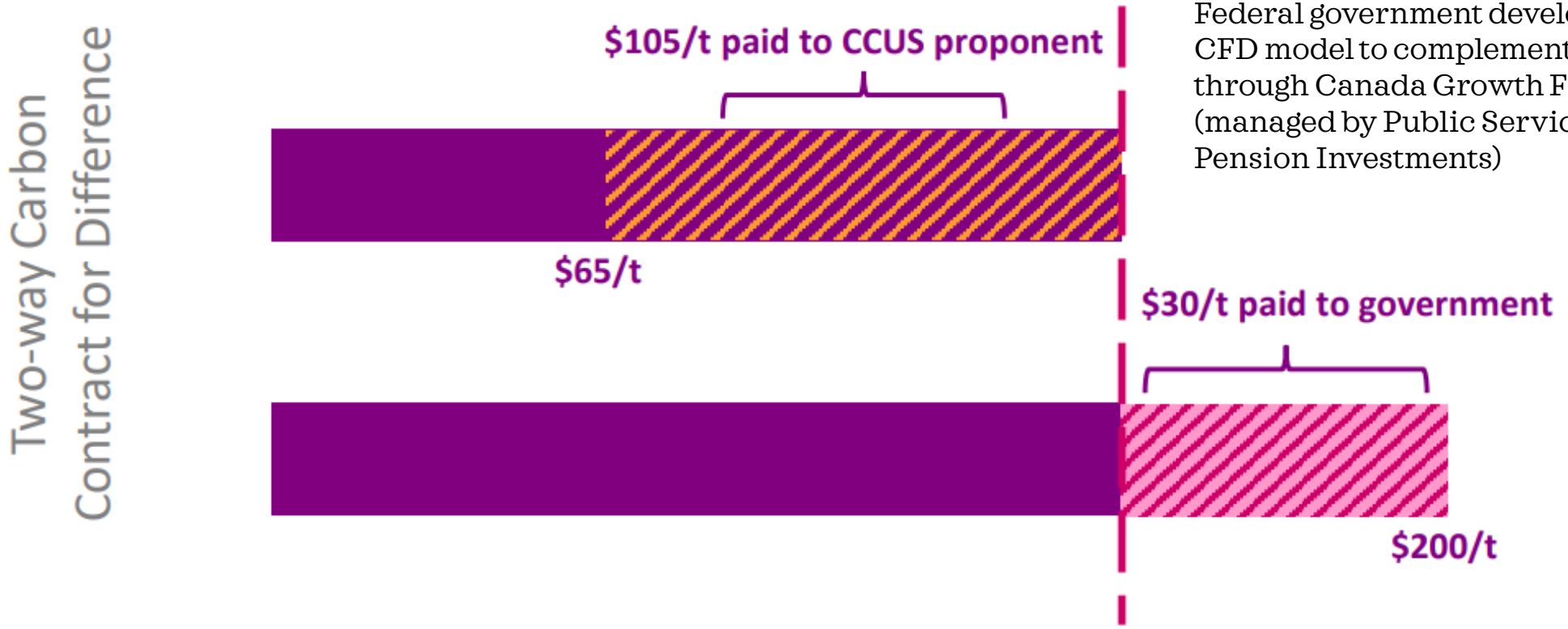


The bankable gap for proponents of equivalent 1 $MtCO_2$ CCS projects attached to cement plants in Alberta and Texas is \$36/tCO_2 on average over a 10-year period. That's 29% less in Alberta.

Investment Tax Credits
(Budget 2023)



Carbon Contracts for Differences
(Budget 2023)



Federal government developing CFD model to complement CFDs through Canada Growth Fund (managed by Public Service Pension Investments)

What are the main barriers?

- Uneven political support
  - If a significant party sees an advantage to threatening to undo incentives or regulations, then the uncertainty will:
    - Paralyze access to capital
    - Encourage industry and investors to “wait and see”
- Uncertain incentives are not bankable – investors are not gamblers
  - Risk translates to cost. Higher uncertainty demands higher returns.
- Need stringent regulations that tighten under a known formula over time
  - Does not work if the next government might undo them

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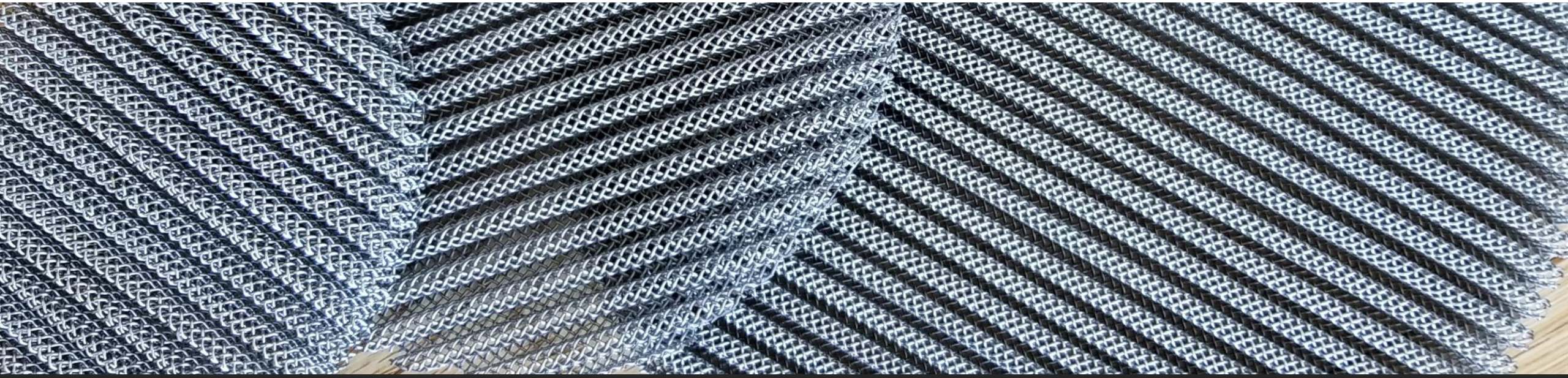


Supplemental Material

MORE STUFF

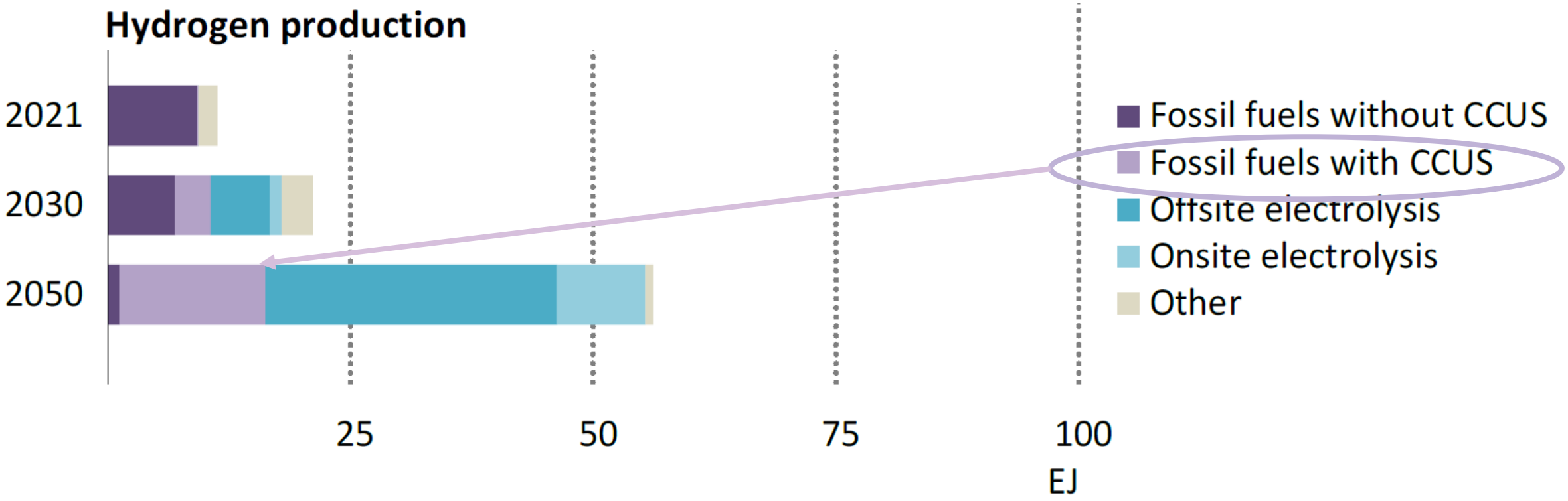
Mt hydrogen equivalent (energy basis)	STEPS 2030	STEPS 2050	APS 2030	APS 2050	NZE 2030	NZE 2050
Total low-emissions hydrogen production	6	24	30	225	90	452
Water electrolysis	4	17	21	167	58	329
Fossil fuels with CCUS	2	8	9	57	31	122
Bioenergy	0	0	0	1	0	2
Transformation	3	10	14	95	50	186
To power generation	0	1	4	19	27	60
To hydrogen-based fuels	0	3	6	69	18	118
To oil refining	2	5	3	6	2	4
To biofuels	1	1	1	1	3	3
Demand by end-use sector	3	15	16	131	40	266
Total final consumption	1	10	12	80	31	174
Onsite production	2	4	4	51	9	92
Low-emissions hydrogen-based fuels	0	3	3	55	15	96
Total final consumption	0	1	3	39	7	68
Power generation	0	2	0	16	8	28
Trade	1	5	4	44	18	73

Notes: Mt = million tonnes. 1 Mt hydrogen = 120 petajoules. Transformation to hydrogen-based fuels incurs energy losses that are the difference between hydrogen inputs to hydrogen-based fuels and the demand for these fuels.

Low emission Fuels

Hydrogen from fossil fuels, even with CCUS, requires stringent controls on upstream leakage

Hydrogen – What's that got to do with CCUS?



Others are catching up

Canada has an opportunity to regain a leading position.

Will we?

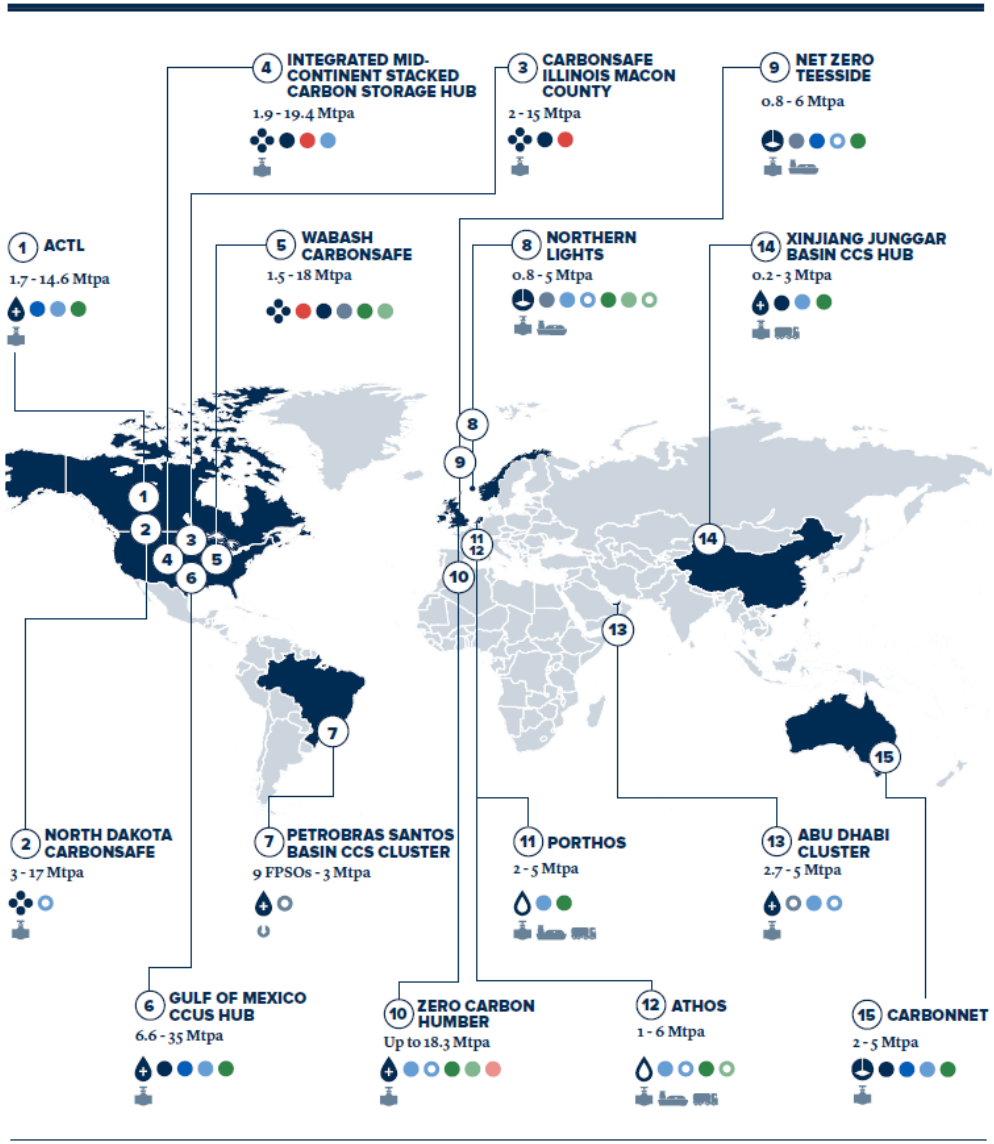
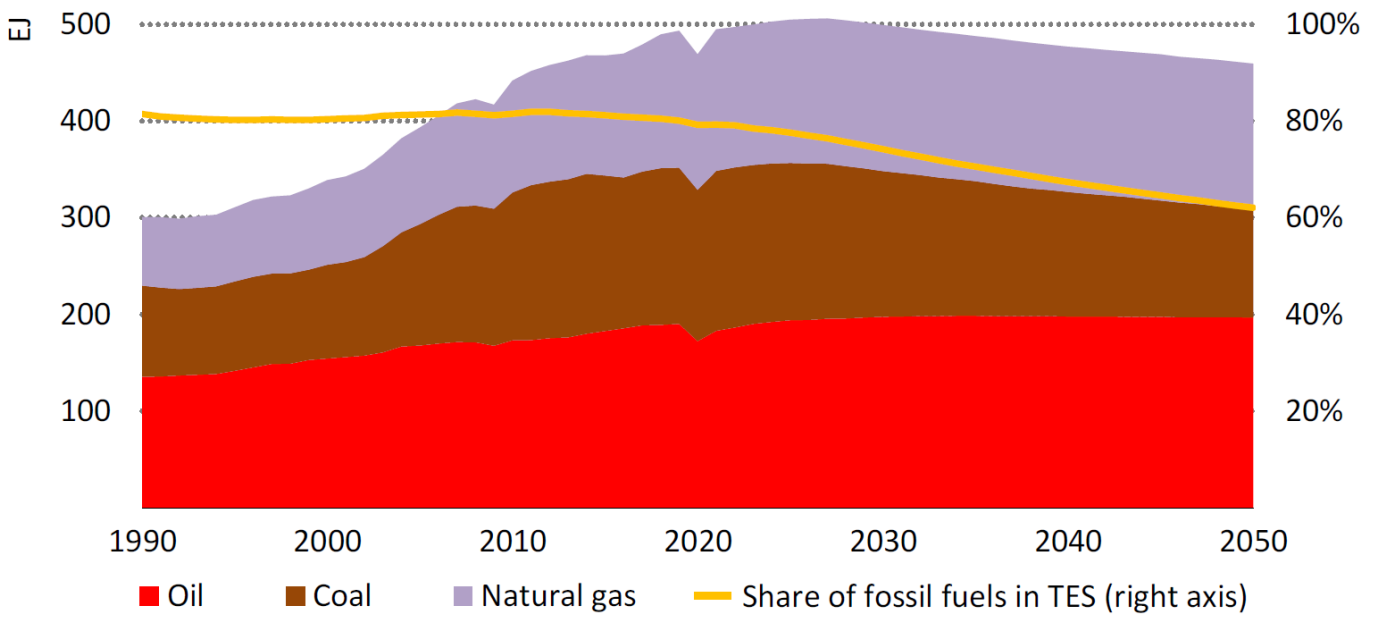


FIGURE 5 CCUS HUBS AND CLUSTERS GLOBALLY, WITH SIGNIFICANT DEVELOPMENTS IN 2019

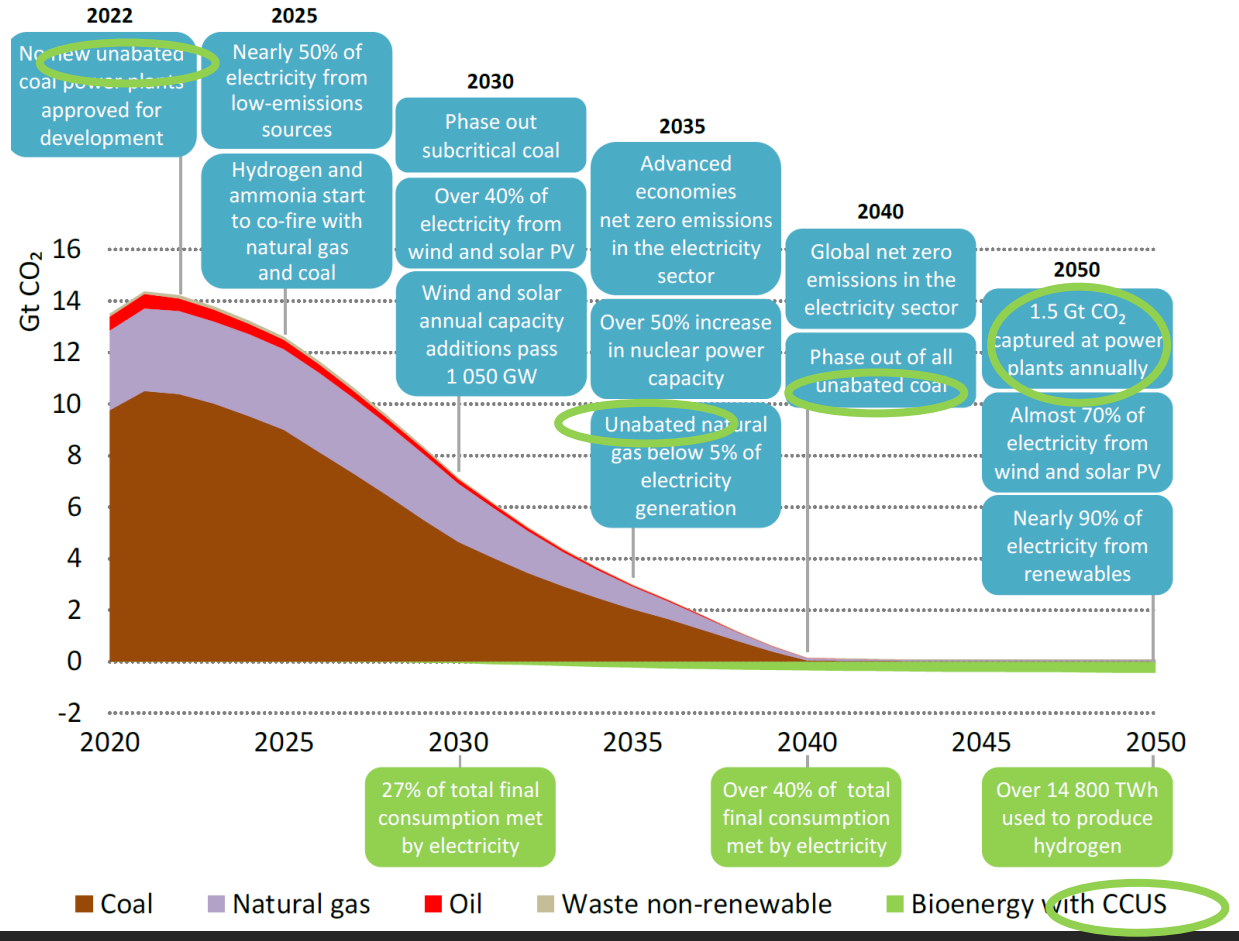
Peak fossil fuel? Maybe, but decline is slow.

Figure 1.9 ▷ **Fossil fuel demand in the STEPS, 1990-2050**



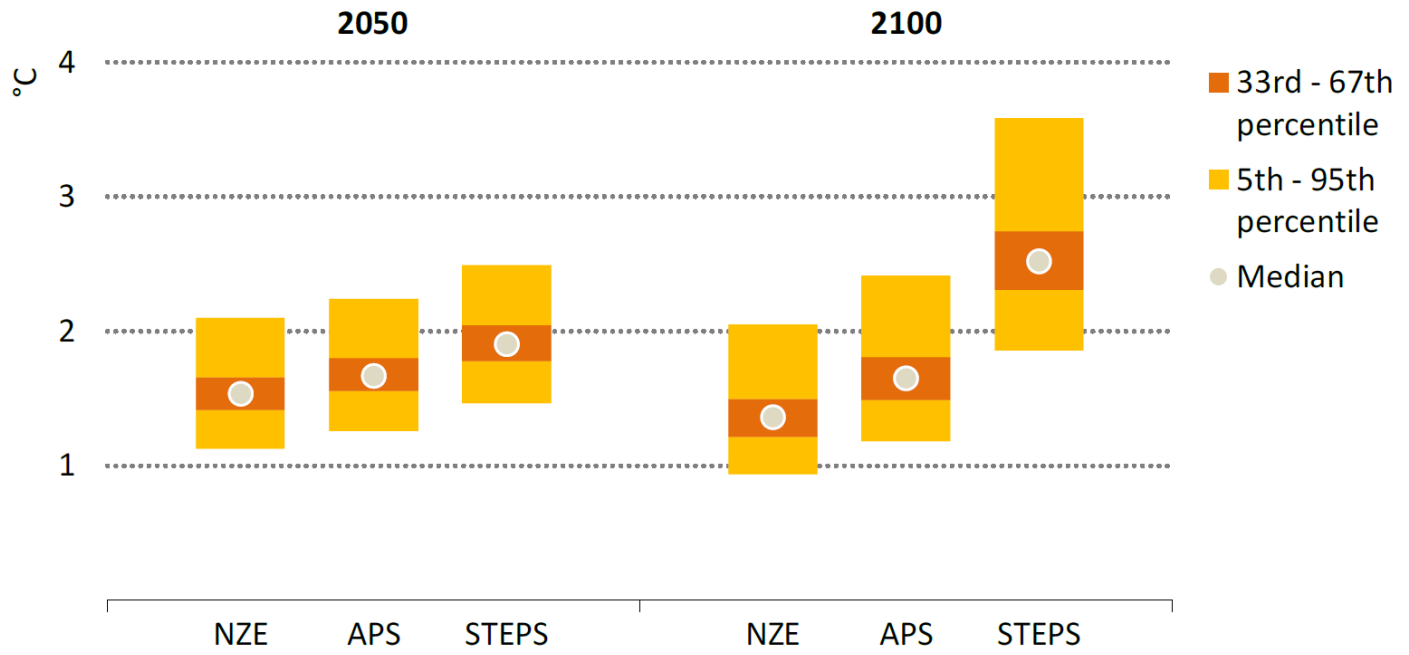
Total fossil fuel use sees a definitive peak for the first time in this year's STEPS. The share of fossil fuels in the energy mix falls to around 60% in 2050, a clear break from past trends

Everything Electrified! (Almost)



So what? We just need to implement, (don't we?)

Figure 3.2 ▷ **Temperature rise in 2050 and 2100 in the *WEO-2022* scenarios**



Temperature rise peaks at less than 1.6 °C in 2050 in the NZE Scenario and falls to around 1.4 °C by 2100. In the STEPS, it exceeds 2 °C around 2060 and continues rising

Key Indicators

By all indicators NZE

- Outperforms
- Is ambitious

But -

- Is it achievable?

	2010	2021	STEPS 2030	STEPS 2050	APS 2030	APS 2050	NZE 2030	NZE 2050
Access (million people)								
Population without access to electricity	1 392	754	663	727	292	112	0	0
Population without access to clean cooking	2 916	2 386	1 880	1 601	783	535	0	0
Premature deaths from (million people):								
Ambient air pollution	n.a.	4.2	4.8	7.1	4.6	6.5	3.3	2.9
Household air pollution	n.a.	3.6	2.9	3.0	1.6	1.9	1.0	1.2
Energy-related CO_2 emissions (Gt)	**32.9**	**36.6**	**36.2**	**32.0**	**31.5**	**12.4**	**22.8**	**0**
CO_2 captured via CCUS	0	0.04	0.1	0.4	0.5	4.3	1.2	6.2
Primary energy supply (EJ)	**542**	**624**	**673**	**740**	**636**	**629**	**561**	**532**
Share of unabated fossil fuels	81%	79%	74%	61%	69%	34%	59%	10%
Energy intensity of GDP (GJ per USD 1 000, PPP)	5.1	4.3	3.4	2.2	3.2	1.9	2.9	1.6
Electricity generation (1 000 TWh)	**22**	**28**	**35**	**50**	**36**	**61**	**38**	**73**
CO_2 intensity of generation (g CO_2/kWh)	524	459	325	158	280	41	165	-5
Share of low-emissions generation	32%	38%	53%	74%	59%	91%	74%	100%
Total final consumption (EJ)	**383**	**439**	**485**	**544**	**451**	**433**	**398**	**337**
Share of unabated fossil fuels	69%	66%	64%	57%	61%	36%	56%	15%
Share of electricity in TFC	17%	20%	22%	28%	24%	39%	28%	52%

Notes: Gt = gigatonnes; CCUS = carbon capture, utilisation and storage; EJ = exajoule; GJ = gigajoule; PPP =

Systems Thinking

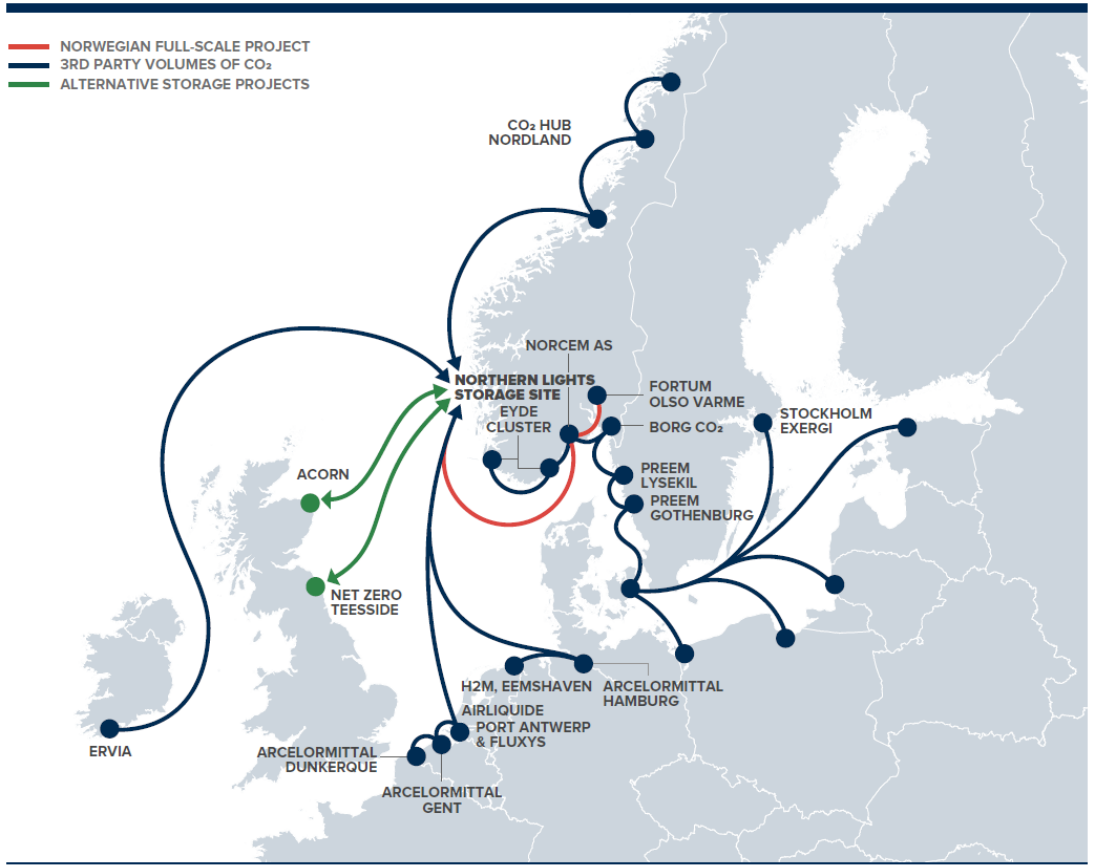


FIGURE 19 POTENTIAL SOURCES OF CO_2 FOR NORTHERN LIGHTS[50]

Norway is the global leader

- Multiple capture sources
- Integrated transportation system
- Designed to expand
- Government investment
  - Long-term revenue model

Global CCS Institute *Global Status of CCS 2019*