Thought Leadership

# Green hockey sticks

## Climate tech passports

A report by the UBS Sustainability and Impact Institute
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# Are climate technologies breaking through?

Deep, rapid, and viable decarbonization is possible only through climate technologies outcompeting and gradually replacing carbon-intensive incumbents. Successes exist—renewables already do, and electric vehicles are close—but most remain commercially uncompetitive, putting the brakes on fast deployment. A portfolio of solutions is needed, but those close to positive tipping points offer the highest climate bang-for-buck in the near-term.

The world is familiar with the theory of change. As solutions scale, typically their quality improves and costs drop, driving a self-reinforcing process of deployment and progress. Eventually, a new technology improves enough to outcompete an incumbent, initiating a transition from old to new. The climate transition is no different. It will involve repeating this process for a broad range of climate techs that either reduce emissions or remove them from the atmosphere, from mechanical technologies like wind turbines to rudimentary interventions that support nature.

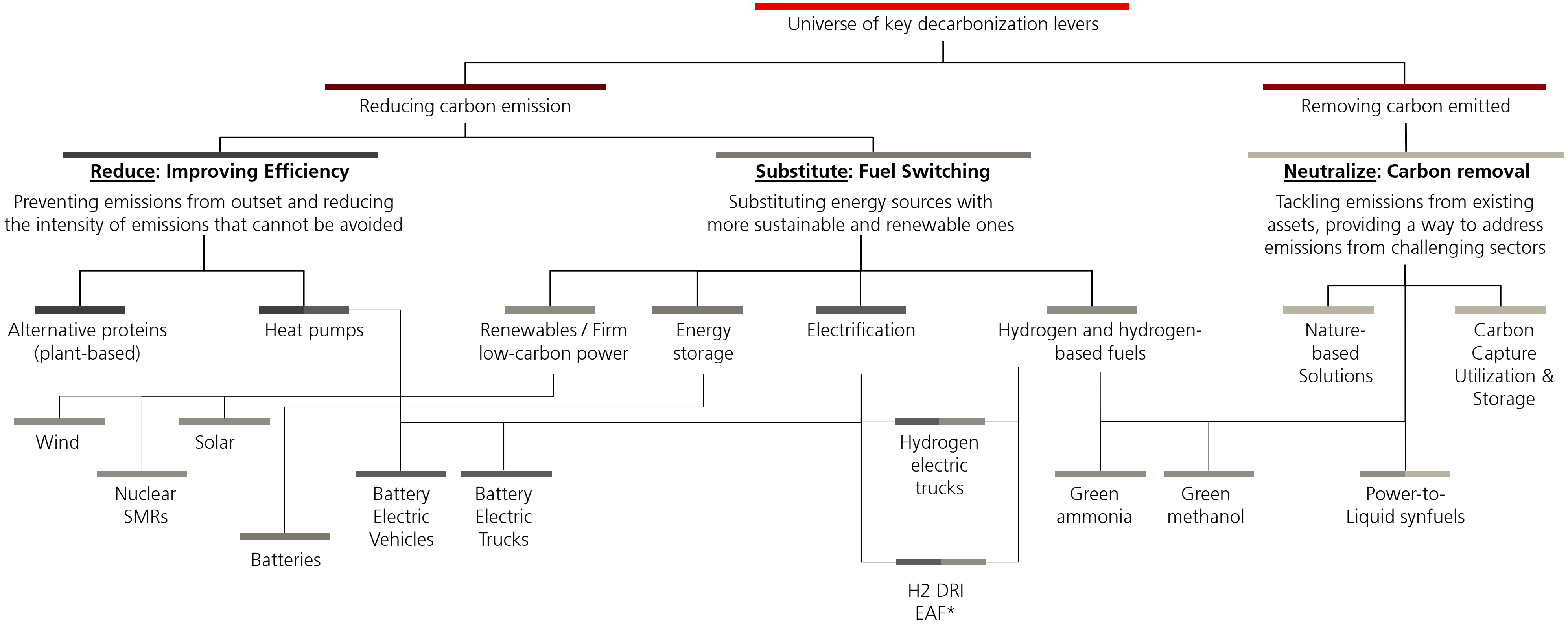
Anticipating where tipping points lie and when they may trigger is important. Policymakers need sight of these trends to inform tax, subsidy, and regulatory options. Financial markets need sight of probable risks and rewards to inform investment and lending decisions. Companies forming a transition plan need a reliable idea of climate tech's future commercial viability to plan how and where to invest today. In this vein, UBS's recent Green hockey sticks report proposes a 3-part framework that provides a what, how, and why for each climate tech: What each tech should aim for in terms of deployment and emissions reduction impact; how it can become commercially competitive to achieve those goals; and why it may or may not be moving towards a positive tipping point.

First, it defines the deployment goal for each technology over the next decade—aligned roughly to below 2°C warming—and the potential GHG emissions reductions this goal implies. Second, it defines the opportunity this goal presents in terms of total addressable market, and the implementation cost. Third, it assesses the commercial maturity of each technology via four criteria: cost, compensation, convenience, and compatibility (see Appendix for full methodology). This informs a "commercial maturity" score for each technology, reflecting its proximity to a potential tipping point after which it could scale rapidly towards its deployment goal (Figure 1).

This document contains a "climate tech passports" that summarize the methodology and findings for each climate technology complementing the report. If each of the 15 analyzed climate techs were fully deployed, they could reduce, avoid, or remove around 200 gigatons of GHG emissions—enough to meet around 70% of the 1.5°C carbon budget. Alone, they are not sufficient to meet Net Zero, but together they offer a range of powerful levers to deliver significant decarbonization over the next decade.

**Figure 1:** Key climate technologies sit across 3 levers of reduce, substitute, or neutralize

*These climate techs either reduce emissions directly—by increasing efficiencies or substituting out carbon-intensive fuels—or remove carbon dioxide from the atmosphere*



* Hydrogen-based Direct Reduced Iron (H2 DRI) steel making, coupled with an electric arc furnace (EAF)
Source: UBS

# Sector: Power

## Wind

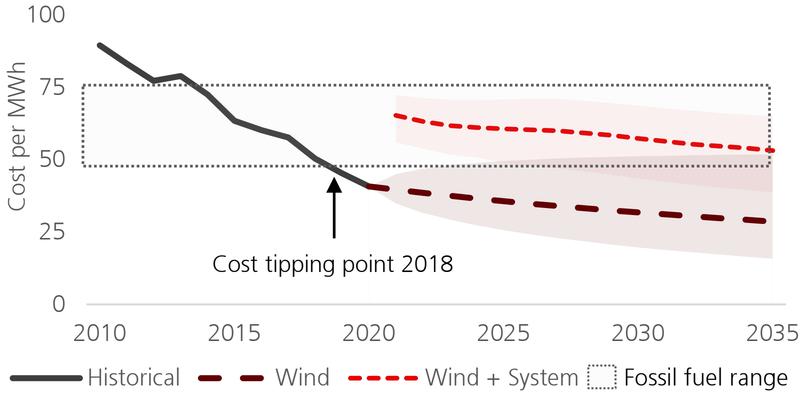
*Background*

Wind energy generated 8% of global electricity in 2023, and it accounted for 7% of new capacity additions. Over 90% of capacity is onshore wind.[1] For every doubling, its project-level costs fall 23%.[2] New wind farms passed a cost tipping point in 2018 when first they produced power at a cheaper price than natural gas. Favorable economics enables +30% penetration of wind in many electricity mixes. However, intermittent wind energy puts strain on grids; more flexibility from fast-response generation, storage, and interconnection is required to smooth supply—and this has a price tag. Accounting for these "system costs," wind is no longer cheaper than gas (see driver spotlight), but its costs are still falling and competitive. Importantly, wind farm operators often do not pay system-integration costs—they tend to be socialized—so they may not widely impact *project*-level competitiveness.

*Outlook*

Since 2020 wind has suffered from a challenging macro environment and supply bottlenecks. Going forward, policy support provides strong tailwinds to further cost reductions. Cost parity with gas including system costs is the next milestone.

## Driver spotlight—Wind energy is already competitive



Notes: Cost is the Levelized Cost of Energy; Grey shows the global average benchmark range for the unsubsidized LCOE of a new combined cycle gas turbine, midpoint to lowest values; 'No transition' scenario from Way et al (2022).
Source: Way, R. et al (2022); Nijsse, F. (2023); Lazard (2024)

## 2035 Goals[3]

*Deployment goal:*

22% of global electricity generation (18%–27%)

*Abatement potential:*

~60 Gigatons of $CO_2$

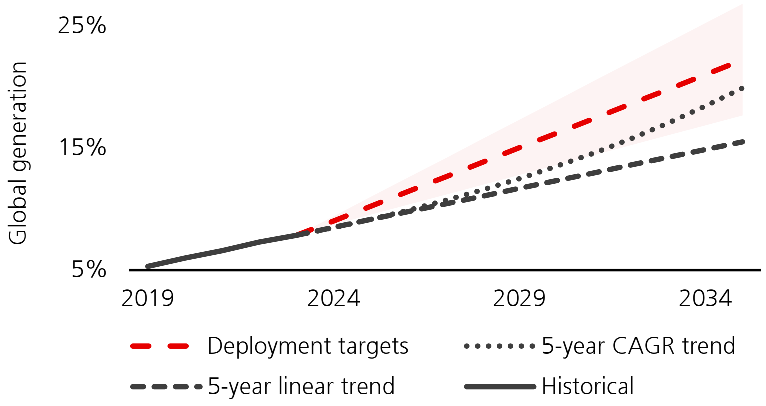
23% of 1.5oC carbon budget

*Total Addressable Market:*

USD 1.4–2.2tr in 2035

*Status:*

Right direction, likely on track for lower bound



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • New wind LCOE < new & existing gas (~USD 50/kWh, depending on location).<br>• New wind + *storage* cheaper than new & existing gas. | • New onshore has been cheaper than gas since 2018 at the global level. Offshore still needs improvement.<br>• New onshore wind + storage is competitive with gas and moving towards cost parity (~USD 90/kWh vs. ~USD 75/kWh).[4] | 4 |
| Compensation | • Growth in capacity slowed since 2020 following COVID-related project delays, subsidy withdrawal, and rising interest rates. Evidence of reliable economics needed to support aggressive project build out. | • Capacity growth bounced back with a loosening macro environment and strong policy support. Yet, growth remains below 2020 levels and high-profile project cancellations occurred in 2023. Capital costs are rising, particularly in "developing" markets. | 3 |
| Convenience | • Wind is intermittent and provides less inertia to grids, requiring additional solutions to bolster grid flexibility. | • This is not a major barrier in the long term. Competitive solutions exist—batteries, interconnection—and the buildout of renewables only improves their economics. Short term, supply-side bottlenecks exist. | 3 |
| Compatibility | • World must add or refurbish 2x the global transmission grid by 2040 (80 million km). Annual investment of USD 600bn is required by 2030.[5] | • Investment levels remain static at USD 300bn, half the required amount. 1,100 GW of wind is in a connection queue—more than today's global capacity.[6] | 2 |

## Solar Photovoltaics (PV)

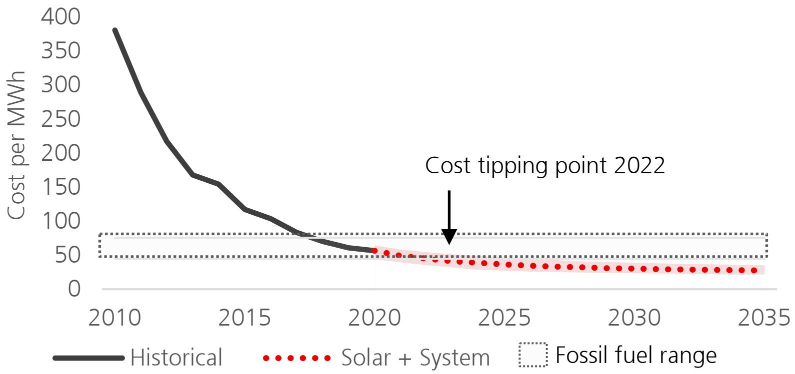
*Background*

In 2023, solar PV generated 6% of electricity and it accounted for 31% of new capacity additions. It is the fastest growing form of clean energy; 73% of all new clean power generating capacity in 2023 was solar PV.[7] Rapid growth begets fast learning; for every doubling, its project-specific costs fall 36%.[8] Solar PV passed a cost tipping point in 2022, when the average cost of producing electricity from solar became cheaper than natural gas in key markets (see driver spotlight). Like wind energy, solar PV suffers from intermittency, requiring additional storage (such as large-scale batteries) to consistently supply energy when the sun is not shining. These additional storage costs are difficult to estimate, and they reduce the competitiveness of solar in the short term. However, the cost of utility-scale batteries is falling quickly, in turn reducing the system costs of new renewables.[9]

*Outlook*

Despite recent interest rater and commodity cost rises, most forecasts see solar PV costs continuing to fall, and the new installations remain cheaper than new natural gas plants. The IEA expects this to be the case even considering system costs.[10]

## Driver spotlight—Solar PV is already competitive



Notes: Cost is the Levelized Cost of Energy; Historical data are global LCOEs, while projected data refers to key markets (Europe, the United States, and China); Fossil range is the global average benchmark for the unsubsidized LCOE of a new combined cycle gas turbine, midpoint to lowest values.
Source: Way, R. et al (2022); Nijsse, F. et al (2023); Lazard (2024)

## 2035 Goals[11]

*Deployment goal:*

28% of global electricity generation (19%–37%)

*Abatement potential:*

~80 Gigatons of CO$_2$

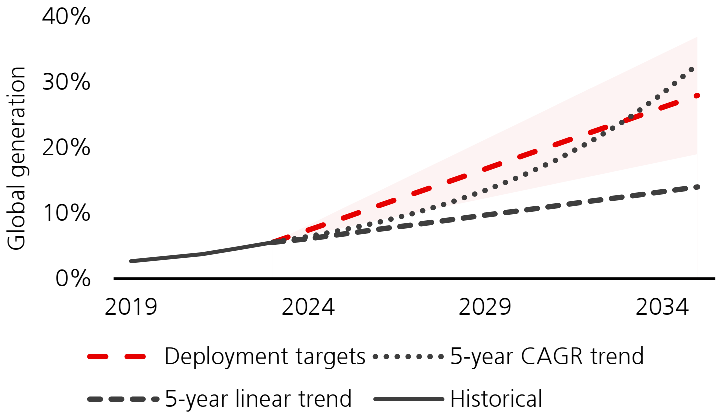
29% of 1.5oC carbon budget

*Total Addressable Market:*

USD 1.6–3.0tr in 2035

*Status:*

Right direction, likely on track for lower bound



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • New solar LCOE < new and existing gas (~USD 50/kWh, depending on location).<br>• New solar + storage cheaper than new & existing gas. | • New solar has been cheaper than gas since 2022 at the global level. Fast learning rate.<br>• New solar + storage is competitive with gas. Close to cost parity in favorable locations (~USD ~60/kWh vs. ~USD 45/kWh).[12] | 5 |
| Compensation | • Evidence of reliable economics needed to support aggressive project build out. | • Capacity grew strongly through recent macroeconomic turbulence. Large connection queue implies strong pipeline. Projects advance without subsidies in favorable locations.<br>• Most forecast growth is driven by policy rather than market drivers (such as subsidies, rather than market-based contracts).[13] | 3 |
| Convenience | • Solar is intermittent and provides less inertia to grids, requiring additional solutions to bolster grid flexibility. | • This is not a major barrier in the long term. Competitive solutions exist—batteries, interconnection—and the buildout of renewables only improves their economics. In the short term, supply-side bottlenecks exist. | 3 |
| Compatibility | • World must add or refurbish 2x the global transmission grid by 2040 (80mn km). Annual investment of USD 600bn required by 2030.[14] | • Investment levels remain static at USD 300bn, half the required amount. 1,800 GW of wind is in a connection queue—more than today's global capacity.[15] | 2 |

## Batteries

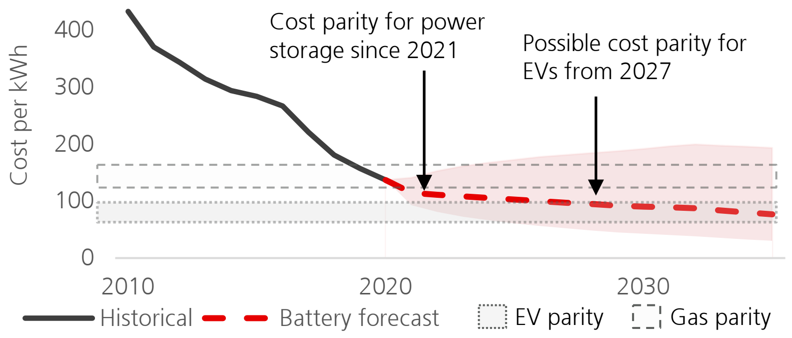
*Background*

Batteries store intermittent clean electricity, making it available when needed. They are the fastest growing commercially-available technology in the energy sector, quadrupling in volume between 2020 and 2023. Around 90% of the increase is driven by EVs, and the rest is power storage, mostly utility scale batteries that are large enough to economically feed power into grids.[16] Costs fall around 19% for every doubling of capacity.[17] Most batteries today are Lithium-Ion (Li-Ion), and although they are used in billions of electronic personal devices, the energy sector accounts for over 90% of demand.[18] Even so, innovation constantly produces new chemistries and designs are improving battery density and weight—storing more energy, supplying more power, and increasing total charge and discharge cycles. Such improvements lead to cascading cost reductions in other climate techs; for cheaper batteries means cheaper EVs (see driver spotlight).

*Outlook*

Announced projects should quadruple capacity by 2030.[19] Growing renewables and EVs deployment provides strong growth drivers. Critical mineral demand may prove a bottle neck; higher recycling and primary supply is likely to minimize constraints.[20]

## Driver spotlight—Battery costs tracking to parity



Notes: EV parity reflects the estimated battery price for EV cost parity with conventional vehicles in the US, from the ICCT; Gas parity is the global average benchmark for the unsubsidized LCOE of a gas peaking plant, midpoint to lowest values, providing a competitiveness proxy for utility-scale batteries; 'No transition' scenario from Way et al, which covers Li-ion packs across transport and power (short duration 4-hour, and long-duration multi-day Va-redox flow batteries).

Source: Way, R. et al (2022); ICCT (2024); Lazard (2024)

## 2035 Goals[21]

*Deployment goal:*

~24,000 GWh of capacity (4,700–52,000)

*Abatement potential:*

Enable ~50 Gigatons of $CO_2$

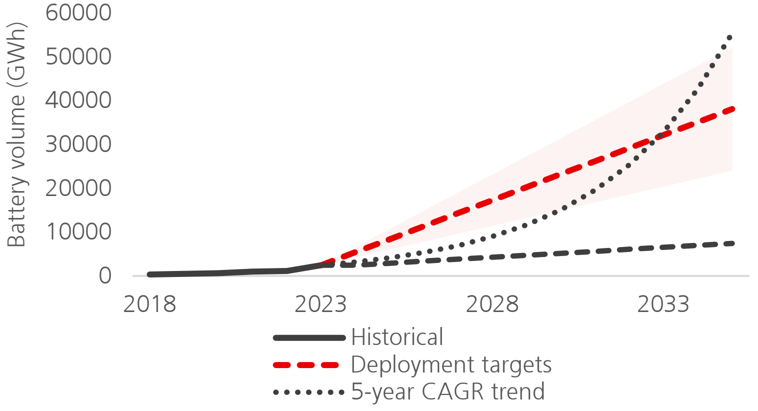
18% of 1.5oC carbon budget

*Total Addressable Market:*

USD 1.1–2.3tr in 2035

*Status:*

Right direction, likely off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • Costs per kWh < ~USD 100/kWh (enabling price parity for EVs with ICE).<br>• Costs per kWh < ~USD 110/kWh (enabling price parity of utility-scale batteries with gas peaking assets). | • Batteries passed the point of cost parity with gas peaking assets around 2021, and they're tracking towards the USD 100/kWh. Yet, they are more expensive than wind or solar on levelized basis. They remain vulnerable to swings in commodity prices.[22] | 3 |
| Compensation | • Evidence of reliable economics needed to support aggressive project build out. | • Over capacity in global manufacturing already generates low margins.<br>• Utility-scale batteries heavily reliant on policy incentives. Business case improves past 2030, more flexibility needed.[23] | 2 |
| Convenience | • Energy density continues improving to facilitate EVs with ranges between 300–500km.[24]<br>• Long duration utility-scale batteries, capable of discharging over multiple days, needed for vital flexibility. | • Sales-weighed average range of new battery EVs was ~350km in 2023, compared to around 600km for conventional vehicles.[25] Improvements since 2020 have been sluggish.<br>• Redox flow batteries could provide multi-day storage, but remain expensive, partly due to reliance on vanadium. | 3 |
| Compatibility | • Supply of critical minerals needs to diversify and remain robust, demand should fall. | • Not a long-term issue: Critical mineral demand likely to peak in 2030s due to higher recycling rates, new battery types, etc.[26] | 4 |

## Nuclear Small Modular Reactors (SMRs)

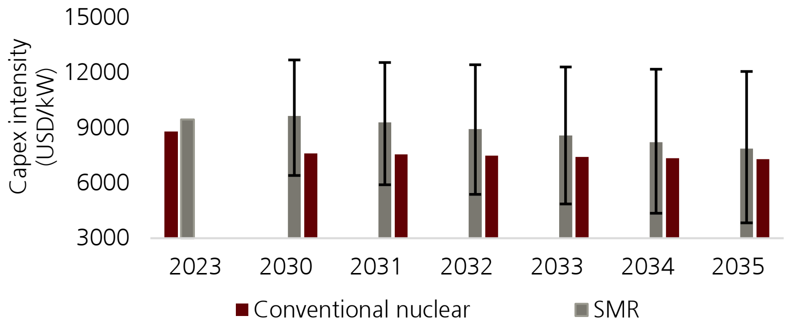
*Background*

Nuclear energy's contribution to global electricity gradually fell from 17% in 2000 to 9% in 2023.[27] However, it provides a reliable source of baseload power which emits zero direct emissions, stabilizing future electricity grids dominated by intermittent renewables. Aside from other issues, its economics are particularly tricky; production costs rose 26% over the last decade.[28] Advances in "factory built" miniature nuclear fission plants, known as SMRs, could offer a route to reversing this trend. They typically have a capacity of 300 MWs—about a third of conventional reactors—and their small size may enable Henry-Ford-style production, standardizing the complicated project management that comes with conventional plants. A small land footprint also enables more use cases. That said, SMRs remain commercially immature and largely untested.[29] There are only 3 in operation today, and their unit costs remain larger than conventional nuclear.[30]

*Outlook*

Relative cost improvements are only likely beyond 2035, limiting SMR rollout over the next decade to below 1% of global electricity generation. Incentives to deploy first-of-a-kind designs will shape the pace of cost improvement; public incentives are becoming increasingly available in the United States and Europe.[31]

## Driver spotlight—High SMR capital-intensity



Notes: US example; definition of SMR is 600MW here, but conventional definitions are 300MW.
Source: NREL (2024)

## 2035 Goals[32]

*Deployment goal:*

0.1% of global electricity generation (0.09%–0.15%)

*Abatement potential:*

~0.2 gigatons of $CO_2$

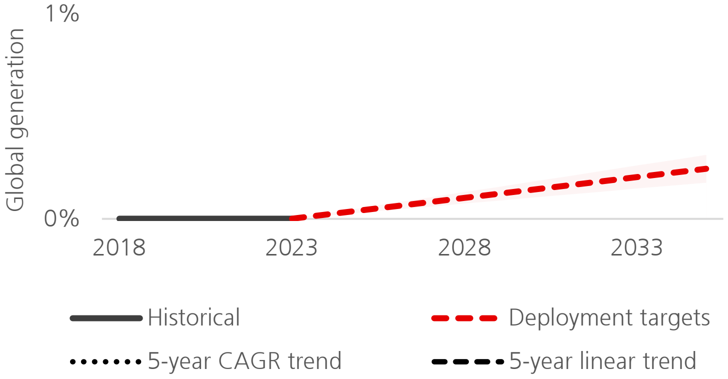
0.1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.04–0.12tn in 2035

*Status:*

Right direction, clearly off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • SMR LCOE < conventional nuclear (~USD 190/MWh).<br>• SMR capex intensity < conventional nuclear (~USD 9000/kWh). | • Data is limited due to few commercial projects.<br>• SMR generation and capex intensity could equalize with conventional nuclear by the late 2030s.[33]<br>• Yet, there is uncertainty given conventional nuclear's high and gradually rising costs. SMRs are based on similar technology. | 1 |
| Compensation | • Evidence of reliable economics needed to support project build out. | • SMRs are at the early innovation stage. There are around 70 reactor designs, of which ~10% are expected to commercialize. Incentives will drive first-of-a-kind projects over the next decade.[34] | 2 |
| Convenience | • SMRs provide reliable and constant power output to complement variable renewables.<br>• Commercialized SMR designs emerge that can flexibly co-locate with demand. | • Grid flexibility services will become only more valuable as more renewables penetrate grids. Over flexibility options, e.g., demand-side response, exist but aren't scaled; SMR's supply-side benefits are known. Although uncommercialized, the small land footprint and capacity of SMRs means they can locate by industrial hubs, unlike large nuclear plants. Such flexibility increases their use cases.[35] | 4 |
| Compatibility | • Grid constraints are overcome via investment infrastructure. | • See solar and wind passports. Electrification of the economy needs more investment in grids. | 3 |

# Sector: Transport

## Light-duty road Battery Electric Vehicles (BEVs)

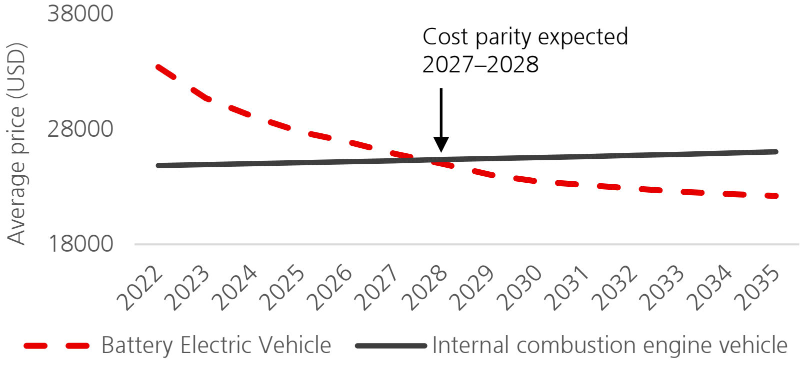
*Background*

Behavior change is an important lever to reduce GHG emissions from transport, but electrification is necessary for full decarbonization. The lifetime emission reduction of BEVs varies by region due to the carbon-intensity of the electricity used to charge them. In Europe, it is 60–70%, whereas it is as little as 20% in China and India (but still positive), where more coal is used to generate electricity.[36] Electrification is proceeding at pace in light-duty road vehicles; In 2023, BEVs accounted for 18% of new car sales, and 13% of new 2/3-wheeler sales. BEVs are getting cheaper, and generally have lower costs over their whole lifetime than conventional vehicles, but upfront purchase prices remain high.[37]

*Outlook*

Purchase costs are falling as governments introduce purchase subsidies and supply mandates, competition intensifies, battery costs fall, and secondhand markets develop.[38] This, together with improving performance, should accelerate deployment. Short-term disruptions include commodity cost spikes (raising battery prices), the withdrawal of subsidies before price parity, and low public charger deployment.

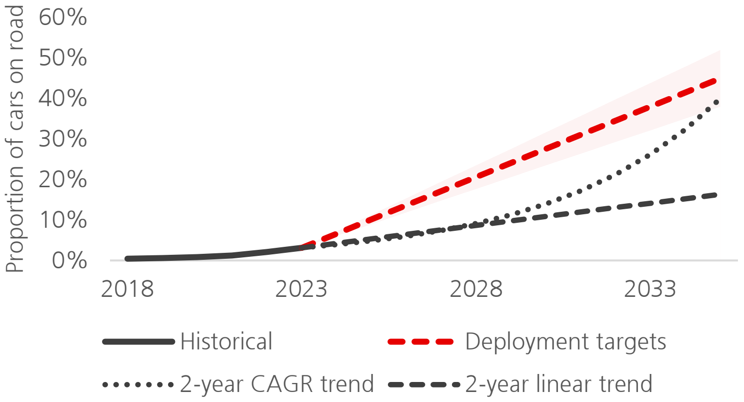
## Driver spotlight—Tracking to cost parity



Notes: Sales-weighted average retail price of small battery electric vehicles in key markets (EU, US, and China); price parity earliest in China, later in EU and USA.
Source: ICCT (2023); ICCT (2021); BNEF (2021)

## 2035 Goals[39]

*Deployment goal:*
45% of cars on the road (38%–52%)
*Abatement potential:*
~15 gigatons of $CO_2$
5% of 1.5oC carbon budget
*Total Addressable Market:*
USD 2.7–3.6tn in 2035
*Status:*
Right direction, likely off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • Reach cost parity on upfront purchase price for BEVs in all major regions. This drives consumer decision making more than lifetime cost. | • Parity has been reached in some key markets. In China, BEVs were 14% cheaper than conventional vehicles in 2023, but were 60% more expensive in the US, and more expensive in most European markets. Global parity expected in late 2020s.[40] | 4 |
| Compensation | • Evidence of reliable economics needed to support continued deployment once purchase subsidies are withdrawn. | • The industry is entering a phase of intense price competition. In cases, EV prices rose 2018–2022 due to larger battery packs.[41]<br>• But subsidy support is growing. Demand drivers are strong; many markets have phase-out dates for 2030s.[42] | 3 |
| Convenience | • BEVs require average driving ranges between 300–500km.<br>• Equivalent number of BEV models needed to conventional vehicles. | • Sales-weighed average range of new battery EVs was ~350km in 2023, compared to around 600km for conventional vehicles.[43]<br>• 590 BEV models available in 2023, 5% annual growth while conventional models declined 3%. Equal numbers expected before 2030.[44] | 3 |
| Compatibility | • Adequate public charging infrastructure required—around 17 million by 2030.[45] | • A significant but closing bottleneck. 36% annual growth in the global public charger network from 2019 to 2023, reaching 3.9mn chargers. At this rate, the target is met before 2030.[46] | 3 |

## Heavy-duty road Battery and Hydrogen Electric Trucks

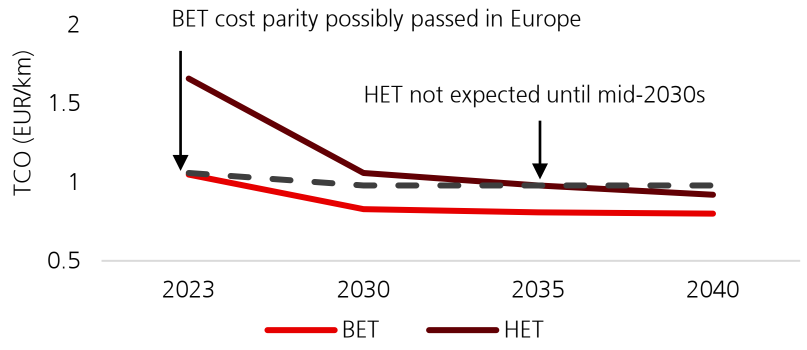
*Background*

Diesel is hard to replace in trucking; its high energy density is perfect for transporting heavy loads over long distances. The main pathways to decarbonization are battery electric trucks (BETs) and hydrogen electric trucks (HETs) powered by fuel cells.[47] Globally, BETs accounted for ~1% of new truck sales in 2023. Data on HETs sales is patchy but almost certainly very small—in 2023, around 100 HETs were sold in Europe, compared to around 2,500 BETs.[48] BETs have attractive operational features—quiet, high torque and able to recover energy lost in breaking—but batteries have a lower energy density than diesel, requiring heavy battery packs on all vehicles. They also require charging, which requires significant infrastructure investment. HETs have less favorable features. They can refuel quickly if hydrogen is available, but clean hydrogen is expensive, and little transport infrastructure exists. The hydrogen itself must be liquified or stored as a gas at high pressures, requiring significant energy and equipment.[49]

*Outlook*

BETs are expected to reach cost parity with diesel trucks in most markets in the mid to late 2020s in urban segments, and mid to late 2030s for the regional and long haul. HET price parity is expected beyond 2040.[50]

## Driver spotlight—Cost parity for BET and HET



Notes: TCO = Total Cost of Ownership; Chart applies to Europe only and heavy-duty regional trucks, and it reflects the underlying assumptions of the relevant scenario.
Source: MPP (2022)

## 2035 Goals[51]

*Deployment goal:*

Trucks on the road: 43% for BETs, 2% for HETs

*Abatement potential:*

~14GT for BETs, ~4GT for HETs

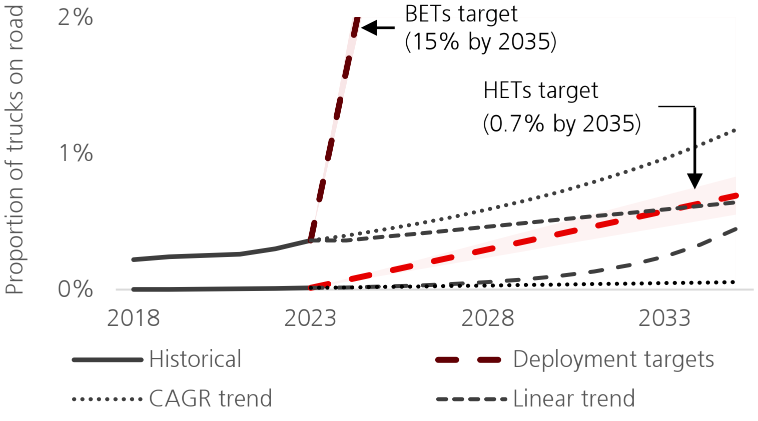
~7% 1.5oC carbon budget

*Total Addressable Market:*

USD 0.4–0.5tn for BETs USD 0.02–0.2tn for HETs, in 2035

*Status:*

Both right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) | |
|---|---|---|---|---|
| | | | BETs | HETs |
| Cost | • Achieve Total Cost of Ownership advantage for BETs and HETs over diesel trucks for all use cases. | • BETs are near parity in most urban markets, tracking towards cost parity by the early 2030s in "first-mover" markets.<br>• HET price parity expected after 2040.[52] | 2 | 1 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • BETs models continue to emerge—840 were announced or available in 2023. Profitability should rise as supply chains and manufacturing matures, and innovation reduces costs.[53]<br>• Given low sales volume and models, it is likely near-term revenue pools are small. | 2 | 1 |
| Convenience | • BETs and HETs have ranges of >500km, meeting long-haul requirements. | • Current BET and HET ranges are ~300–500km, one-third that of diesel, but well suited to regulated 4–5h driving with regular stops.[54] Weight of battery/fuel cells a low constraint; volume matters. | 2 | 1 |
| Compatibility | • ~2.5 million chargers needed by 2035, ~25% high speed + focused on high-traffic routes and industrial hubs.[55] | • Buildout of public charging infrastructure is low on long-hauls but progressing in urban segments.<br>• Only early planning of initial H2 networks; e.g., Europe has ~50 refueling stations.[56] | 2 | 2 |

## Aviation power-to-liquid (P-to-X) synthetic fuels

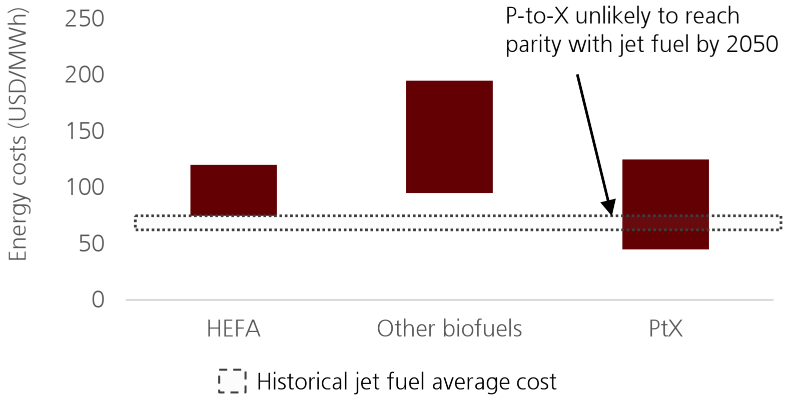
*Background*

Decarbonization of aviation will be driven by energy efficiency, new plane types (hydrogen and battery electric), and sustainable aviation fuels. New plane types are limited by technical constraints, so sustainable aviation fuel is expected to provide 65% of 2050 final energy demand in a Net Zero scenario.[57] Sustainable Aviation fuels include bio-derived fuels and synthetic P-to-L fuels. Bio-derived fuels are likely to face supply constraints.[58] This leaves P-to-L fuels as the primary decarbonization solution, which are produced by combining green hydrogen with carbon dioxide. It produces a synthetic hydrocarbon that can “drop into” existing planes as a blend with fossil kerosene, producing few emissions compared to the conventional jet fuel it displaces. P-to-L fuels are under 0.1% of aviation fuel today, remain commercially immature, and they’re 3–9x more expensive than historical jet fuel.[59]

*Outlook*

Few projects exist, but some 30 sit in the pipeline that could generate over 1.3bn gallons by 2030.[60] This will produce vital learnings to reduce costs, but most analyses see P-to-L fuels commanding a premium until at least the late 2040s.

## Driver spotlight—Cost of P-to-X compared to biofuels



Source: MPP (2022)

## 2035 Goals[61]

*Deployment goal:*

6% of aviation fuel mix by 2035

*Abatement potential:*

~0.5 gigatons of $CO_2$

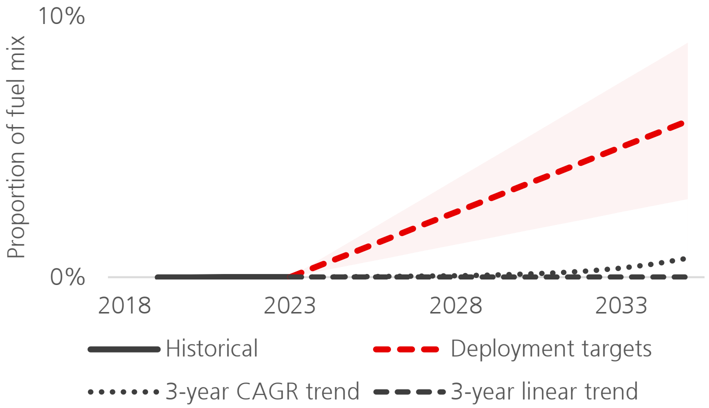
>1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.01–0.03tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • P-to-L fuel competitive with historical jet fuel costs in favorable locations (i.e., where green hydrogen costs are lowest). | • P-to-L fuels should remain more expensive than jet fuel by 2050 (1–2.5x) without a high carbon price (>USD 200/ton) and highly ambitious green hydrogen price point (>USD1/kg).[62] | 1 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • High costs of P-to-L limits revenue potential.<br>• However, there is a sizeable pipeline of P-to-L projects, and future P-to-L blending mandates (1.2% for 2030 in the EU) and offtake agreements shore up future demand.[63] | 2 |
| Convenience | • P-to-L fuels can fully drop into operational planes, avoiding the need for significant new infrastructure or types of plane. | • Current plane engines can blend up 10-50% of fuel with SAF. Fully SAF compatible models are already in the market, and are expected to replace current stock with asset turnover.[64] | 4 |
| Compatibility | • Infrastructure in place to deliver P-to-L fuels to airports.<br>• Reliable and sustainable supply of $CO_2$ needed to produce P-to-L fuels. | • P-to-L fuels use existing fueling infrastructure, avoiding replacement or retrofit costs.<br>• Needs supply of captured $CO_2$; the existing removals and transport industry is nascent, but it will grow over time. | 4 |

## Shipping green ammonia and methanol fuels

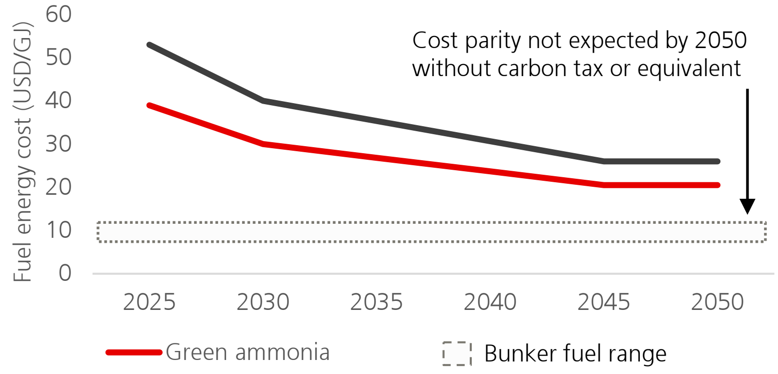
*Background*

Long-haul shipping will be decarbonized through a combination of efficiency improvements and sustainable fuels displacing carbon-intensive bunker fuel. Green methanol and ethanol will play the largest role, given constraints around sustainable biomass supply, and hydrogen's volumetric density.[65] Green ammonia is produced by combining green hydrogen with nitrogen. It can be combusted in boilers to produce steam, or to run hydrogen fuel cells. Green methanol is produced by combining green hydrogen with carbon. It is a liquid alcohol, which can be used to run internal combustion engines or fuel cells. Both fuels account for under 1% of consumed fuel.[66]

*Outlook*

Green methanol has a head start on ammonia—it is more mature, and so more widely used in shipping. New zero-emission ship purchases are mostly for methanol-compatible. Yet, green ammonia is widely expected to dominate future; it is already lower cost, and this gap will grow given methanol depends on expensive carbon removal technologies.[67]

## Driver spotlight—Cost of ammonia and methanol



Notes: Historic bunker fuel range relates to very low sulfur fuel oil for 2020, prior to recent volatility; ammonia and methanol fuel costs from the UMAS low-cost scenario.
Source: UMAS (2023); IEA (2020)

## 2035 Goals[68]

*Deployment goal:*

Ammonia 14% and methanol 3% of shipping fuel mix 2035

*Abatement potential:*

Together ~1 gigaton of $CO_2$

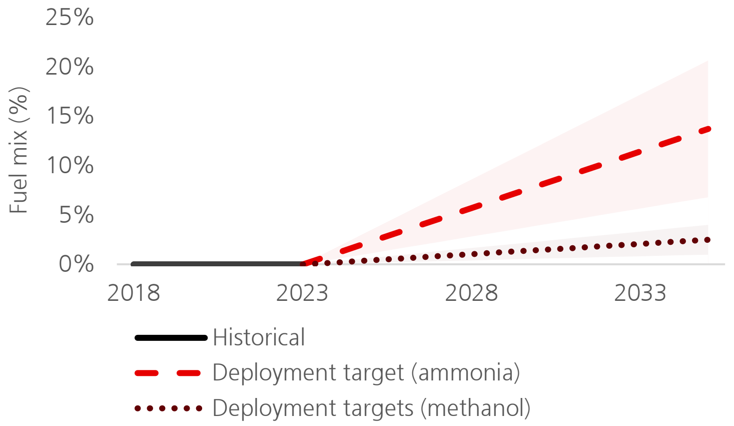
>1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.01–0.05tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) | |
|---|---|---|---|---|
| | | | Ammonia | Methanol |
| Cost | • Cost parity for green ammonia and methanol with bunker fuel. | • Running vessels on ammonia and methanol will cost ~1.5x and ~2.5x more than conventional vessels by 2035. Parity for ammonia possible by 2035 with carbon price >USD 150/ton and highly ambitious green hydrogen cost (<USD 2 / kg).[69] | 2 | 1 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • Ship operators have ordered nearly 300 vessels. However, few have secured reliable supplies of fuels. No zero-emission shipping fuel plants are operating, but four are financed.[70] | 2 | 2 |
| Convenience | • Ammonia- and methanol-ready ship models emerge. | • First ammonia-ready ships from 2026, 11 orders in 2023. First methanol-ready ships from 2024, over 100 orders.<br>• Order book is only 25% of needed vessels for decarbonization goals. Shipyards have ~2–3 year wait time for new output.[71] | 4 | 4 |
| Compatibility | • Major ports install the refueling infrastructure. | • Multiple ports plan for new facilities. Due to production costs, ammonia is likely to be globally traded, methanol bunkered in key hubs.[72] | 4 | 1 |

# Sector: Food and Agriculture

## Alternative proteins

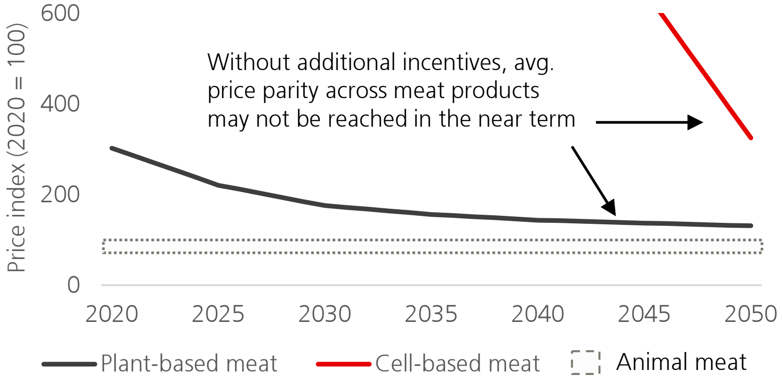
*Background*

Multiple levers are needed to decarbonize food and agriculture. Alternative proteins are included here given their standardized production could generate S-curve deployment dynamics, and they emit ~95% fewer emissions than animal-derived protein.[73] Plant-based alternative proteins are the most economically mature type and the focus. Other types include micro-organism- and animal-cell-based alternative proteins, which are more expensive than plant-based proteins but share similar technologies, so learnings in one type could drive cost reductions in others. Alternative proteins are niche, making up just 2% of the global protein market in 2020, although they are rapidly growing in some markets.[74]

*Outlook*

Survey evidence suggests consumers expect improvements in taste, texture, and smell before alternative proteins are considered substitutable with meat. Most forecasts expect market share to hit between 10-30% of the protein market by 2035, but this hinges on cost improvements.[75] Premiums in the US range from 43% for meat to 7% for butter, but several products may reach price parity by 2030.[76]

## Driver spotlight—Alternative proteins are expensive



Notes: Meat types include poultry, ruminant, and monogastric; excludes dairy, which is a much cheaper alternative protein that may reach price parity sooner; average price across meat types is used; price index = price of animal meat in 2020; assumes no tax on animal meat.
Source: Inevitable Policy Response (2023)

## 2035 Goals[77]

*Deployment goal:*

13% of protein market by 2035

*Abatement potential:*

~5 gigatons of $CO_2$

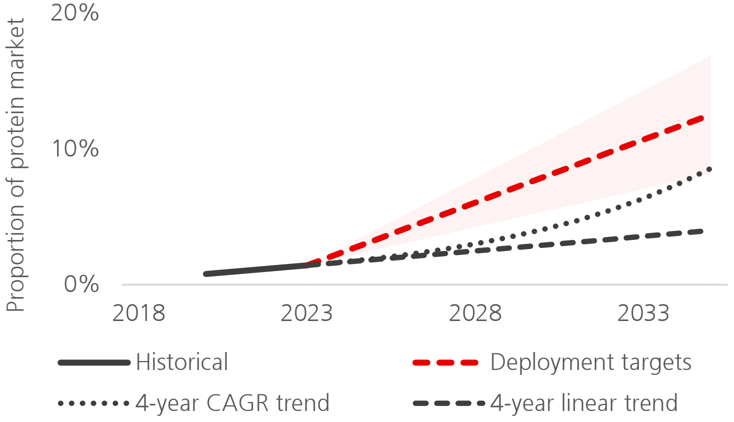
~2% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.2–0.4tn in 2035

*Status:*

Right direction, likely off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | - Cost parity between alternative proteins and animal-derived protein in high-consumption markets. | - Previous forecasts estimated price parity by 2023, but this did not materialize.[78] They remain more expensive than animal proteins across products. More evidence is needed on their learning rate. | 2 |
| Compensation | - Evidence of reliable economics needed to support continued deployment. | - Alternative proteins show strong growth across some food products, like milk, but alternative meat product sales remain stagnant. There were high-profile withdrawals of products from key markets in 2022 and dedicated alternative protein companies have struggled recently.[79] | 2 |
| Convenience | - Appeal to mass market by mimicking animal protein in taste and texture, as well as overcoming nutritional content concern. | - Just 13% of consumers in key markets eat alternative proteins exclusively; 27% state they would if health, nutrition, and taste improve.[80] | 3 |
| Compatibility | - Alternative protein products are widely available in stores and in restaurants. | - Alternative protein products exist in most fast-food chains and grocery stores. Presence in other restaurants should spread as costs fall and consumption rises. | 4 |

## Green fertilizer

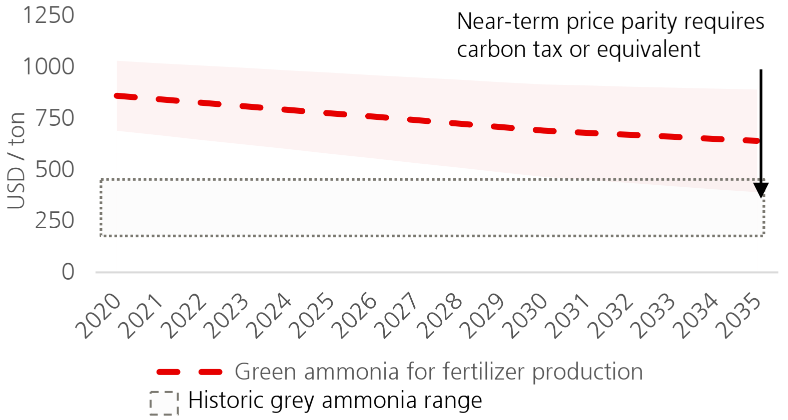
*Background*

Synthetic fertilizers are responsible for around 5% of global GHG emissions. Around 2% comes from its energy-intensive production. The remaining 3% is produced when fertilizers are used; nitrogen encourages soil bacteria to release nitrous oxide—a potent GHG—and other processes release further GHGs.[81] Optimizing fertilizer use is a key lever to reduce its emissions, but the focus here is on producing clean fertilizer upstream of its use, because this is technology-driven and could show S-curve dynamics. While emissions from ammonia production can be reduced by capturing CO$_2$, producing "blue ammonia," the largest emission reductions lie in manufacturing it with renewable electricity and hydrogen to make "green ammonia." Green ammonia is typically 2–4x more expensive than natural gas-based ammonia today, depending on the region, due to hydrogen costs.[82]

*Outlook*

Green fertilizer costs are rapidly falling due to cheaper equipment and renewable energy. Price parity is expected in the cheapest markets by 2026, a more widely in the early 2030s. The challenge is developing capacity and stimulating demand.[83]

## Driver spotlight—Green ammonia price parity is far



Notes: Upper range relates to higher cost projects today, while the low range is from projects in more advantaged regions.
Source: MPP (2022)

## 2035 Goals[84]

*Deployment goal:*

45% of fertilizer market by 2035

*Abatement potential:*

~0.7 gigatons of CO$_2$

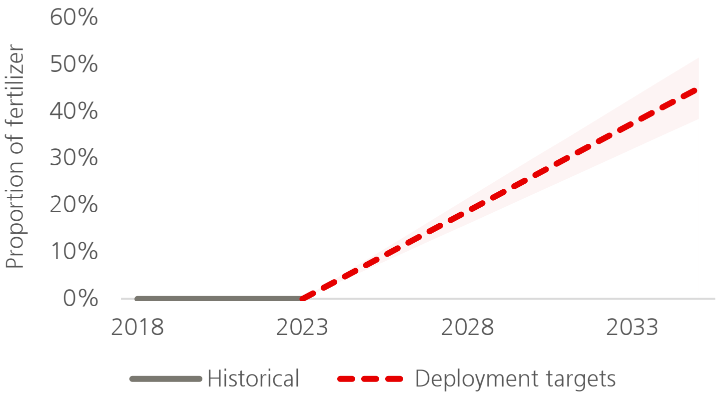
>1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.15–0.2tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • Cost parity of new green ammonia with the historical average price of natural gas-based ammonia (USD 200–400/ton). | • Green ammonia currently > USD 900–2000/ton compared to >USD 200–500/ton for natural gas-based ammonia.[85]<br>• On track for cost parity in low-cost regions by 2026, and over half of markets by 2035. | 3 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • Clear pipeline for new green ammonia plants: 185 projects, 45 with off taker agreements, 15 under construction.[86]<br>• Demand is low. Off taker agreements are not always leading to financed projects. Requires policy incentives and corporate demand.[87] | 2 |
| Convenience | • Green fertilizer substitutes conventional fertilizer. | • Green ammonia is identical to conventional ammonia; one can frictionlessly replace the other, requiring no change in downstream practices or assets. | 5 |
| Compatibility | • Production capacity, transport and storage infrastructure required to transport green ammonia from low-cost production hubs to demand centers.<br>• Expansion in renewables and hydrogen production. | • Renewables capacity expanding and electrolyzers costs for hydrogen production falling quickly.<br>• Can be transported/stored easily, but exporting and importing infrastructure needed.[88] | 3 |

# Sector: Carbon Removals

## Valuing nature-based solutions

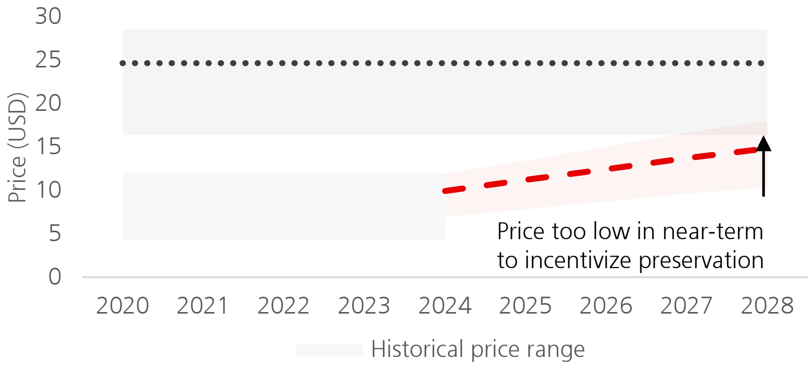
*Background*

Land-use change accounts for around 10% of global GHG emissions. Conversion of land for deforestation-linked commodities is the primary driver of ecosystem loss in many areas—one study estimates it is responsible for at least 90% of deforestation in tropical areas.[89] Mechanisms that place a value on nature can promote land protection if they are credible and offer competitive payoffs. These can include ecotourism and payments for ecosystem services, but the focus here is on credible nature-based credits on the carbon market, given recent positive market and policy signals. Credits linked to nature-based solutions were around half of the voluntary carbon market from 2021 to 2022, growing from 28% in 2019.[90]

*Outlook*

Better transparency and credibility is needed to appeal to a wider pool of mostly corporate buyers (e.g., robust additionality, valuing co-benefits). Recent price increases for high-integrity credits imply buyers are focusing more on quality. This shift is also being reflected in tighter market standards. Forecasts are generally bullish on growth prospects due to rising corporate demand to meet climate goals.[91]

## Driver spotlight—Required value of credits



Notes: Indicative only; the gap between the required and current/forecast price provides a rough proxy for the value to landowners of either converting land to produce physical commodities, or conserve it to generate nature-base carbon credits; forecast relates to credit prices for jurisdictional REDD+ projects; current price relates to REDD+ credit fluctuation.

Source: Kindermann, G. et al (2008); McCall-Landry, D. et al (2024); UBS analysis.

## 2035 Goals[92]

*Deployment goal:*

Additional 2.4 gigatons of $CO_2$ a year by 2035

*Abatement potential:*

~18 gigatons of $CO_2$

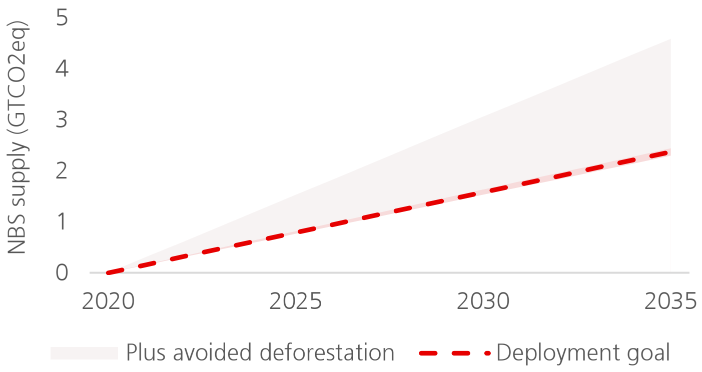
~7% of 1.5oC carbon budget

*Total Addressable Market:*

~USD 0.1tn in 2035

*Status:*

Right direction, likely off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost (price of credits) | • Value of preserving land (to landowner) > value of converting land for other purposes.<br>• Taxes/fines to lower payoff of deforestation-linked commodities. | • Recent rises in credit value; e.g., the price of forest and land-use credits rose 75% from 2021 to 2022. Yet, large gulf between required value and current value. Price paid on international markets ~one-third of agricultural commodity prices.[93] | 1 |
| Compensation (reliability of cash flow) | • Voluntary carbon market is liquid, with consistently high and stable quality credit prices for landowners to earn a reliable and sufficient income. | • Market liquidity dropped 51% 2021–2022, albeit from record levels in 2021. Prices can fluctuate over 50% year-on-year. Emerging brokers may promote stability.[94]<br>• Reported focus of buyers on higher-quality premium credits implies landowners may see better returns per credit going forward. | 2 |
| Convenience | • Barriers to selling and buying credits are falling. | • Governance/standards/transparency remain inhibitor for buyers. Policies on corporate use of offsets may promote standardization.[95]<br>• Guidance on issuing exists but reaches few landholders. | 2 |
| Compatibility | • Infrastructure exists to certify and trade high-quality credits. | • More companies involved in rating and trading, improving liquidity and products (e.g., standard contracts, insurance). Geospatial innovation ongoing. | 3 |

## Direct Air Carbon Capture (DACC)

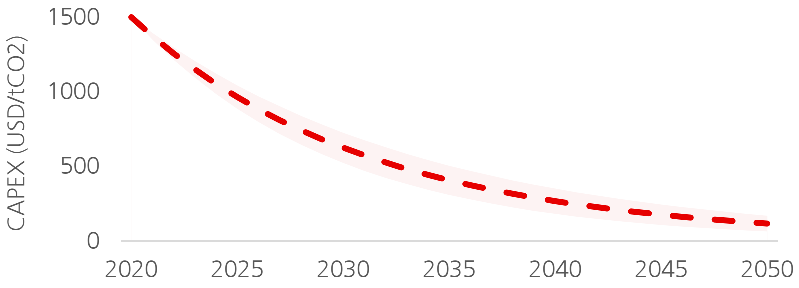
*Background*

Carbon removals will be required in 2050. A portfolio of solutions will be required, and while nature-based solutions offer significant opportunities for low-cost removals, engineered removals will also be required. Unlike capturing carbon from point sources, DACC plants remove carbon from ambient air. There are around 20 operating DACC plants today—far less than required under decarbonization scenarios. Together, they have with a capacity to remove 0.01 megatons of $CO_2$ a year, which is less than 0.001% of the removals needed under IPCC projections.[96] DACC is energy intensive and expensive, especially next to industry removals and cheap nature-based solutions. Yet, it is also some of the most reliable storage. Demand is limited to a small set of corporates willing to pay premium, and plant profitability hinges on how sustainable this demand is.[97] If costs fall, demand may be high from industries with few economic decarbonization options today (such as aviation). Tech is still really in the demonstration phase.

*Outlook*

Next decade is about reducing costs and energy intensity, with significant investment to scale after 2035. Likely to always be more expensive than other removals due to energy intensity, so it needs to maintain high quality of permanence to command premium in voluntary carbon markets.

## Driver spotlight—DACC capital expenditure intensity



Notes: Derived from Energy Transition Commission modelling; range reflects plausible learning rates of 10% and 15%, although this is to the lower end of other estimates.
Source: ETC (2022); UBS analysis

## 2035 Goals[98]

*Deployment goal:*

0.12 gigatons of $CO_2$ removal by 2035

*Abatement potential:*

0.12 gigatons of $CO_2$

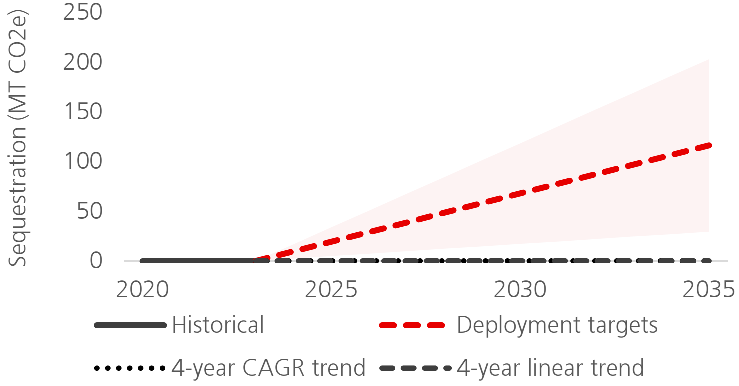
>1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.002–0.02tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | - Levelized cost of storage competitive with other engineered removals. | - Levelized cost of capture estimates for large-scale DACC range from around USD 150–350 t/$CO_2$—around 3x higher than carbon capture in industry (which benefits from higher $CO_2$ concentrations in flue gas, lower costs). Costs have not fallen much over the last decade, reflecting a low learning rate.[99] | 1 |
| Compensation | - Evidence of reliable economics needed to support continued deployment. | - It is too early to fairly judge the sustainability of business models. DACC is at the demonstration phase and the market is without historical precedent. Current buyers are willing to pay a premium for the high quality of its credits. | 1 |
| Convenience | - Minimal barriers to trading.<br>- High credit integrity—clear additionality, permanence, and independent verification. | - The ecosystem for buying, selling, and verifying credits is developing quickly. Credits can be traded OTC or on exchanges.<br>- DACC credits are high integrity. | 3 |
| Compatibility | - It is energy-intensive, requiring more renewables.<br>- Reliable storage sites are developed, with associated transport infrastructure. | - Renewables are developing at pace, so they are unlikely to act as a bottleneck.<br>- Ample geological storage globally for the quantities of DACC needed in net zero scenarios. Projects tend to co-locate with it today, given little transport infrastructure.[100] | 2 |

# Sector: Industrials

## Green steel via H2-DRI-EAF*

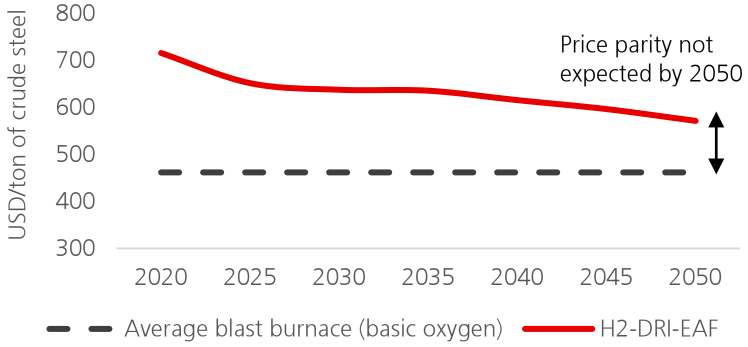
*Background*

Multiple solutions will be needed to decarbonize steel, which accounts for 7% of global GHG emissions. Material efficiency and more scrap in production will be important, as will equipping existing blast furnaces with carbon capture, given many of their asset lives extend beyond 2050.[101] The focus here is on hydrogen direct reduced-iron (DRI) based steelmaking, which offers a low-emission way to produce steel without CCS, offering the larger mitigation potential than other solutions. Under this process, green hydrogen is used as a reducing agent for iron rather than carbon from fossil fuels. The resulting iron is melted in an electric arc furnace (EAF), which can be powered by renewables, to produce steel.

*Outlook*

The technology is in the early demonstration phases; the first batch was only produced in 2022. Pilot projects are being introduced; around 20 by 2030 (vs. over 400 operating conventional steel plants), and 6 have final investment decisions.[102] The first wave of plants will generate learnings, driving down green hydrogen production costs, but price parity is not expected without a sizable carbon price.

## Driver spotlight—Parity beyond 2050



Notes: Carbon moratorium scenario, using H2-DRI-EAF with 100% hydrogen; average blast furnace is assumed fixed at 2020 levelized cost.
Source: MPP (2022)

## 2035 Goals[103]

*Deployment goal:*

16% of steel production by 2035

*Abatement potential:*

~3 gigatons of $CO_2$

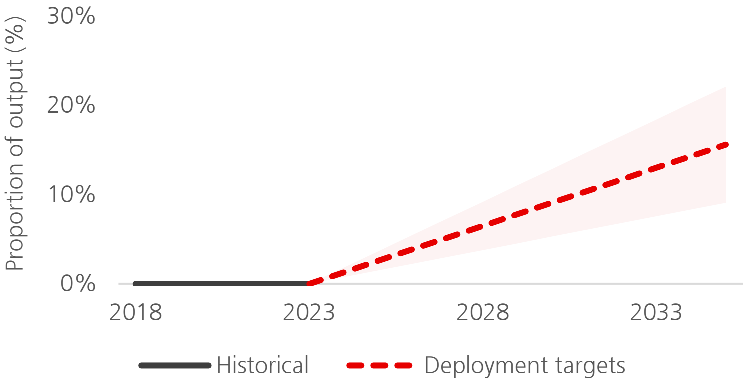
~1% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.1–0.3tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • Cost parity where the levelized cost of steel for green steel < conventional blast furnace steel. | • Green steel is expensive. Price parity is not expected before 2050 without a carbon price.<br>• With a carbon price of USD 100t/$CO_2$ and green hydrogen below USD 2/kg, parity expected by 2025.[104] | 2 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • No operating zero-emission steel factories today, but an established pipeline exists—a result of cross-value chain collaboration, and public incentives.<br>• Unclear if buyers will be willing to shoulder the green premium for steel. | 2 |
| Convenience | • Green steel is a direct substitute for conventionally-produced blast furnace steel. | • Steel produced via H2-DRI-EAF is almost identical to blast furnace steel. | 5 |
| Compatibility | • Expansion of hydrogen production and renewables for production.<br>• More high-grade ore and greater pre-processing to enable use in DRI-EAF. | • Renewable electricity and hydrogen production likely integrated as part of green steel projects.<br>• Only 3-4% of iron ore shipped today can be used in DRI EAF – significant barrier.[105] | 3 |

## Industry and carbon capture and storage

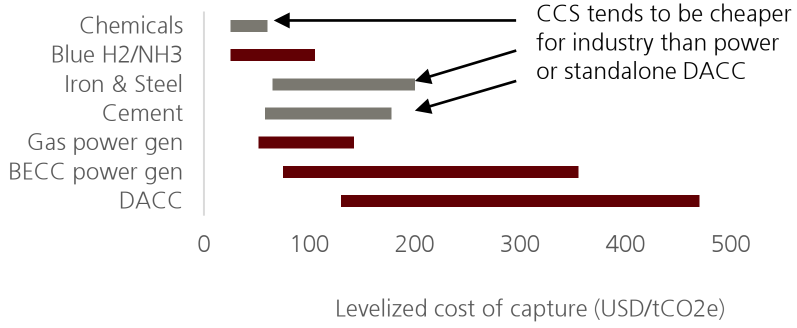
*Background*

Industry accounted for ~25% of global energy system emissions in 2022.[106] Carbon capture and storage will be vital where industrial processes cannot be fully decarbonized by other zero-carbon solutions, or where it is the lowest-cost solution given local resources and costs. For instance, while emissions from cement production can be reduced by altering production or reducing demand, chemical reactions at the heart of the process release $CO_2$; therefore, some CCS is likely to always be required. Indeed, in net zero scenarios, 10–15% of the energy mix in 2050 could still be fossil energy with CCS.[107] CCS can be attached to industrial plants to capture $CO_2$ from their waste gas streams from industrial activities, and then either transported and permanently stored, or used as an input into other processes, such as producing plastics. There are around 45 commercial CCS projects capturing $CO_2$ from industrial and power activities today. Cost reductions will likely be gradual.[108]

*Outlook*

A significant scale up to around 300 projects is needed by 2030, as well as centralized transport infrastructure and reliable permanent geological storage.[109] Incentives are needed to encourage adoption to reduce costs.

## Driver spotlight—CCS costs by activity



CCS tends to be cheaper for industry than power or standalone DACC

Notes: Shows selected technologies from a wider review conducted by the Energy Transition Commission; ranges reflect current spread of costs across markets.
Source: ETC (2022)

## 2035 Goals[110]

*Deployment goals:*

Output of steel, cement, and chemicals covered by CCS is 5%, 33%, & 22% respectively in 2035

*Abatement potential:*

~9 gigatons of $CO_2$

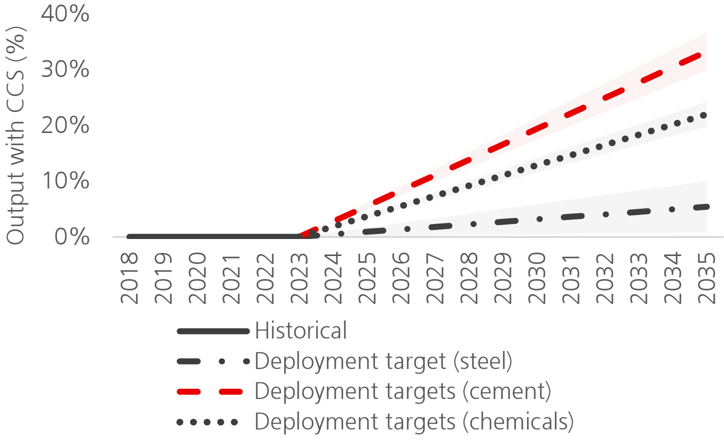
~3% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.03–0.08tn in 2035

*Status:*

Right direction, off track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • NA – CCS is not competing with any incumbent technology, so there is no relative cost goal that would trigger a tipping point.<br>• A possible trigger is if the price of capturing carbon is cheaper than a tax, therefore: Levelized cost of storage < price of carbon. | • Costs for capturing $CO_2$ from steel, cement, and chemicals are around USD 75–125/$tCO_2$.[111]<br>• Carbon prices in compliance markets are generally around USD 60–80/$tCO_2$ (75% of emission trading schemes cover industrial activities). The difference is too small to incentivize investment in CCS today.[112] | 2 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • Regulation is fundamentally required to create adequate demand for CCS; limited revenue pools today. | 1 |
| Convenience | • CCS retrofits possible to most industrial production processes. | • CCS has been demonstrated at scale for most applications—90% capture rates are feasible.[113]<br>• Retrofitting is resource-intensive with safety risks and technical challenges. | 2 |
| Compatibility | • Need large expansion of centralized transport infrastructure (e.g., compressor and pipeline network), and reliable storage. | • Centralized transport infrastructure non-existent today. Some countries, e.g., UK, have progressed plans for networks.[114]<br>• Reliable geological storage is largely undeveloped but plenty of pilots. | 1 |

# Sector: Buildings

## Heat pumps for residential buildings

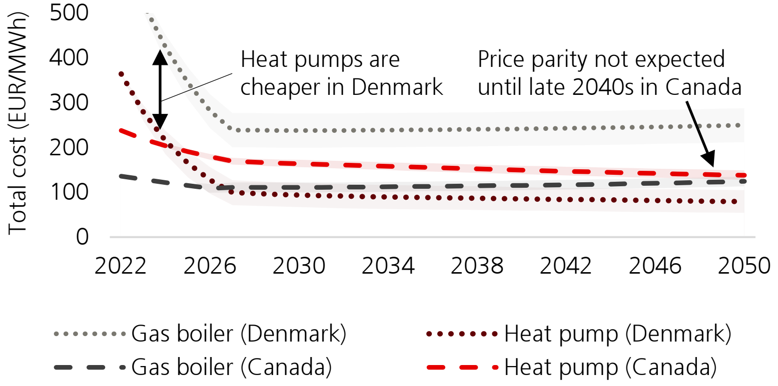
*Background*

Direct emissions from residential buildings were ~6% of global emissions in 2022, half from burning gas to heat buildings.[115] Heat pumps are expected to be the main technology to replace gas boilers for residential homes; they can heat as well as cool, run on renewable electricity, and they require 3–5x less energy than gas boilers to deliver the same amount of heat.[116] They also provide energy security benefits for countries that are net-importers of gas.[117] Heat pumps are named based on where they source heat—from either the air, water, or the ground. Air-source heat pumps are likely to be the most popular due to lower costs and easier installation. They are almost always more expensive to buy and install than gas boilers, but their efficiency means they generally have lower operational costs.

*Outlook*

Heat pump prices are expected to fall around 30% by 2035 on current trends, but enduring subsidies will be needed to encourage their uptake given high upfront costs.[118] Labor shortages also affect many markets, slowing installation. But double-digit growth rates are expected on the back of improving costs and policy support.

## Driver spotlight—Cost significantly varies



Notes: The heat pump shown for each country is the most popular in that market (air-to-air for Denmark, air-to-water for Canada)
Source: Lynch, C. et al (2023).

## 2035 Goals[119]

*Deployment goal:*

32% of space heat demand by 2035

*Abatement potential:*

~6 gigatons of $CO_2$

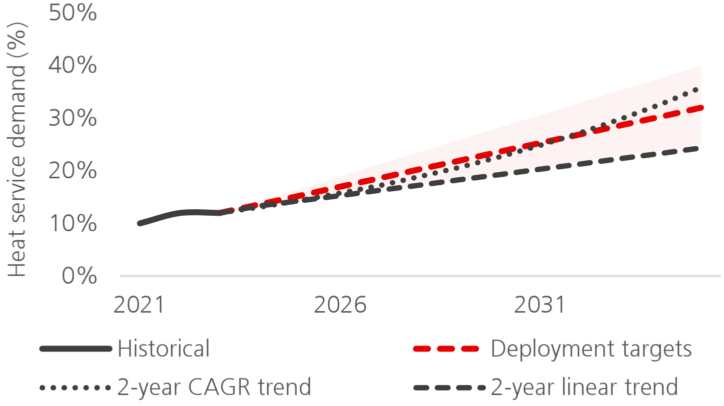
~2% of 1.5oC carbon budget

*Total Addressable Market:*

USD 0.4–0.9tn in 2035

*Status:*

Right direction, likely on track



## Commercial maturity drivers—Four Cs

| | Target conditions | Progress | Score (/5) |
|---|---|---|---|
| Cost | • Price parity of Heat Pump (purchase price and installation cost) vs. gas boilers.<br>• Lower operational costs for heat pumps than gas boilers. | • Heat pump upfront costs are higher in most countries than gas boilers. Subsidies are needed.<br>• Lifetime costs of a heat pump are lower; while gas is cheaper than electricity, heat pumps are 300–500% energy efficient, while gas boilers are 90% efficient.[120] | 2 |
| Compensation | • Evidence of reliable economics needed to support continued deployment. | • Some heat pump markets are growing fast. Europe has achieved double-digit growth rates since 2015 (20% of all gas boilers have been replaced). China is following suit.<br>• Global growth was only 3% in 2020.[121] | 2 |
| Convenience | • Overcome installation time disadvantage and other practical challenges. | • No easy fixes to overcome the labor- and time-intensive installation process for heat pumps. 3–8 days installation time for heat pumps, versus 1-3 days for gas boilers.[122]<br>• Heat pump efficiency has improved ~2% p.a. | 3 |
| Compatibility | • Infrastructure grid expansion required, and better building energy efficiency.<br>• Overcome workforce shortages via retraining. | • Building retrofit rates only 1% p.a. globally. Heat pumps are expected to add significantly to electricity demand.[123]<br>• Workforce deficits in most markets; jobs in supply chain triple by 2030; there are incentives to reskill once demand develops.[124] | 3 |

# Appendix

## A1: The 3-part framework

Our methodology is split into three sections:

1) What: Defining key climate technologies and each one's deployment goal, abatement potential, total addressable market, implementation cost.

2) How: Commercial readiness and tipping points via the four Cs (cost, compensation, convenience, and compatibility).

3) Why: The opportunity each climate tech presents to accelerate decarbonization

**What: Key climate technologies**

There is no universal definition of a climate technology. We take a broad definition to include any solution that can facilitate reduced atmospheric concentrations of greenhouse gases, and then prioritize the "most important." Some climate techs are nascent (and therefore lacking data), or they are not a priority to track because they are unlikely to drive much decarbonization by themselves (e.g., a wind turbine clearly avoids emissions; the case is less clear for carbon accounting software). Following a review of mainstream scenarios and analysis, we prioritized solutions that are:
Included in mainstream Net Zero scenarios as a feasible climate solution;
Data exist today for us to track their progress, as well as publicly available third-party forecasts (e.g., global data on the cost of EVs vs. internal combustion engine vehicles exists).

**What: Deployment goal**

For each climate tech, deployment goals were derived from existing Net Zero scenarios aligned to global heating of between 1.5°C and 2°C. Each scenario sets out a plausible deployment for climate tech to achieve a temperature goal, but the exact level varies a lot. Taking their average, and presenting deployment goals as a range, is a reasonable way to reflect the average opinion of how much a climate tech needs to scale to meet a particular temperature goal. The approach follows similar analyses, such as the work of the University of Exeter's Systems Change Lab. All deployment goals are set for 2023 to 2035.

### What: Abatement potential

Abatement potential refers to how many GHG emissions a technology reduces, avoids, or removes for a given level of deployment. It involves calculating a baseline of emissions that would happen if that climate tech did not deploy and calculating the saved emissions attributable to its existence—such as the GHG emissions removed from the atmosphere by CCS, or the emissions of conventional cars that are avoided by putting more EVs on road. Total abatement potential was calculated in this way and adjusted for each climate tech's lifecycle emissions. We prioritized figures here scenarios provided abatement potential, but for more novel technologies that are poorly reflected in scenarios, such as nuclear Small Modular Reactors, we performed our own calculations.

### What: Total Addressable Market

Total Addressable Market refers to the future potential revenue a climate tech could generate, on a global level, if it hits its deployment goal. We used a simple top-down approach: taking a measure of today's market size, growing it until 2035 at a reasonable growth rate, and assuming the climate tech's 2035 deployment goal was their share of market revenue. For instance, for power sector climate techs, we took the total revenue from listed businesses in the power sector and grew it at the average of equity analyst's expectations of compound annual growth over the next five year (using data from Aswath Damodaran's public repository). If wind energy's deployment goal is 22% of power generation in 2035, its Total Addressable Market is estimated as 22% of the future power market revenue. The range reflects upper and lower deployment goal.

### What: Implementation cost

Implementation cost refers to the capital investment required to implement a climate tech's deployment goal. We took a simple top-down approach, using production cost estimates from scenarios and multiplying them by production levels needed to hit deployment targets. Where possible, we prioritized empirically derived cost estimates that incorporated learning effects. Implementation cost does not consider the system costs of implementing solutions (such as the number of chargers required to support EVs). We also focus on capital costs and ignore operating costs, which tend to be lower for climate techs.

### How: Proximity to tipping points via the four Cs

After setting goals, we analyzed how likely climate techs are to make progress in the near term by looking at their proximity to tipping points. The four Cs are explained in the next section of the Appendix. It follows a similar rating-style approach to SystemIQ (2023), to compare dissimilar technologies on a roughly even playing field. Inevitably, ratings involve a degree of subjectivity, so for transparency, the logic is included in each Climate Tech Passport.

### Why: Transition impact

Analyzing the potential impact of climate techs involves comparing their deployment and commercial goals to their proximity to tipping points. Climate techs with high abatement potential, which are also close to tipping points, may generate the largest climate impact in the near term. Those with smaller abatement potential and larger distances to tipping points are only likely to have tangible climate impacts in the 2040s.

# A2: The four Cs framework

Novel technologies moving from slow to exponential growth, and zero to gradually building market share, have common attributes. Meeting them signals commercial maturity and readiness to scale, providing a yardstick to judge whether a new technology is on the verge of breaking through. We structure these common attributes as the "Four Cs":

1. **Cost:** Once a solution becomes cost competitive with incumbents, rapid deployment often follows. In the 1960s, once cheap natural gas was discovered in the North Sea, it supplanted coal in the UK within 30 years.
2. **Compensation:** Generating revenue and eventually profits—the hallmark of technologies with effective business models—depends on more than falling costs, such as proven business models, and the nature of markets and policy support. For instance, wind energy is cheap today, but investment can suddenly drop if relative profitability suffers, such as through an end to subsidies, or if revenues are too volatile to assuage capital lenders of a project's risks.[1] Even if a technology is cheap, it may struggle to generate consistent reliable revenues, requiring further innovation to find a reliable product-market fit.
3. **Convenience:** Non-cost features such as higher quality, better reliability, or new capabilities increase a technology's convenience, and therefore commercial maturity. For instance, climate techs inherently reduce emissions, and so they can enjoy a "green halo" effect in market segments where this enhances their perceived quality. Wider trends can also render a technology more attractive to consumers, such as if social norms shift in favor of alternative proteins.
4. **Compatibility:** A technology's growth could be limited by broader factors beyond its control that act as a bottleneck on deployment. Current examples among climate techs include renewables' struggle to connect to electricity grids due to infrastructural bottle necks, and consumers remaining resistant to buying EVs in some places due to a lack of public charging stations.

### Limitations

Like all frameworks and the analyses they guide, this one too has limits. For one, we don't cover all climate techs. Other analyses have done this, such as a recent proprietary UBS analysis which documented over 450.[1] While all solutions should be on the table to decarbonize, each sector has one or two solutions that could deliver the bulk of supply-side emissions reduction. This means we can present a fair state-of-play by focusing on a few "key" climate techs rather than covering every technology under the sun, with the added benefit of simplicity. Similarly, the competitiveness of each climate tech and incumbents at a regional or national level is not reflected in this analysis. We focus on the state of climate tech at a high level—either globally or across key markets if data is not widely available, particularly the EU, US, and China.

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