2023-IP13: IEA Net Zero Roadmap 2023 Update

On 26 September 2023, the IEA released its update of the 2021 Net Zero Roadmap. This update addresses the significant changes that the energy sector has seen in the past two years: the post-pandemic rebound in emissions, the exceptional growth in some areas of the clean energy sector, the issue of energy security during geopolitical conflicts and record high profits of fossil fuel companies during the cost-of-living crisis. The following information paper (IP) summarises the main conclusions and changes. For a summary of the original 2021 Roadmap, please see IEAGHG's 2021-IP08 'IEA Net Zero Roadmap'.

Overall key messages:

- Global carbon dioxide (CO_2) emissions from the energy sector reached a new record high of 37 billion tonnes (Gt) in 2022, 1% above their pre-pandemic level, but are set to peak this decade. This is encouraging, but not nearly enough for the 1.5 °C goal.
- Positive developments over the past two years include solar PV installations and electric car sales tracking in line with the milestones set out for them in the 2021 Roadmap.
- Ramping up renewables, improving energy efficiency, cutting methane (CH_4) emissions and increasing electrification with technologies available today deliver more than 80% of the emissions reductions needed by 2030.
- Tripling global installed renewables capacity to 11,000 gigawatts by 2030 provides the largest emissions reductions to 2030 in the NZE Scenario.
- Doubling the annual rate of energy intensity improvement by 2030 in the NZE Scenario saves the energy equivalent of all oil consumption in road transport today, reduces emissions, boosts energy security and improves affordability.
- These last two actions reduce fossil fuel demand, enabling continued adherence to a key milestone of the 2021 Roadmap: an immediate end to new approvals of unabated coal plants.
- Booming technologies like electric vehicles and heat pumps drive electrification across the energy system, providing nearly one-fifth of the emissions reductions to 2030 in the NZE Scenario.
- Today much of the momentum is in small, modular clean energy technologies like solar PV and batteries, but these alone are not sufficient to deliver net zero emissions. Other options are needed, including carbon capture, utilisation and storage (CCUS) and carbon dioxide removal (CDR).
- Electricity transmission and distribution grids need to expand by around 2 million km each year to 2030.. Similarly, CO_2 storage capacity needs to increase 20-fold (from 50 Mt to 1 Gt) and CO_2 pipeline infrastructure needs to expand by around 20,000 – 40,000 km by 2030. Expedition of permitting and construction of required infrastructure will be very important.
- CCUS, hydrogen and hydrogen-based fuels, and sustainable bioenergy are critical to achieve net zero emissions; rapid progress is needed by 2030. The roadmap's executive summary states that "The history of CCUS has largely been one of underperformance". [Note IEAGHG interprets this to mean under-deployment, as many projects have performed well]. Fossil fuel based power plants with CCUS have been moving more slowly than previously projected but progress is evident in other areas, e.g. cement with CCUS, chemicals with CCUS, and steam methane reforming with CCUS. Natural gas with CCUS has been revised downward, due to a downward revision in hydrogen demand and a rebalancing in favour of electrolytic hydrogen. Although the recent surge of announced projects for CCUS and hydrogen is encouraging, the majority have yet to reach final investment decision (FID) and need further policy support to

boost demand and facilitate new enabling infrastructure. More than USD 8.5 billion of public support was made available for CCUS but only 30% of it spent, highlighting the need for more effective funding programmes. If all announced CCUS capacity is realised, capacity could rise from around 45 Mt/yr today to 400 Mt/yr in 2030, and ultimately providing 8% of cumulative emissions reductions in 2050, i.e. the main emissions reductions from CCUS will happen after 2030.

- The world is set to invest a record USD 1.8 trillion in clean energy in 2023: this needs to climb to around USD 4.5 trillion a year by the early 2030s to be in line with the NZE pathway.
- Cutting CH_4 emissions from the energy sector by 75% by 2030 is one of the least cost opportunities to limit global warming in the near term. This costs around USD 75 billion in cumulative spending to 2030, equivalent to just 2% of the net income received by the oil and gas industry in 2022. Much of this would be accompanied by net cost savings through the sale of captured CH_4. Without efforts to reduce CH_4 emissions from fossil fuel supply, global energy sector CO_2 emissions would need to reach net zero already by around 2045, rather than 2050.
- The stringent and effective policies in the NZE Scenario spur clean energy deployment and cut fossil fuel demand by more than 25% by 2030 and 80% in 2050. No new long-lead time upstream oil and gas projects are needed in the NZE Scenario, neither are new coal mines, mine extensions or new unabated coal plants. The drop in fossil fuel demand and supply reduces traditional risks to energy security, but they do not disappear – especially in a complex and low trust geopolitical environment.
- Particular attention needs to be paid to bridging the looming supply and demand gap for critical minerals. Large quantities of critical minerals are required for clean energy technologies and their supporting infrastructure, ranging from wind turbines and EV batteries to CO_2 pipelines and power grids. Announced mining projects for minerals such as nickel and lithium fall short of booming demand in the NZE Scenario in 2030.
- Extraordinary advances in clean energy technology supply chains have kept the door to net zero emissions open but have been accompanied by a high degree of geographical concentration. This presents an increased risk of disruption, such as from geopolitical tensions, extreme weather events or a simple industrial accident. As electricity becomes the “new oil” of the global energy system in the NZE Scenario, secure electricity supplies become even more important. This hugely increased need for electricity system flexibility requires massive growth in certain areas, including fossil fuel capacity with CCUS.
- Current Nationally Determined Contributions (NDCs) are not in line with countries’ own net zero emissions pledges, and those pledges are not sufficient to put the world on a pathway to net zero emissions by 2050. The NZE Scenario is a global but differentiated pathway: each country will follow its own route based on its resources and circumstances. However, all must act much more strongly than they are today.
- Nearly 5 Gt CO_2 would have to be removed from the atmosphere every year during the second half of this century. If CDR technologies fail to deliver at such scale, returning the temperature to 1.5°C would not be possible. Removing carbon from the atmosphere is costly and uncertain, thus everything possible to stop putting it there in the first place must be done.
- The energy sector is changing faster than many people think, but much more needs to be done and time is short.

<u>Select other and/or more detailed messages, esp. on CCUS/CDR from the main report:</u>

- Large-scale technologies, such as CCUS, liquid biofuel or hydrogen-based steel production, have seen slower deployment over the last decade than smaller mass manufactured and modular technologies. For example, less new CO_2 capture capacity was added between 2015 and 2022 than between 2010 and 2015. In recent years, however, the number of announced projects for large-scale technologies has increased significantly. For example, the number of CCUS projects in the pipeline nearly tripled in 2021 and have nearly doubled again since then. If all projects in the pipeline were realised, CO_2 capture capacity would expand more than eight-fold, rising from about 45 Mt today to reach nearly 400 Mt per year in 2030 (see **Figure *1***). However, so far only about 5% of announced projects have reached FID stage.

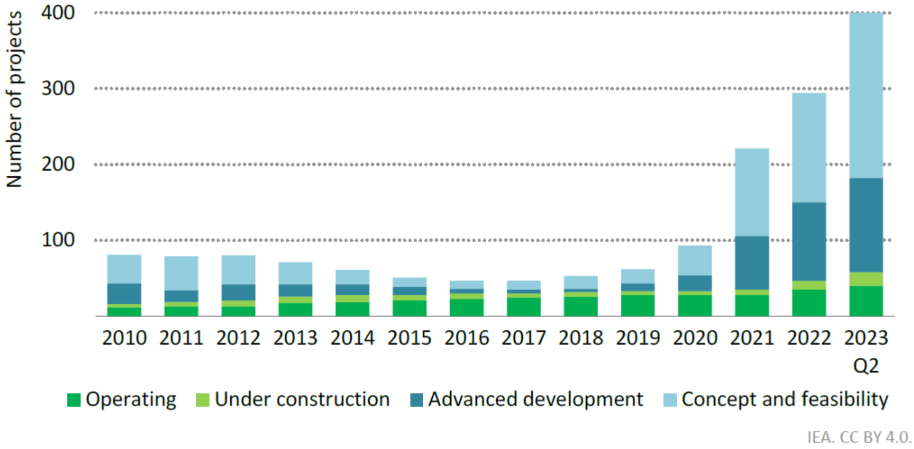


Figure 1 Global CO_2 capture project pipeline, 2010-2023

- Considerable progress has been made in recent years to address pressing innovation gaps, and this has resulted in upgrades in the technology readiness level of some critical clean energy technologies. Selected illustrative examples include:
  - Scaling up carbon capture via direct separation in cement production is underway (an FID taken for LEILAC-2 with production of 100 kt CO_2/year).
  - In Iceland, a first-of-a-kind (FOAK) 4 kt CO_2/year direct air capture (DAC) project has begun, storing the CO_2 underground with plans to expand to 36 kt CO_2/year as part of a broader effort to demonstrate multi-megatonne capacity by 2030. A 0.5 Mt/year plant is under construction in the United States and aims to begin operations in 2025.
- Hydrogen and hydrogen-based fuels and CCUS have an important part to play to reduce emissions in heavy industry and long-distance transport. In the 2023 NZE Scenario, they provide one-fifth of all emissions reductions between 2030 and 2050. But the part they play is smaller than in the 2021 version, particularly in the near term. This reflects slower technological and market development progress than envisaged in 2021 and stronger electrification prospects.
- While the goal of net zero energy sector CO_2 emissions by 2050 is retained, emissions to 2030 are higher in this edition of the scenario (24 Gt cp. to 21.1 Gt, also see ***Figure 2***), reflecting the extremely strong rebound in economic activity and emissions in the wake of the Covid-19 pandemic, as well as the failure to act in recent years at the speed envisaged in the original Roadmap.

	2021 version		2023 version	
	Peak warming	2100 warming	Peak warming	2100 warming
Median temperature increase (°C)	Consistent with IPCC C1 scenarios	1.4	Consistent with IPCC C1 scenarios	1.4
	2030	2050	2030	2050
Total net energy sector CO_2 emissions (Gt)	21.1	0.0	24.0	0.0
Share of unabated fossil fuels in total energy supply (%)	58%	11%	62%	11%
Total final consumption (EJ)	390	340	410	340
Solar PV capacity additions (GW)	630	630	820	820
Wind capacity additions (GW)	390	350	320	350
Share of EVs in car sales (%)	60%	90%	65%	95%
Total CO_2 capture (Gt)	1.8	7.7	1.0	6.1
Total CO_2 removal (Gt)	0.3	1.9	0.2	1.7
Installed stationary battery capacity (GW)	590	3 100	1 020	4 200
Share of electricity in total final consumption (%)	26%	49%	28%	53%
Share of H_2 and H_2-based fuels in total final consumption (%)	2%	10%	1%	8%

Figure 2 Selected indicators in the 2021 and 2023 NZE Scenarios

- Regarding comparisons with other scenarios, e.g. IPCC: Determined action, particularly in advanced economies and in large oil and gas producing countries, cause oil and natural gas emissions of both CO_2 and CH_4 to fall faster in the NZE Scenario than in comparable scenarios assessed by the IPCC. Emissions from coal fall more slowly in the NZE Scenario than in comparable scenarios assessed by the IPCC.
- Atmospheric removals through direct air capture and storage (DACS) and bioenergy with carbon capture and storage (BECCS) start to scale up rapidly and reach around 0.6 Gt in 2035 and 1.7 Gt in 2050. Total energy sector CO_2 emissions reach net zero in 2050, with residual gross emissions balanced by gross removals from the atmosphere through BECCS and DACS (see **Figure *3***). This is achieved without offsets from land-use measures.

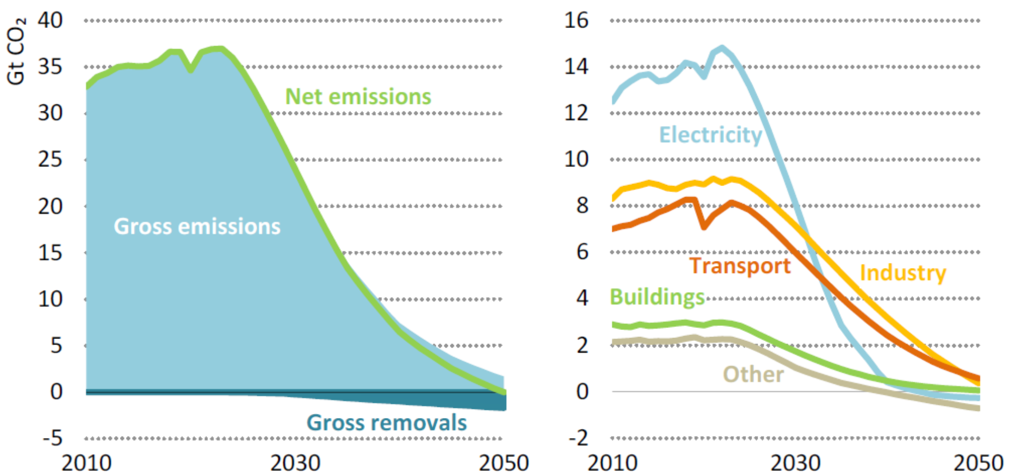


Figure 3 Energy sector gross emissions and removals, total net CO_2 emissions, and net emissions by sector in the NZE

- In the NZE Scenario, temperature rises to a peak of just below 1.6 °C around 2040, and then gradually falls to around 1.4 °C in 2100. This reduction in temperature from the peak is caused by two effects. First is strong reductions in CH_4 emissions to 2050. Second is that temperatures are also reduced after reaching net zero CO_2 emissions as the land and oceans draw down atmospheric carbon in line with the latest generation of Earth system models. These effects are consistent with the Working Group I (WGI) contribution to the IPCC's Sixth Assessment Report (AR6) and each contribute about 0.1°C of cooling between 2040-2100. The NZE Scenario therefore meets the criteria of a limited overshoot 1.5°C pathway as defined by the IPCC. By contrast, the IEA Stated Policies Scenario (STEPS) sees temperatures heading towards 2.4°C in 2100.
- There is a rapidly closing window to secure a liveable and sustainable future for all. Deep, rapid and sustained cuts in CO_2 emissions to net zero can limit future warming, but societies will have to adapt to the effects of the climate change that is already happening.
- For the period 2022 – 2050, the largest total contribution to emissions reductions in the energy sector is from solar PV and wind, which account for 25% of all cumulative emissions reductions in the NZE Scenario. In addition, measures to reduce demand through increase energy efficiency, more efficient use of materials and behavioural change together account for a further almost 25%. Expanding electrification in the transport, industry and buildings sectors provides 20% of abatement as electricity generation is progressively decarbonised. Increased bioenergy and other fuel shifts account for slightly less than 20%, and hydrogen and CCUS account for slightly less than 15% (see **Figure *4***).

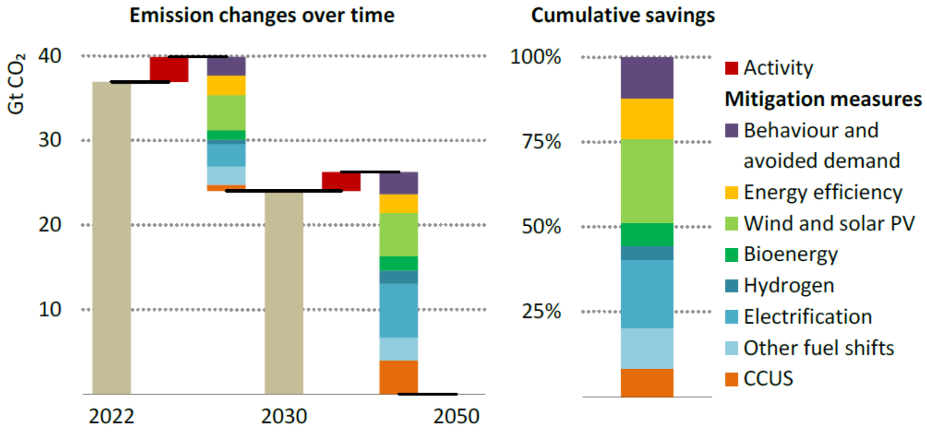


Figure 4 CO_2 emissions reductions by mitigation measure in the NZE

- The share of emissions reductions in the NZE Scenario in 2050 from technologies at either demonstration or prototype stage, i.e. not yet available on the market, has been reduced from around half in the 2021 NZE Scenario to around 35% in the 2023 version. Key selected examples include:
    - Fossil fuel-based electricity generation from facilities equipped with CCUS – an area currently with several technologies at demonstration stage – is moving more slowly than projected in 2021. The contribution of CCUS to emissions reductions in power generation by 2050 has been reduced by around 40% in the 2023 NZE Scenario.
    - Progress is evident in cement production, both on CCUS through indirect calcination, and on alternatives to conventional raw materials and clinker. CCUS applications for a broad range of chemicals are maturing from prototype to demonstration stages. The

pipeline of projects for low-emissions ammonia production has expanded rapidly since 2021, mostly electrolytic and some via steam methane reforming with CCUS.

- Total demand for fossil fuels falls by slightly more than one-quarter, or 140 EJ, by 2030. Coal falls the most at slightly less than 75 EJ reflecting the higher level of maturity of emissions reduction technologies in electricity generation which today accounts for most coal use. This decline in coal demand is much less than in comparable scenarios assessed by the IPCC. Oil demand declines by around 39 EJ. Natural gas drops the least, around 26 EJ, partly reflecting its increasing use in combination with CCUS to produce hydrogen. The rising use of fossil fuels combined with CCUS is far smaller than the decline of unabated fossil fuels. Unabated fossil fuel demand falls by around 150 EJ to 2030, while the use of fossil fuels combined with CCUS increases by around 7.5 EJ to 2030, despite the strong push on CCUS seen in the NZE Scenario. After 2030, the pattern of energy supply continues to evolve rapidly and it is transformed by 2050. Abated fossil fuels with CCUS account for 5% of total energy supply. Unabated fossil fuels, excluding those used for non-energy purposes, decline from around three-quarters of total energy supply in 2022 to around 5% by 2050. Just under 90 EJ of fossil fuels are consumed in 2050 in the NZE Scenario. One-third of this, including 60% of natural gas and 80% of coal, is used in facilities equipped with CCUS. A further 40%, including 70% of oil, is consumed in applications where the carbon is embodied in the product and there are no direct CO2 emissions, e.g. chemical feedstocks, lubricants, paraffin waxes and asphalt. The remaining 25% is used in sectors where clean energy technologies are least feasible and cost effective, for example, oil accounts for around 20% of fuel use in aviation in 2050 in the NZE Scenario. The unabated combustion of fossil fuels results in 1.4 Gt CO_2 emissions in 2050 which are fully balanced by CDR through BECCS and DACS. The share of fossil fuels with CCUS, notably natural gas, is lower than in the 2021 NZE Scenario. This reflects a downward revision to hydrogen demand, caused in part by boosted confidence in the possibility that direct electrification can play a larger role in uses such as trucking. It also reflects a rebalancing towards electrolytic hydrogen production and away from production using natural gas with CCUS; this takes account of the slow pace of current progress on the development of CCUS. In the 2023 NZE Scenario, reduced CCUS deployment is compensated by more renewables and electrification.
- Step changes in the emissions intensity of industrial production – particularly of emissions-intensive bulk materials like steel, cement and primary chemicals – are required, and these are achieved in large part by the use of hydrogen, CCUS and direct electrification technologies (see **Figure *5***).

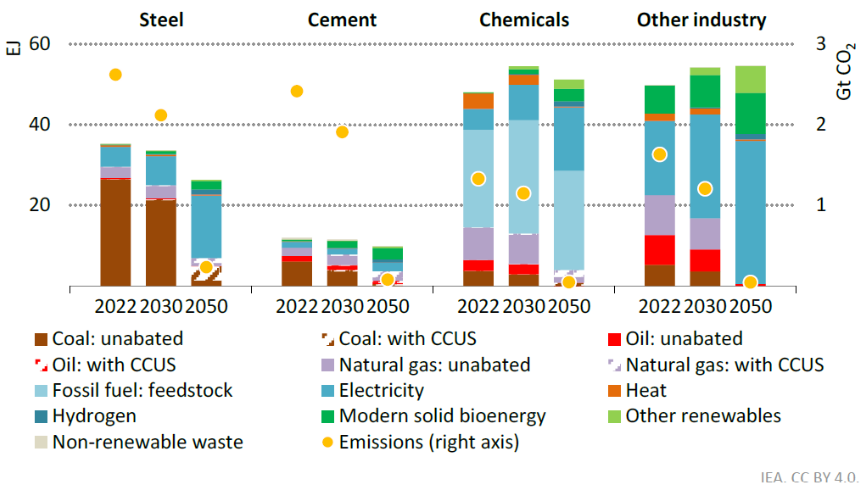
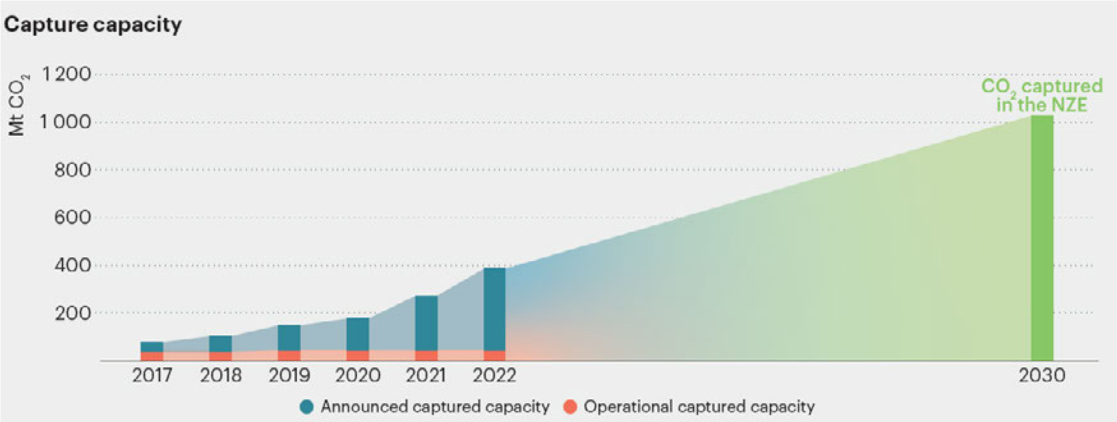
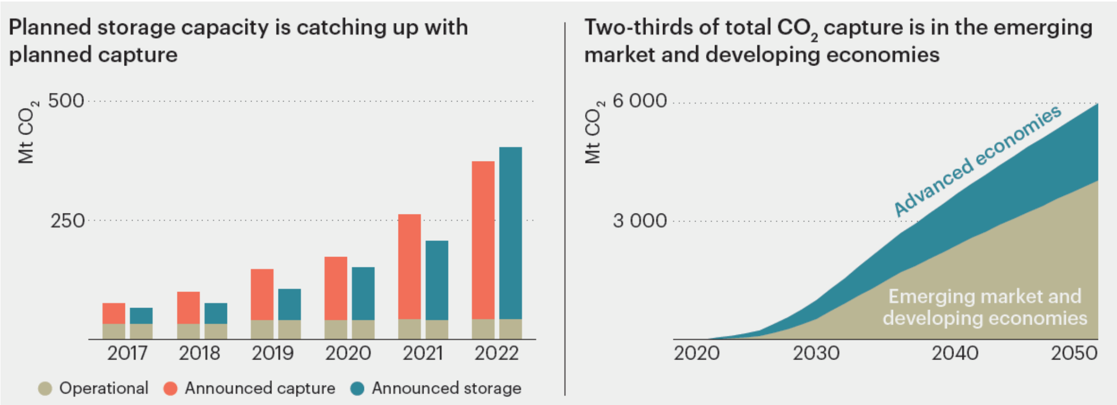


Figure 5 Final energy consumption by fuel in selected industries

- The 'Net Zero Emissions Guide' section of the report contains 1-pagers with key highlights and data for several areas/technologies. There is one for CCUS, underlining that if all announced CO_2 capture capacity is realised and the current growth trend continues, global capacity could reach NZE levels by 2030, providing 8% of cumulative emissions reductions in 2050. Reducing project lead times, particularly related to the development of CO_2 storage, will be critical to achieve those levels:





- Emerging technologies such as hydrogen and CCUS cut emissions mainly after 2030. If all announced projects for hydrogen electrolysis capacity are realised, they would provide around 70% of what is required in the NZE Scenario by 2030. Announced CCUS projects, currently mostly in advanced economies, would provide nearly 40% of what is needed by 2030 globally. A stronger policy focus on creating demand for low-emissions products and fuels is needed.
- CCUS deployment is hindered by a lack of available CO_2 storage sites. CO_2 storage capacity expands in the NZE Scenario from less than 50 Mt today to around 1 Gt by 2030 – a more than a 20-fold increase – while CO_2 pipeline infrastructure expands from around 9 500 km today to between 30 000-50 000 km by 2030 (see **Figure *6***). New hydrogen infrastructure is also necessary. If lead times for hydrogen and CCUS infrastructure projects are roughly on a par with those for previous natural gas infrastructure projects, infrastructure development may hinder the production and demand projects to which they are linked. Repurposing existing oil and gas assets, including natural gas networks, shipping terminals and offshore platforms, could help to fast track the deployment of hydrogen and CO_2 infrastructure, reduce lead times and investment costs.

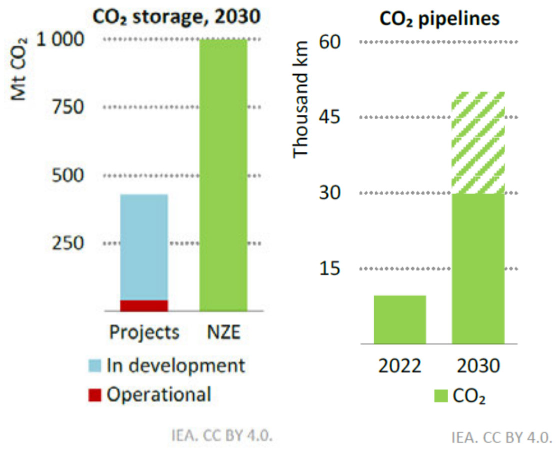


Figure 6 CO_2 storage and pipeline infrastructure needs

- The planning and permitting processes for major new clean energy infrastructure typically take three to eight years to complete before construction can start and could be longer for FOAK projects (see **Figure 7**). In the case of electricity lines and pipelines, line route plans may need to be assessed by a multitude of regulatory authorities, jurisdictions and other stakeholders. When involving new types of infrastructure, such as storage sites for CO_2, it is not always clear which regulator should be in charge of the permitting process. As large infrastructure projects often cross or impact multiple landowners, early and frequent stakeholder engagement and an appropriate communication strategy are required to minimise potential increases in lead times due to public opposition. As highlighted in the IEA Special Report on Grids (forthcoming), there is evidence of permitting bottlenecks forcing the delay of some large electric transmission line projects. However, there are some signs of recognition of the urgent need to expedite permitting of clean energy infrastructure.

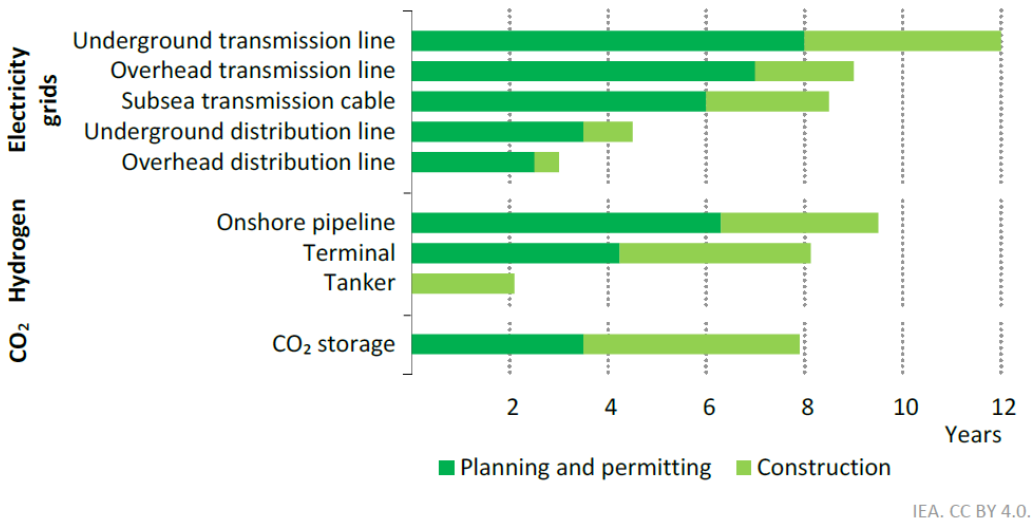


Figure 7 Typical lead times for selected infrastructure projects

- CH_4 emissions have an outsized impact on global temperatures in the short term, as CH_4 is a short-lived climate forcer with powerful warming potential, albeit with a short atmospheric lifetime. Thus, after CO_2, cutting CH_4 emissions has the single largest impact on limiting the temperature rise to 2050 in the NZE Scenario. Estimations indicate that fossil fuels were responsible for around 125 Mt of CH_4 emissions in 2022, a slight increase over 2021. Many major emitters have not yet pledged to act on CH_4. However, CH_4 abatement is very cost effective in the oil and gas sector. 40% of CH_4 emissions from oil and gas operations could be avoided at no net cost because the outlays for the abatement measures are less than the market value of the additional gas that is captured. If the record natural gas prices seen around the world in 2022 are used for the calculations instead, about 80% of the options to reduce emissions from oil and gas operations worldwide could be implemented at no net cost.

- After years of "underperformance", CCUS must now show it can deliver. So far, the history of CCUS has largely been one of unmet expectations. Progress has been slow and deployment relatively flat for years. The current level of annual CO_2 capture of 45 Mt represents only 0.1% of total annual energy sector emissions. This lack of progress has led to progressive downward revisions in the role of CCUS in climate mitigation scenarios, including the 2023 NZE Scenario. If all announced capture projects are built, around 400 Mt CO_2 could be captured every year globally by 2030 – more than eight-times current capacity. However, only around 20 commercial capture projects under development had reached the stage of FID by June 2023; and even if all announced projects proceed, they would only provide around 40% of the annual CO_2 capture of 1 Gt/year needed by 2030 in the NZE Scenario.
- More than USD 8.5 billion of public support was made available for CCUS. Ultimately less than 30% of the funding was spent, and many CCUS projects could not advance fast enough to hit the near-term spending milestones required by the support programmes. Industry needs to prove CCUS that can operate at scale. Governments should develop effective support packages to help with operating as well as capital costs and find realistic ways of managing the long-term liabilities associated with CO_2 storage. Achieving the 2030 level of global deployment of CCUS in the NZE Scenario also hinges on cutting project lead times, which currently average about six years. Essential requirements for further progress include the development of legal and regulatory frameworks and the provision of incentives for the development of CCUS.
- Today hydrogen production is more of a climate problem than a climate solution. Demand for hydrogen is rising, reaching 95 Mt in 2022, but most of it is met by emissions-intensive supply, resulting in more than 0.9 Gt of direct CO_2 emissions in 2022. There has also been some progress with low-emissions hydrogen production from natural gas with CCUS, but there is much further to go. Slower progress has led to a downward revision of the contribution of low-emissions hydrogen from fossil fuels with CCUS (see **Figure *8***).

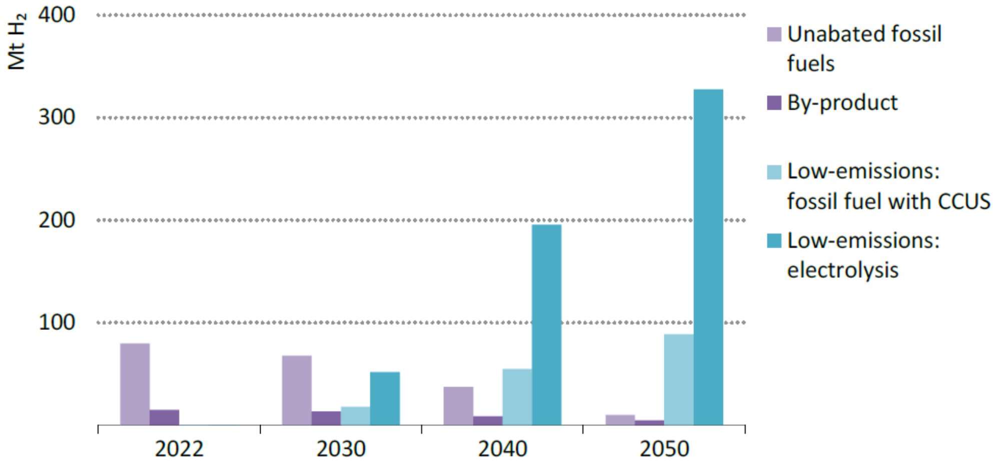


Figure 8 Global hydrogen supply by source in the NZE

- The world has already delayed too long to avoid hard choices. The NZE Scenario can only be achieved with substantial changes to operating patterns and the early closure of some existing fossil fuel-based infrastructure. The rate of reduction in oil and gas demand necessary to reach net zero emissions by 2050 is now so fast that it may imply the early closure of some existing oil and gas fields.
- In the Delayed Action Case, bringing the global increase in average temperatures back down to below 1.5 °C would require scaling up CO_2 removal from the atmosphere through BECCS and DACS to over 5 Gt CO_2 every year during the second-half of this century. The 2 Gt CO_2 removal each year through BECCS required in the Delayed Action Case is twice the amount required in the NZE Scenario and might require 135 Mha of land. The extent to which BECCS can be increased is constrained by limits on sustainable bioenergy supply as well as by the economic and logistical challenges. While the deployment of DACS is not restricted by the availability of feedstock or suitable sites, it is much more energy intensive and costly than BECCS. Capturing around 3.3 Gt CO_2 with DACS by 2100 would require around 30 EJ of energy annually. If the energy required for the deployment of DACS was provided by solar PV, this would require around 4.5 Mha of land for solar PV and DACS facilities. Removing 2 Gt with BECCS and 3.3 Gt with DACS each year by the end of the century would cost around USD 1.3 trillion per year (see **Figure *9***). Thus, DACS cannot substitute for deep emissions reductions and its use should be minimised as much as possible. However, DACS can play an important role in balancing the last remaining residual emissions and in providing climate neutral carbon feedstock.

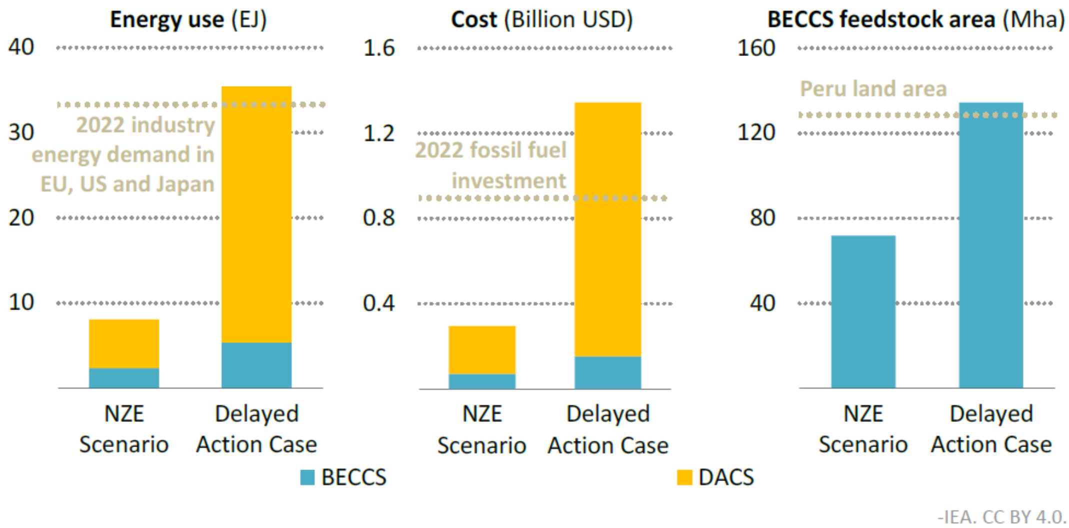


Figure 9 Requirements for CDR technologies in the Delayed Action Case in 2100

- Fossil fuel subsidies reached record levels in 2022 but are largely removed by 2030 in the NZE Scenario.
- In the NZE Scenario, 30 million new clean energy jobs are added by 2030 while close to 13 million jobs in fossil fuel-related industries are lost.
- The credibility of carbon credits has suffered in recent years as a result of market design imperfections and some cases of abuse. It is essential to ensure that carbon credits are generated from real, verified, additional and permanent emissions reductions or removals. Applying industry guidelines such as those of the Integrity Council for the Voluntary Carbon

Markets Core Carbon Principles6 and following guidance under Article 6 of the Paris Agreement should help in this respect.
- Recommended policy actions to boost clean energy demonstration include tapping into existing fora such as the IEA Technology Collaboration Programmes (TCPs) and Mission Innovation (MI), and can help share technology and policy best practice across borders.

IEAGHG comments and conclusions:

IEAGHG notes the language used in the executive summary "The history of CCUS has largely been one of underperformance". IEAGHG interprets this to mean under-deployment, as many projects have performed technically as intended, and those few that have not have been projects whose primary purpose is to test and demonstrate technologies at commercial-scale, ie to enable learning by doing to then better enable the second generation of projects.

No IEAGHG reports are cited, most references are to other IEA reports and materials. IEAGHG have not been asked to review this report, and it seems no other TCPs have reviewed it either.

References

The IEA Net Zero Roadmaps can be found here:
2021 edition:
https://www.iea.org/reports/net-zero-by-2050
2023 edition:
https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

IEAGHG 2021-IP08 'IEA Net Zero Roadmap':
https://documents.ieaghg.org/index.php/s/kpOrrfF5LWJLPWu

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