Goldman Sachs Research

EQUITY RESEARCH | October 9, 2024 | 6:00PM CEST

Carbonomics

The GS net zero carbon scenarios – a reality check

We update our paths to net zero carbon that we introduced in June 2021, reflecting rising emissions and coal use since the 2022 energy crisis and material changes to our Carbonomics cost curve. We now present three global paths for de-carbonization by sector and technology, adding a GS 2.0° scenario alongside our GS 1.5° and GS <2.0° scenarios. We highlight four main changes since 2021: 1) The 1.5° scenario would require an acceleration in de-carbonization efforts that we view as increasingly difficult to achieve (e.g. global coal retirement by the early 2030s, implying $1.7 trn of stranded assets, and full electrification of auto sales by 2035). 2) The more realistic, but still ambitious scenario aligned with 2.0° of global warming would imply lower coal stranded assets, but also a likely material increase in adaptation costs by 2050 (vs the 1.5° scenario). 3) Tracking the progress by technology, we highlight an acceleration in adoption of EVs, solar and nuclear, while technologies higher on the cost curve have shown slower take-up than expected (hydrogen, carbon capture). 4) We see a longer life for hydrocarbon assets, with peak oil demand occurring beyond 2030 and demand growing for natural gas as a transition fuel until 2050. This implies new greenfield oil & gas developments are likely to be needed beyond 2040. We translate these net zero scenarios into pathways for emission intensity reduction for 30 key emitting corporate industries, providing an updated framework for gauging corporate emission reduction targets.

Michele Della Vigna, CFA
+39 02 8022-2242
michele.dellavigna@gs.com
Goldman Sachs Bank Europe SE - Milan branch

Anastasia Shalaeva
+971 4 214-9908
anastasia.shalaeva@gs.com
Goldman Sachs International

Yulia Bocharnikova
+971 4 214-9957
yulia.bocharnikova@gs.com
Goldman Sachs International

Quentin Marbach
+44 20 7774-7644
quentin.marbach@gs.com
Goldman Sachs International

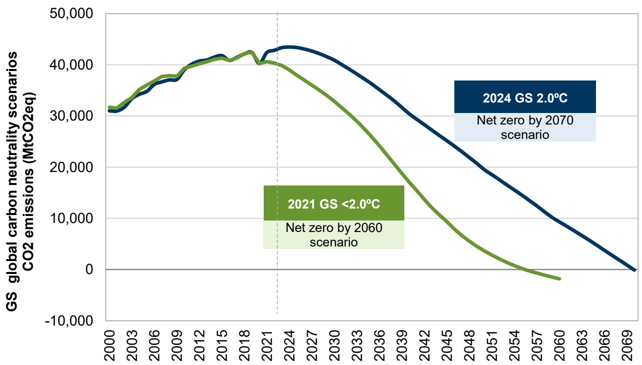
Alberto Gandolfi
+39 02 8022-0157
alberto.gandolfi@gs.com
Goldman Sachs Bank Europe SE - Milan branch

Nikhil Bhandari
+65 6889-2867
nikhil.bhandari@gs.com
Goldman Sachs (Singapore) Pte

Table of Contents

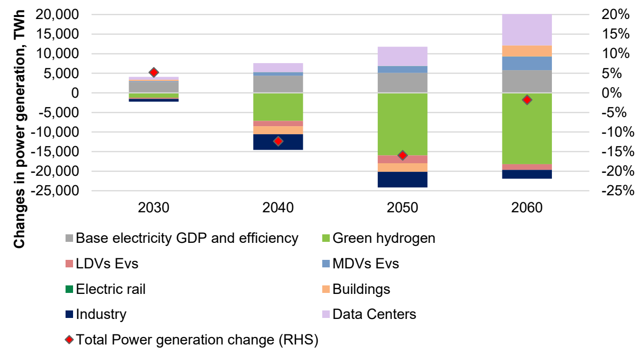
Thesis in 18 charts

Exhibit 1: Our updated GS 2.0 degrees emissions scenario shows a 66% increase in cumulative emissions vs. our 2021 Paris Agreement-aligned scenario...
GS Global net zero carbon scenarios CO2 emissions (MtCO2): 2024 vs 2021 scenarios comparison



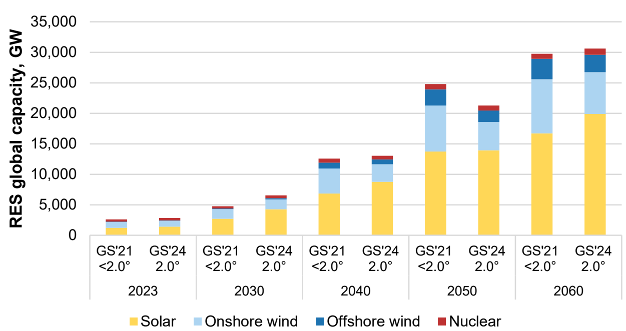
Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 2: ....with a slower development of electricity demand, mainly impacted by slower green hydrogen developments...
Changes in power generation demand by sector in 2024 GS 2.0 degrees vs 2021 GS <2 degrees scenarios



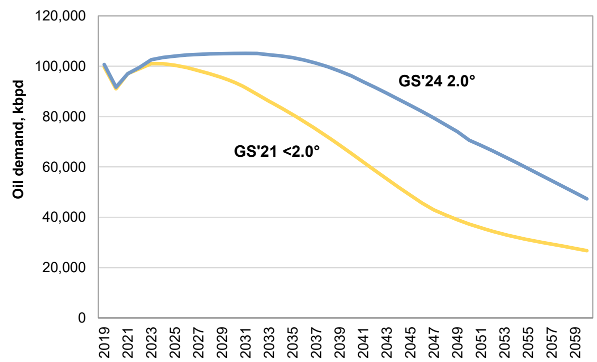
Source: Goldman Sachs Global Investment Research

Exhibit 3: ...and solar PV and nuclear surpassing our previous estimates, but slower wind capacity.
Global RES installed capacity, GW: 2024 GS 2.0 degrees scenario vs 2021 GS <2 degrees



Source: Ember, Goldman Sachs Global Investment Research

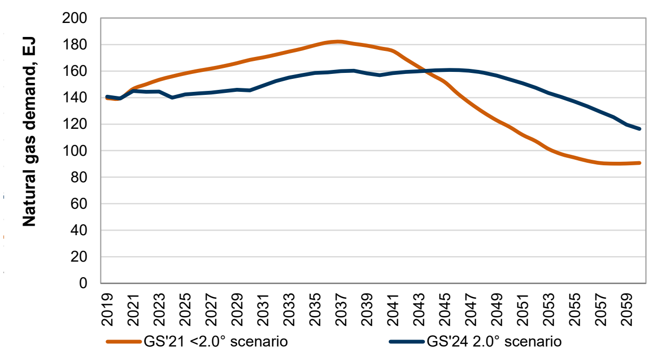
Exhibit 4: We now estimate peak oil demand to take place in the early-2030s...
Oil demand (kbpd) under our two highlighted paths



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 5: ...while natural gas remains a key transition fuel until late-2040s

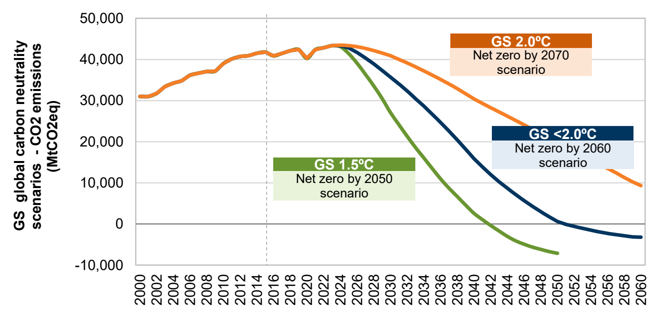
Natural gas demand (EJ) under our two highlighted paths



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 6: We have constructed three global carbon neutrality scenarios: one aspirational scenario consistent with 1.5°C global warming by 2100; one consistent with well below 2.0°C global warming, in line with the Paris Agreement ambition; and the scenario we see as most realistic, with global net zero being achieved by 2070 and global warming reaching 2.0°C by 2100, short of the Paris Agreement ambitions

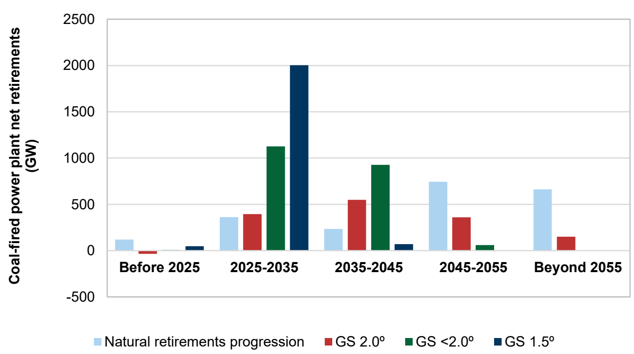
GS Global net zero carbon scenarios CO2 emissions (MtCO2)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, Goldman Sachs Global Investment Research, GCB

Exhibit 7: We believe 1.5° is becoming increasingly difficult to achieve including $1.1 trn of potentially stranded coal assets...

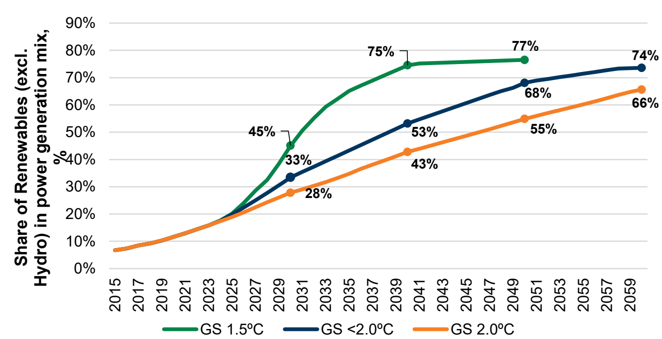
Coal-fired power plant net retirements (GW)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 8: ...while renewable power grows strongly in all scenarios...

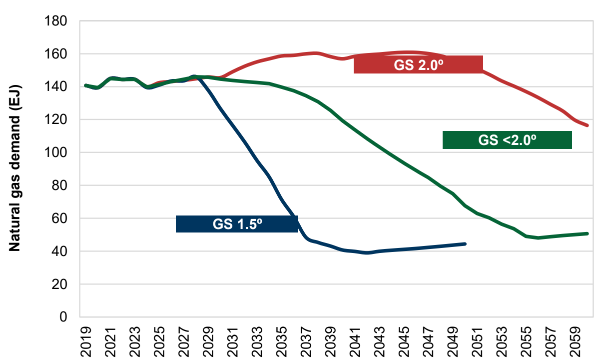
RES share in power generation mix, %



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 9: ...and natural gas is most sensitive to the scenarios given its role as a transitional fuel

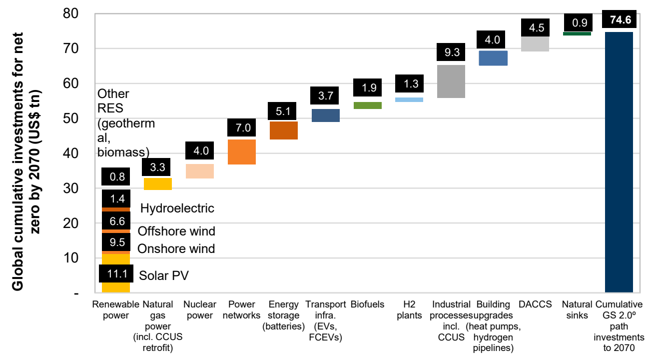
Natural gas demand (EJ)



Source: Goldman Sachs Global Investment Research

Exhibit 10: We estimate that there exists in aggregate a c.US$74.6 tn investment opportunity across sectors on the path to global net zero by 2070

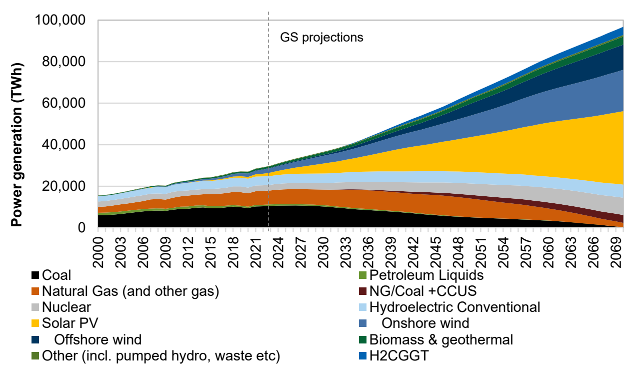
Cumulative investment opportunity across sectors for our GS 2.0° global net zero by 2070 scenario (US$ tn)



Source: Goldman Sachs Global Investment Research

Exhibit 11: Based on our global net zero by 2070 path, power generation demand increases three-fold to 2070...

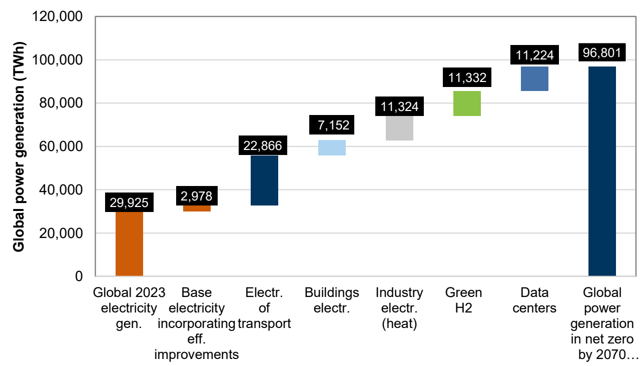
Global electricity generation (TWh)



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 12: ...as it forms a critical part of the de-carbonization route for other sectors

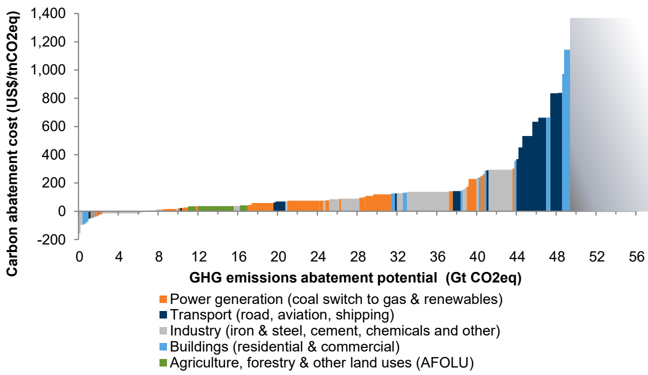
Global electricity generation bridge to 2070E (TWh)



Source: Goldman Sachs Global Investment Research, Ember

Exhibit 13: Transportation mostly sits in the 'high-cost' area of our de-carbonization cost curve...

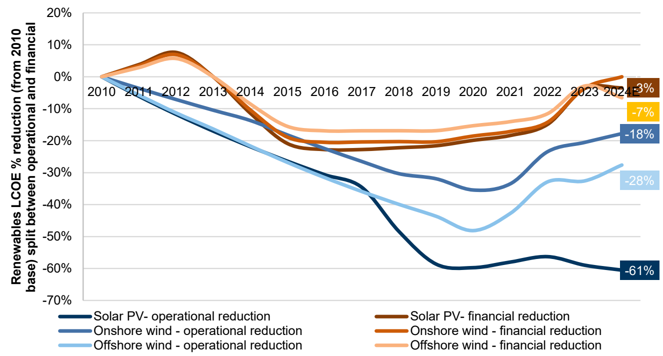
2023 carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and current costs, assuming economies of scale for technologies in the pilot phase



Source: Goldman Sachs Global Investment Research

Exhibit 14: ...while renewable power (mostly wind) is seeing a temporary set-back due to higher rates...

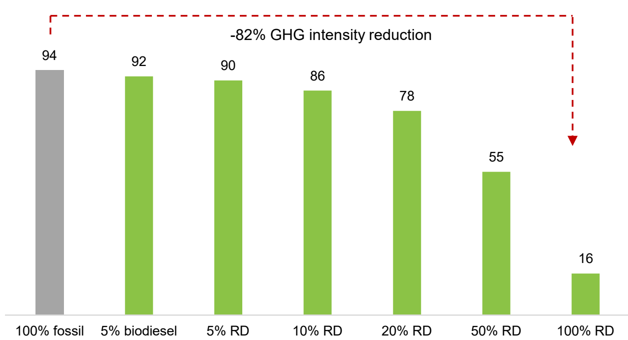
LCOE for solar PV, wind onshore and wind offshore for select regions, % reduction split by operational and financial



Source: Goldman Sachs Global Investment Research

Exhibit 15: Biofuels have scope to de-carbonize transportation within current infrastructure

Liquid fuels GHG intensity, gCO2e/MJ

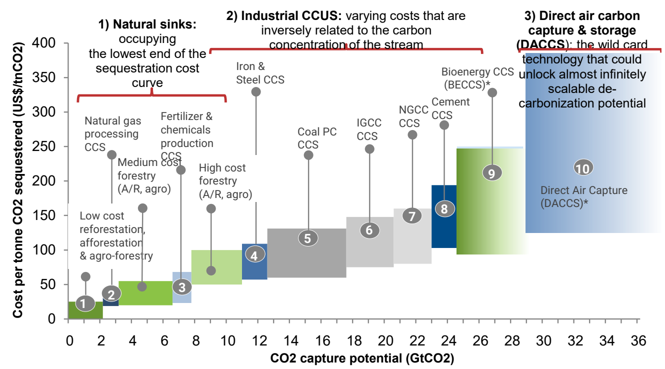


RD is renewable diesel, GHG intensity is based on used cooking oil feedstock

Source: EU RED II Directive, compiled by Goldman Sachs Global Investment Research

Exhibit 16: Carbon sequestration remains a core part of the net zero solution

Carbon sequestration cost curve (US$/tnCO2eq) and the GHG emissions abatement potential (GtCO2eq)

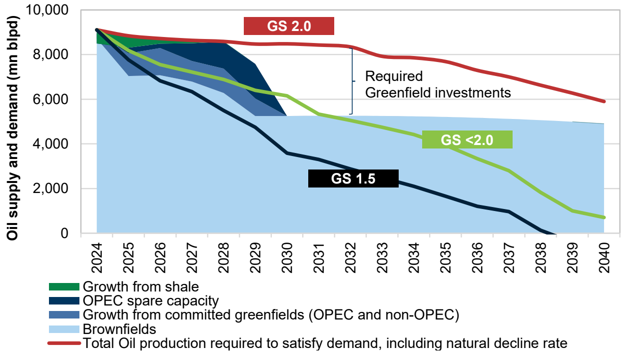


*Indicates technologies primarily in early development/pilot phase with wide variability in the estimates of costs.

Source: IPCC, Global CCS Institute, Goldman Sachs Global Investment Research

Exhibit 17: We estimate that investments in oil will continue to be needed beyond 2040...

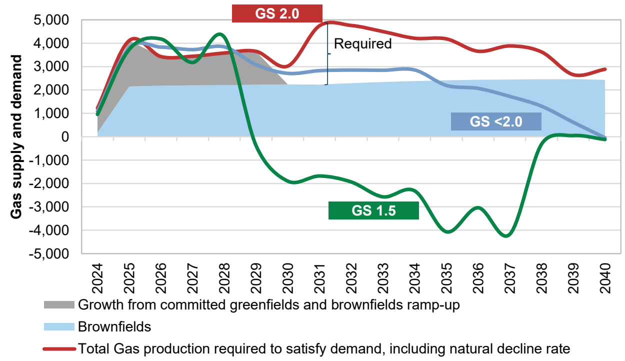
Total Oil production required to satisfy demand, including natural decline rate



Source: Goldman Sachs Global Investment Research

Exhibit 18: ...and towards 2050 for natural gas

Total Gas production required to satisfy demand, including natural decline rate



Source: Goldman Sachs Global Investment Research

Assessing emissions path developments in 2021-23 versus our 2021 expectations

In our 2021 Carbonomics report, we presented our modeling of the paths to net zero carbon, outlining two global scenarios of de-carbonization by sector and technology, leveraging our Carbonomics cost curve. Back then, we presented a scenario consistent with the Paris Agreement's goal to keep global warming well below 2°C (**GS <2.0°**), and a more aspirational path, aiming for global net zero by 2050, consistent with limiting global warming to 1.5°C (**GS 1.5°**). Now, three years later, we look at how the emissions path has played out so far versus our 2021 expectations (Exhibit 19 and Exhibit 20), and update our net zero scenarios to account for the latest macro developments, technology trends and green project pipelines, among other factors.

Total global CO2 emissions reached a record high of 43.2 Gt in 2023 (incl. LULUCF), on our estimates, increasing by 2.2% in 2021-23, far from our initial 2021 expectation of a 5% drop in emissions during this period. Overall, we observe that **global CO2 emissions in 2021-23 overshot our 2021 expectations by c.6% on average,** primarily driven by power generation, agriculture (including LULUCF) and transport, with some offset coming from reduced emissions from buildings and industry emissions that were largely in line with our expectations.

The *Power Generation* sector contributed the second largest increase (after transport) in emissions from 2021 to 2023. We had expected emissions to fall 5% over this period, but they instead rose by 2%. This is despite **renewable power generation exceeding our 2021 expectations** in terms of installed capacity and share of the power mix: total global renewables capacity had reached >2400GW by 2023, exceeding the initially expected c.2200GW, mainly driven by the rapid acceleration of solar power installed capacity, which expanded significantly in 2023, accounting for c.75% of total renewable capacity additions for that year. Global capacity additions of wind and solar PV reached a record of almost 462 GW in 2023, up 67% from the level of 2022. China stood at the forefront of the renewables capacity expansion last year, contributing as much solar PV as the entire world did in 2022. Growth in nuclear power capacity also surpassed our 2021 projections, reaching 400GW by 2023, which can be explained by the revival of global interest in nuclear energy, with many countries planning and starting nuclear power programmes to reach climate policy objectives. At the same time**, fossil-fuel power generation remained resilient in 2022-23 amid higher gas prices and lower hydropower output due to the droughts in 2023**. China and India saw substantial increases in emissions from coal combustion, driven by reduced hydropower generation and strong electricity demand growth, which were only partially offset by declines in advanced economies, preventing a decline in global emissions in the electricity sector.

In *Transport*, **EV (BEV and PHEV) penetration in passenger car sales in 2021-23 overshot our 2021 expectations**, primarily due to faster-than-expected EV penetration in China. In 2023, the global EV share in passenger car sales reached 16% compared with 10% based on our 2021 expectation. China became a leader in EV penetration with c.35% EV sales share in 2023, significantly exceeding the 13% projection of our global

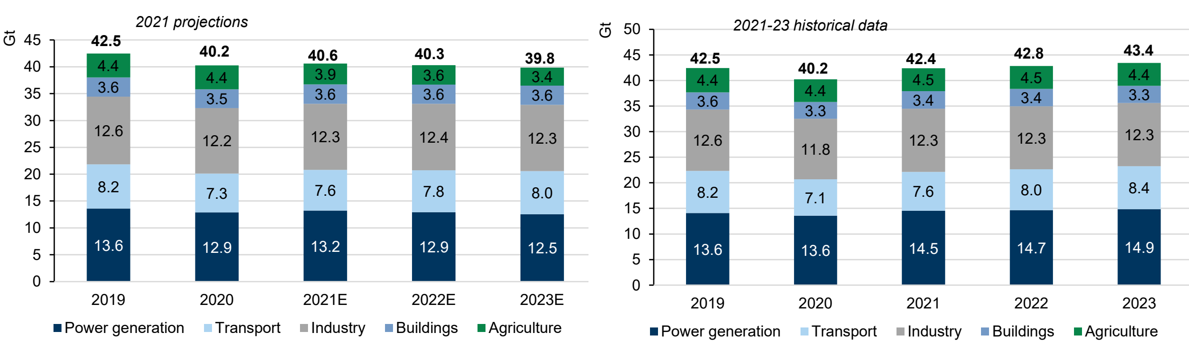
Auto team, supported by government subsidies, tax breaks and other policy incentives, as well as a number of homegrown EV brands. At the same time, we note lower fuel efficiency savings in ICE cars and higher-than-expected adoption of hybrids due to their significant advantage in payback period compared to EV. Overall, transport CO2 emissions in 2021-23 overshot our 2021 forecasts by c.1.5%, or 360 mn t.

In *Industry,* CO2 emissions in 2021-23 came in broadly in line with our expectations, with **weaker-than-expected industrial production** offsetting **slower-than-expected adoption of several green technologies,** especially **green hydrogen and carbon capture.**

In *Agriculture* (including LULUCF), CO2 emissions remained almost unchanged in 2021-23, higher than we had forecast. The trend for AFOLU remains more uncertain, due to the multitude of drivers that affect emissions and removals for land use, land-use change and forestry.

Buildings was **the only sector to see emissions fall at the global level, decreasing by 2% in 2021-23**, surpassing the 1% decrease we previously expected. In Buildings, we have seen faster-than-expected deployment of low-carbon technologies, including heat pumps and renewables, and lower gas consumption owing to milder temperatures experienced in 2023. The share of low-carbon energy sources reached 41% by 2023 vs the 36% that we had projected in the previous edition of this report.

Exhibit 19: CO2 emissions overshot our 2021 expectations, primarily in power generation, land use and transport
Emissions CO2 by sector incl. LUFUC 2021 projections versus historical data



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

Exhibit 20: Comparison of 2021-23-25E scenarios; 2024 and 2021 editions

	2021 edition (<2.0°C)			2024 edition (2.0°C)			Trend
	2021E	2023E	2025E	2021	2023	2025E	
Summary: total CO2 emissions (MtCO2)							
Power generation	13,228	12,540	11,520	14,533	14,872	14,885	deceleration
Transport	7,595	8,031	7,984	7,610	8,332	8,494	deceleration
Industry	12,294	12,343	12,188	12,349	12,350	12,325	deceleration
Buildings	3,586	3,563	3,463	3,440	3,350	3,302	acceleration
AFOLU	3,918	3,353	2,769	4,472	4,448	4,359	deceleration
Total	**40,621**	**39,831**	**37,924**	**42,404**	**43,352**	**43,366**	
Power generation							
Power generation, TWh	28,673	30,120	31,007	28,548	29,925	32,070	
Power mix, %							
Coal	36%	33%	30%	36%	35%	33%	deceleration
Gas	27%	27%	27%	23%	23%	22%	acceleration
Renewables (wind, solar, biomass)	12%	15%	18%	13%	16%	19%	acceleration
Nuclear	9%	8%	8%	10%	9%	9%	acceleration
Generation capacity, GW							
Solar	885	1,212	1,572	874	1,419	2,097	acceleration
Onshore wind	804	961	1,128	770	945	1,125	deceleration
Offshore wind	41	53	65	54	73	105	acceleration
Nuclear	401	390	382	402	400	422	acceleration
Transport							
LDV sales mix							
ICE+HEV share	94%	90%	82%	92%	84%	78%	
BEV+PHEV share	6%	10%	18%	8%	16%	22%	acceleration
HDV sales mix							
ICE share	100%	100%	99%	99%	98%	95%	
BEV+FCEV share	0%	0%	1%	1%	2%	5%	acceleration
LDV fleet, mn units	**1,272**	**1,315**	**1,362**	**1,268**	**1,297**	**1,367**	
ICE+HEV	1,258	1,285	1,302	1,252	1,256	1,288	
BEV+PHEV	14	30	59	16	40	78	
HDV fleet, mn units	**41**	**44**	**46**	**72**	**70**	**71**	
ICE	41	44	46	71	69	70	
BEV+FCEV	0	0	0	1	1	2	
Industry							
Volumes, mn t							
Iron&steel	1,773	1,884	1,917	1,960	1,888	1,910	
Non-metallic minerals (lime, clay, cement)	4,072	4,090	4,105	4,271	4,100	4,147	
Aluminium	98	103	109	94	97	103	
Chems - ammonia	187	200	211	183	191	199	
Chems - methanol	107	112	117	107	108	114	
Chems - HVCs	254	269	282	282	294	312	
Share of CCUS, hydrogen, electricity, bioenergy %							
Iron&steel	30%	31%	34%	30%	28%	31%	deceleration
Non-metallic minerals (lime, clay, cement)	1%	2%	3%	2%	4%	6%	acceleration
Aluminium	33%	33%	33%	28%	27%	28%	deceleration
Chems - ammonia	1%	1%	2%	1%	1%	2%	
Chems - methanol	0%	0%	1%	0%	0%	0%	
Chems - HVCs	2%	5%	7%	0%	1%	2%	
Buildings							
Share of electricity, bioenergy, renewables %	35%	36%	37%	39%	41%	43%	acceleration
CCUS							
Carbon captured annually, mn t	49	140	236	10	16	53	deceleration
Hydrogen							
Green hydrogen demand, mn t	2	5	9	0	0	1	deceleration

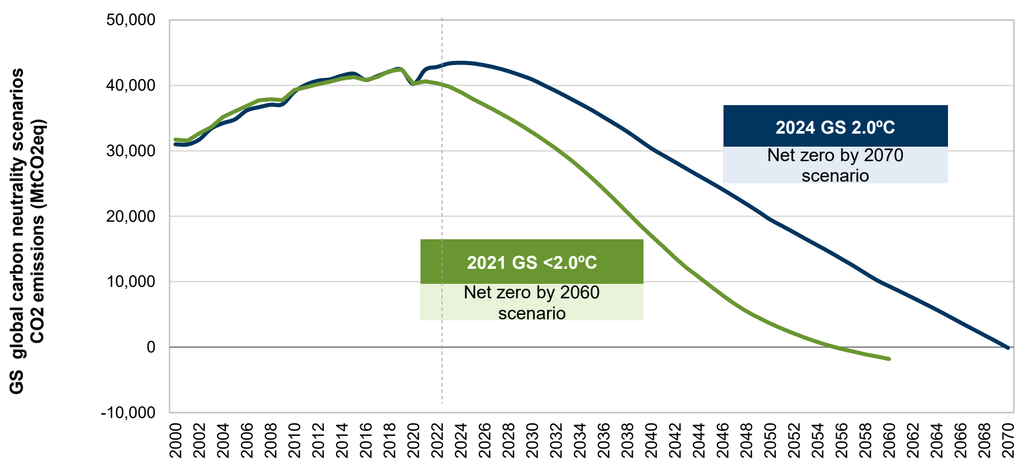
*acceleration/deceleration stand for the trajectory of the decarbonization trend

Source: Goldman Sachs Global Investment Research, Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Ember, Energy Institute Statistical Review of World Energy

What's changed compared to the 2021 GS <2.0°C scenario?

As described in the previous section of this report, over the last three years, total global CO2 emissions have continued to rise, reaching a record high level of 43.2 Gt in 2023, contrary to our previous projections. Since our 2021 report, the energy sector has faced many changes, including the global energy crisis, accelerated by Russia's invasion of Ukraine. This has spurred many countries, especially in Europe, to adapt to the reshaped energy world: the last two years have seen remarkable progress in developing and deploying some key clean energy technologies. This 2024 update of our GS global emissions path sets out a revised trajectory to net zero by 2070, taking into account key developments that have occurred since 2021. In this section, **we compare our new GS 2.0° scenario – a more realistic, but still ambitious path to global net zero by 2070 – with the previous GS <2.0° scenario, a path consistent with global net zero by 2060.**

Exhibit 21: 2024 update of our GS global emissions path sets out a revised trajectory to net zero by 2070
GS Global net zero carbon scenarios CO2 emissions (MtCO2): comparison of 2024 and 2021 most realistic, but still ambitious scenarios



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 22: Comparison of 2030-40-50-60E scenarios; 2024 and 2021 editions

	2021 edition (<2.0°C)				2024 edition (2.0°C)				Trend
	2030E	2040E	2050E	2060E	2030E	2040E	2050E	2060E	
Summary: total CO2 emissions (MtCO2)									
Power generation	9,758	5,887	1,661	175	13,490	9,184	6,801	4,682	deceleration
Transport	7,405	4,878	1,764	368	8,570	7,913	6,079	3,782	deceleration
Industry	11,292	6,913	3,299	893	12,004	9,508	6,141	3,636	deceleration
Buildings	2,989	1,291	148	15	3,081	2,183	1,306	670	deceleration
AFOLU	1,392	-1,476	-2,660	-2,660	3,763	2,060	-237	-2,851	deceleration
Total	**32,836**	**17,494**	**4,212**	**-1,209**	**40,908**	**30,847**	**20,090**	**9,918**	deceleration
Power generation									
Power generation, TWh	34,763	56,746	77,643	83,307	36,572	49,738	65,229	81,820	deceleration
Power mix, %									
Coal	23%	6%	0%	0%	28%	15%	7%	4%	deceleration
Gas	27%	19%	5%	0%	20%	18%	14%	7%	mixed
Renewables (wind, solar, biomass)	25%	45%	65%	73%	28%	43%	55%	66%	mixed
Nuclear	6%	7%	7%	6%	9%	9%	9%	9%	acceleration
Generation capacity, GW									
Solar	2,689	6,853	13,740	16,692	4,245	8,760	13,935	19,887	acceleration
Onshore wind	1,599	4,083	7,538	8,882	1,645	2,898	4,643	6,845	deceleration
Offshore wind	112	985	2,644	3,357	186	767	1,870	2,860	deceleration
Nuclear	360	632	870	812	462	622	816	1,023	mixed
Transport					58%	28%	1%	19%	
LDV sales mix									
ICE+HEV share	60%	6%	0%	0%	57%	29%	0%	0%	
BEV+PHEV share	40%	94%	100%	100%	43%	71%	100%	100%	mixed
HDV sales mix									
ICE share	95%	37%	0%	0%	83%	36%	11%	0%	
BEV+FCEV share	5%	63%	100%	100%	17%	64%	89%	100%	acceleration
LDV fleet, mn units	**1,443**	**1,732**	**2,177**	**2,723**	**1,575**	**2,079**	**2,431**	**2,860**	
ICE+HEV	1,229	703	138	0	1,329	1,236	840	512	
BEV+PHEV	214	1,029	2,040	2,723	246	843	1,591	2,348	deceleration
HDV fleet, mn units	**52**	**64**	**80**	**96**	**73**	**99**	**148**	**188**	
ICE	51	50	17	3	68	59	47	30	
BEV+FCEV	1	14	63	93	6	40	101	159	acceleration
Industry									
Volumes, mn t									
Iron&steel	1,982	2,042	2,094	2,147	1,955	2,015	2,066	2,118	
Non-metallic minerals (lime, clay, cement)	4,138	4,174	4,186	4,190	4,249	4,363	4,403	4,417	
Aluminium	121	149	185	229	119	152	194	249	
Chems - ammonia	242	354	570	730	219	267	326	397	
Chems - methanol	127	152	180	214	126	154	187	229	
Chems - HVCs	314	387	478	591	351	444	503	521	
Share of CCUS, hydrogen, electricity, bioenergy %									
Iron&steel	44%	73%	94%	100%	42%	73%	93%	100%	deceleration
Non-metallic minerals (lime, clay, cement)	4%	21%	62%	97%	11%	37%	70%	95%	acceleration
Aluminium	35%	39%	46%	63%	30%	38%	60%	74%	mixed
Chems - ammonia	7%	34%	63%	98%	7%	31%	48%	75%	deceleration
Chems - methanol	4%	23%	60%	98%	5%	23%	43%	71%	deceleration
Chems - HVCs	13%	30%	50%	66%	5%	26%	56%	75%	
Buildings									
Share of electricity, bioenergy, renewables %	42%	70%	94%	99%	47%	59%	72%	84%	deceleration
CCUS									
Carbon captured annually, mn t	691	3,929	6,766	7,720	193	2,010	4,068	5,935	deceleration
Hydrogen									
Green hydrogen demand, mn t	24	135	299	375	8	38	84	145	deceleration

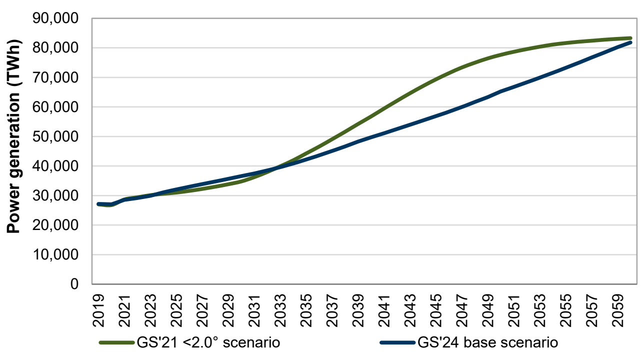
*acceleration/deceleration stand for the trajectory of the decarbonization trend

Source: Goldman Sachs Global Investment Research, Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Ember, Energy Institute Statistical Review of World Energy

Power generation

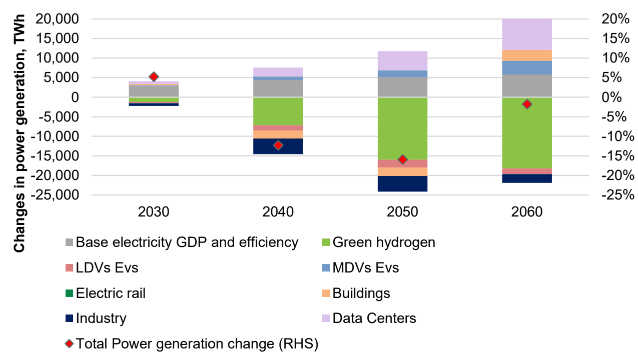
Global electricity generation increases by c.2.7 times by 2060 vs 2023 in the GS 2024 base scenario (vs 2.8 times in our previous report). We see total electricity demand growing faster by the end of the decade, with an average annual growth rate of c.3% vs c.2% expected before, reflecting near-term rapid acceleration of Chinese electricity demand on the back of increased electrification in the transport, buildings and industry sectors. Despite slightly higher power generation in the near term, we see slower development of electricity demand in the longer term, mainly impacted by significantly slower clean hydrogen development and slower adoption of EVs and heat pumps after 2030, partly offset by the new rising source of electricity consumption – data centers and cryptocurrencies. We estimate electricity consumption of data centres (including cryptocurrencies) to account for about c.2% of global electricity demand in 2030, potentially rising to c.10% by 2060.

Exhibit 23: Global electricity generation increases by c.2.7 times by 2060 vs 2023 in our GS 2024 base scenario (vs 2.8 times in our previous report)
Power generation (TWh): 2024 GS 2.0 degrees scenario vs 2021 GS <2 degrees



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 24: We see slower development of electricity demand in the longer term, mainly impacted by slower clean hydrogen development and slower adoption of EVs and heat pumps after 2030, partly offset by the new rising source of electricity consumption - data centers and cryptocurrencies
Changes in power generation demand by sector in 2024 GS 2.0 degrees scenario vs 2021 GS <2 degrees

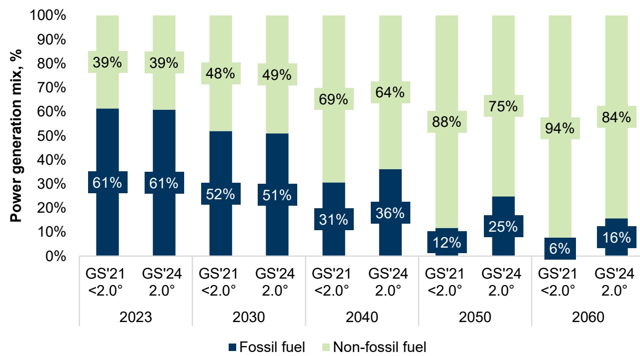


Source: Goldman Sachs Global Investment Research

The 2024 GS 2.0 degrees scenario, a more realistic, but still ambitious path, assumes **a slower pace of transition towards non-fossil energy sources**: until 2030, we project the same split between fossil and clean energy sources as we had in the **2021 GS <2.0° pathway, with the share of non-fossil fuel reaching c.50% by 2030.** However, low-emission sources of electricity – renewables, nuclear and hydrogen – expand at a less rapid pace thereafter vs our 2021 assumptions, overtaking unabated fossil fuels just after 2030 and reaching 75% of total generation by 2050 and c.84% by 2060. Besides the smaller share of renewables in the power generation mix, we assume that **natural gas plays less of a role, as a swing producer, until 2040 due to the slower phase-out of coal in the 2024 scenario than in the 2021 version**. We have lowered natural gas's share in power generation from 27% to 20% in 2030 driven by the increased share of coal from 23% to 28% on the back of the continuing growth observed in coal-fired power generation in the last three years, partly caused by the energy crisis and record-high natural gas prices. However, **starting from 2050, we**

attribute a higher share in the power generation mix to natural gas (14% in 2050 and 7% in 2060 vs 5% and 0%, respectively, in our 2021 report) due to the more gradual phase-out of gas and slower adoption of clean electricity sources.

Exhibit 25: The 2024 GS 2.0 degrees scenario assumes a slower pace of transition towards non-fossil energy sources
Power generation mix (%): 2024 GS 2.0 degrees vs 2021 GS <2 degrees



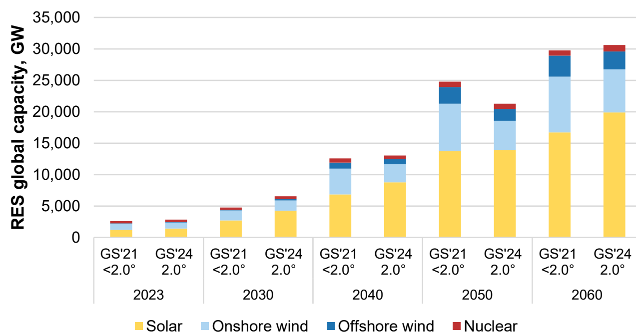
Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

We expect global RES capacity additions to diverge from our 2021 GS <2.0°C scenario, with solar PV and nuclear capacity additions surpassing our previous estimates, but a slower pace of wind capacity developments

Our 2024 GS net zero path includes **a faster and larger increase in solar PV capacity than the 2021 version**. Solar PV capacity is c.60% and c.19% higher in 2030E and 2060E, respectively, than in the 2021 GS <2.0°C scenario, reflecting recent market acceleration and the rapid scaling up of manufacturing capabilities. We also expect the **increased interest in nuclear power** observed in the last two years **to continue, with growing acceptance of the need for nuclear energy as part of de-carbonization efforts**. In particular, at COP28, more than 20 countries launched a declaration to triple nuclear energy capacity by 2050 vs 2020. We project global installed nuclear power capacity to double by 2050 vs 2020, exceeding our previous estimates by c.30% in 2030/60, reflecting strengthened policy support in leading markets and small modular reactors paving the way for a nuclear energy revival. On the other hand, we project a **deceleration in wind power generation, with global installed capacity c.20% lower by 2060 than in our 2021 report due to a tough macroeconomic environment**. The wind industry, especially in Europe and North America, is facing challenges owing to a combination of ongoing supply chain disruptions, higher costs and long permitting timelines. Reflecting these challenges, we have lowered our forecasts for onshore and offshore wind additions as overall project development has been slower than expected. Hydrogen and fossil fuels with carbon capture also play a smaller role than in our 2021 report as a result of continuing high costs and a smaller-than-expected number of projects.

Exhibit 26: Solar PV and nuclear capacity additions surpass our previous estimates, but wind capacity shows a slower pace of development

Global RES installed capacity, GW: 2024 2.0 degrees scenario vs 2021 GS <2 degrees

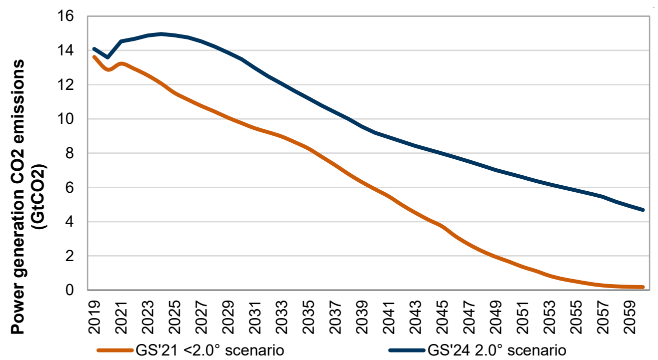


Source: Ember, Goldman Sachs Global Investment Research

We estimate a 1.8x increase in power generation emissions vs the 2021 GS <2.0°C scenario

Overall, we expect **growth in CO2 emissions from power generation, with cumulative CO2 emissions from 2024 to 2060 increasing by 1.8x vs the 2021 GS <2.0°C scenario, driven by a higher share of fossil fuels in the energy mix**. We now project 2025 as the first year when the trend reverses and power generation emissions start to drop consistently, while previously we had 2022 as a starting point for emissions reduction. While in the previous scenario, power generation was one of the fastest sectors to de-carbonize and become almost emissions-free by 2060, we now model some emissions in 2070 due to the unabated fossil fuels such as coal and natural gas consumed in emerging markets and developing economies, which still account for c.7% of the power generation mix (incl. fossil fuels equipped with CCUS). The total carbon budget allocation to the sector is 431Gt, representing 35% of the total carbon budget to 2070, while in the 2021 GS <2.0°C scenario, power generation contributed c.246Gt to RCB (Remaining Carbon Budget).

Exhibit 27: We estimate a 1.8x increase in power generation emissions to 2060 vs the 2021 GS <2.0°C scenario
Power generation CO2 emissions (GtCO2): 2024 vs 2021 comparison

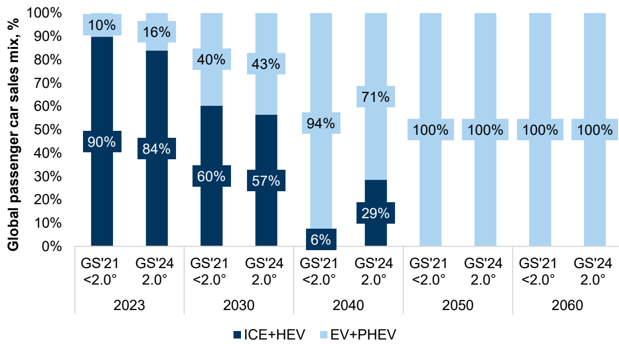


Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, Goldman Sachs Global Investment Research

Transport

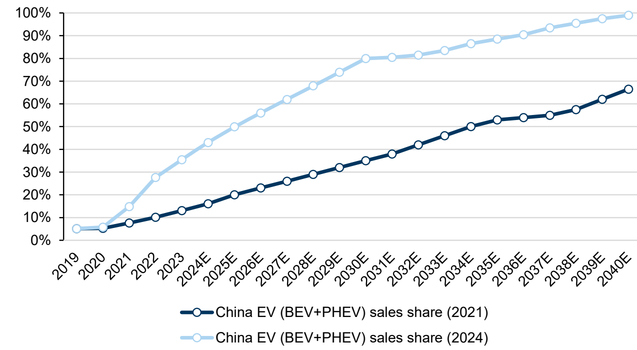
In the transport sector, **EV (BEV and PHEV) penetration in passenger car sales in 2021-23 overshot our 2021 expectations** primarily due to faster-than-expected EV penetration in China. In 2023, the global EV share in passenger car sales reached 16% compared with our 10% expectation in 2021. China became a leader in EV penetration with c.35% EV sales share in 2023, significantly exceeding the 13% projection of our global Auto team, supported by government subsidies, tax breaks and other policy incentives, as well as a number of homegrown EV brands. Our global Auto team now expect the EV sales share in China to reach 80% in 2030 (vs a previous expectation of 35%) and 99% in 2040 (previously expected at 67%). The US and Europe have slightly undershot their EV expectations (Exhibit 30 and Exhibit 31), and they have lowered their 2024-2027 EV penetration forecasts to account for the recent slowdown in EV sales (link), with several automakers having said that concerns about driving range and charging infrastructure are increasing. Overall, the 2024 GS net zero path includes **faster EV penetration by 2030 than the 2021 version,** primarily due to higher EV adoption in China, and **slower adoption post 2030,** as we moderate our assumptions for the rest of the world: **we now model EV sales share reaching 100% globally in 2050 vs 2042 before (Exhibit 28).**

Exhibit 28: 2024 GS net zero path includes faster EV penetration by 2030 than the 2021 version, and slower adoption post 2030
Global EV (BEV+PHEV) share in LDV sales, 2024 vs 2021 projections comparison



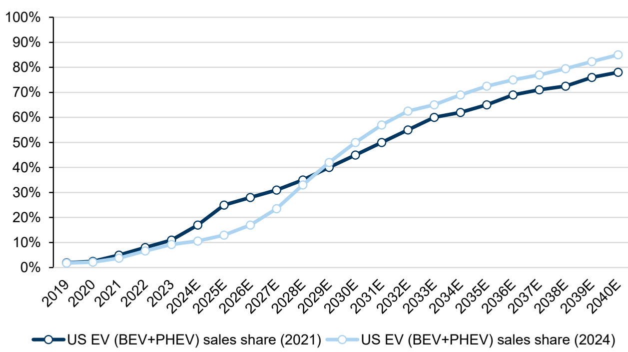
Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 29: China far overshot our 2021 EV sales expectations
China EV (BEV+PHEV) share in LDV sales, 2024 vs 2021 projections comparison (Powertrain model)



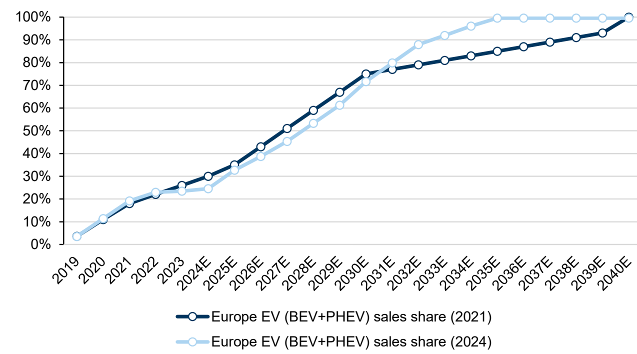
Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 30: Our global Autos team now model lower EV sales share in the US in 2024-28 than they did in 2021
US EV (BEV+PHEV) share in LDV sales, 2024 vs 2021 projections comparison (Powertrain model)



Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 31: Europe EV penetration has been roughly in line with expectations; we model some slowdown in 2024-25 before penetration accelerates and reaches 100% by 2035E
Europe EV (BEV+PHEV) share in LDV sales, 2024 vs 2021 projections comparison (Powertrain model)

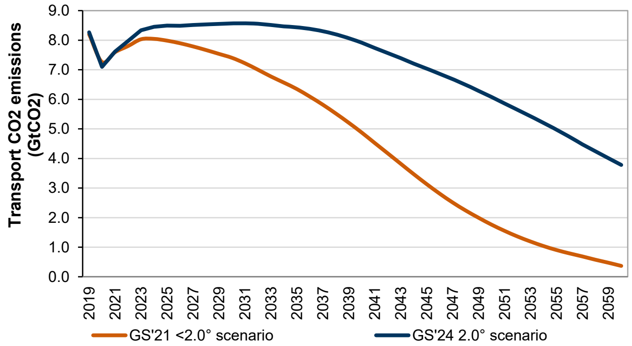


Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

With regard to our global car fleet forecast, we leverage the analysis of our APAC Energy team and their global ROAD (Refining Oil Auto Demand) to account for global passenger vehicle fleet growth and increased vehicle ownership in EM. Our APAC Energy team expect the global passenger vehicle fleet to grow at a c.3% CAGR in 2024-2030E, supported by India, where the adoption of 4-wheel cars is set to accelerate, and vehicles penetration to increase from <40/thousand people to almost 100 by 2040E (180 global average in 2023 and c.600-700 in DM), as well as China, where they expect vehicle penetration to increase from 200/thousand people to almost 350 by 2040. Therefore, **the 2024 GS net zero path envisages global ICE fleet growth of c.6% by 2030 vs a decline of 4% in our 2021 edition,** and a much slower phase-out of ICE cars post 2030 than previously expected (see Exhibit 33); this results in higher oil demand and higher transport emissions than previously expected: **cumulative CO_2 emissions from 2024 to 2060 increase by 70% vs the 2021 GS <2.0°C scenario (Exhibit 32).**

Exhibit 32: Cumulative CO2 emissions from 2024 to 2060 increase by 70% vs the 2021 GS <2.0°C scenario

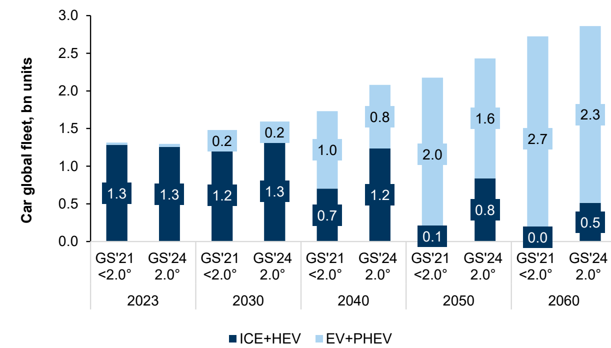
Transport CO2 emissions (GtCO2): 2024 vs 2021 comparison



Source: Goldman Sachs Global Investment Research

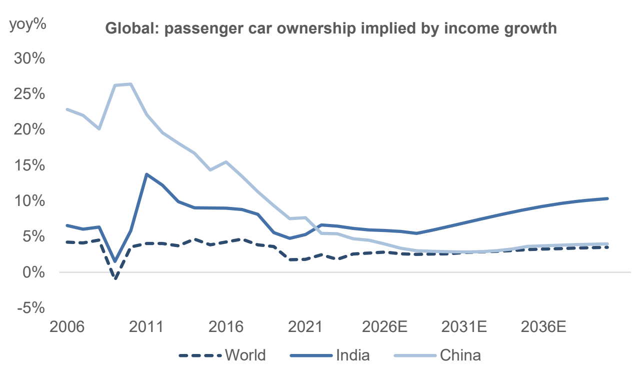
Exhibit 33: We increase our estimates for the ICE fleet in line with our APAC energy team's projections

Global car fleet split, bn units, 2024 vs 2021 projections comparison



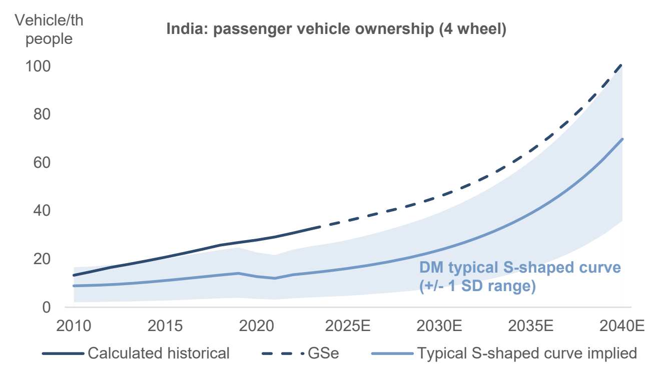
Source: Goldman Sachs Global Investment Research

Exhibit 34: The global passenger vehicle fleet could continue to grow at a c.3% CAGR



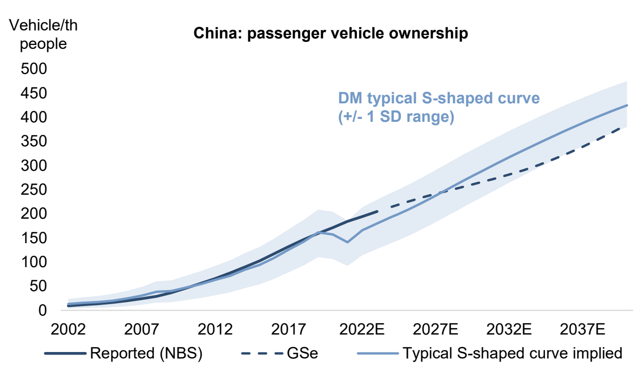
Source: Respective government statistics agencies, World Bank, Goldman Sachs Global Investment Research

Exhibit 35: India's adoption of 4-wheel cars is set to accelerate as income grows



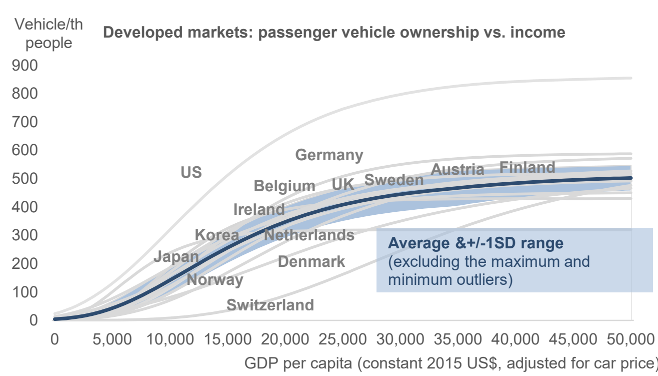
Source: SIAM, World Bank, Wind, Goldman Sachs Global Investment Research

Exhibit 36: For China, vehicles penetration is set to increase from 200/thousand people to almost 350 by 2040E



Source: NBS, World Bank, Goldman Sachs Global Investment Research

Exhibit 37: Typical S-shape curve for vehicle ownership from the historical data of developed economies



The average line represents the simple average of sample DMs

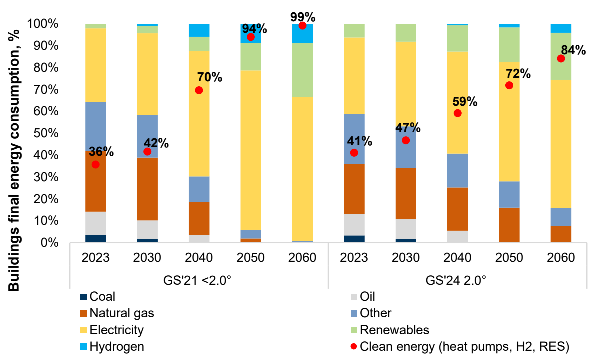
Source: Respective government statistics agencies, World Bank, Goldman Sachs Global Investment Research

Buildings

In the buildings sector, the main changes are a slower switch from natural gas to electricity, which primarily reflects a slower take-up of heat pumps and slower adoption of clean hydrogen in heating. By 2030, we project faster than previously expected deployment of clean energy sources in buildings, including heat pumps, hydrogen and renewables; we now assume the share of low-carbon energy sources reaches 47% by 2030 vs a 42% projection in our 2021 report. However, **in the long term, we forecast slower adoption of low-carbon energy, reaching c.84% by 2060 vs our previous assumption of c.99%, reflecting the challenges of retrofitting old buildings with heat pumps especially in emerging markets.** A higher share of low-carbon energy sources by 2030 leads to lower emissions from buildings vs the 2021 GS <2.0°C scenario; however, when the trend reverses, CO2 emissions start to surpass our previous estimates, with a more gradual reduction than previously expected (average annual decline rate of 4% vs 13% before). Overall, we forecast **growth in CO2 emissions from the buildings sector, with cumulative CO2 emissions from 2024 to 2060 increasing by 1.5x vs the 2021 GS <2.0°C scenario.** The total carbon budget allocation to the sector is 94Gt, representing c.7% of the total carbon budget to 2070, while in the 2021 GS <2.0°C scenario, power generation contributed c.64Gt to Remaining Carbon Budget (RCB).

Exhibit 38: In the buildings sector, the main changes are a slower switch from natural gas to electricity, which primarily reflects a slower take-up of heat pumps and slower adoption of clean hydrogen in heating

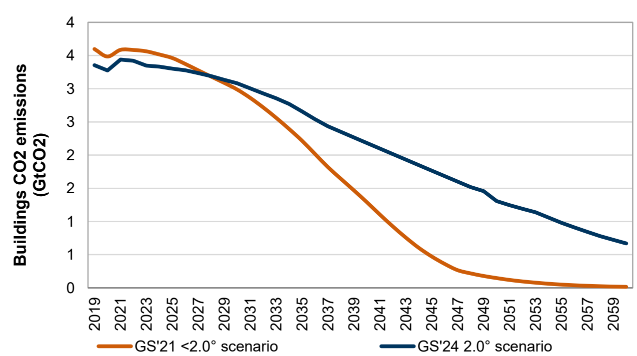
Buildings final energy consumption mix 2024 vs 2021 scenarios comparison, %



Source: Goldman Sachs Global Investment Research

Exhibit 39: We expect growth in CO2 emissions from the buildings sector, with cumulative CO2 emissions from 2024 to 2060 increasing by 1.5x vs the 2021 GS <2.0°C scenario

Buildings CO2 emissions (GtCO2): 2024 vs 2021 comparison



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, Goldman Sachs Global Investment Research

Hydrogen

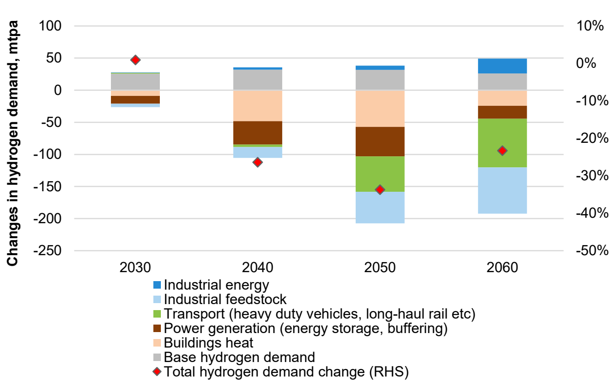
In the 2021 GS <2.0°C scenario, we estimated that the hydrogen market could increase eightfold by 2060 to >600 Mtpa, with clean hydrogen contributing c.20% of global de-carbonization. However, during the last year, we have observed some slowdown in the development of hydrogen projects driven by the high interest rate environment, more expensive renewable power generation and uncertainty associated with the publication of conditions to qualify for 45V incentives under the US IRA. **We are reflecting this slowdown in our global hydrogen demand forecasts, and now**

estimate that the hydrogen market could increase fivefold by 2060 to >470 Mtpa, with clean hydrogen contributing c.12% of global de-carbonization. The slowdown in FID and development of H2 projects has been observed across almost all industries. In transport, we have revised down consumption of hydrogen and hydrogen-based fuels, with the share of FCEVs in the HDV sales mix reaching c.17% by 2060 vs c.55% in our previous scenario. A similar downward revision was also applied to hydrogen use in buildings: the share of hydrogen in the buildings energy consumption mix has decreased from c.9% in 2060 based on our 2021 report to 4% in our 2024 GS 2.0 degrees scenario. We have also diminished the role of H2CGGT in the power generation mix, reducing its share from 4% to 3% in 2050. In contrast, we see more demand in industry for hydrogen, with the number of project announcements for hydrogen-based direct reduced iron (DRI) steel production increasing significantly since 2021; this is reflected in growth in the assumed share of H2 DRI-EAF in the technology mix of iron and steel production, from 26% in 2060 as of 2021 to c.50% in our 2024 2.0 degrees scenario.

Overall, we now expect lower global demand for green hydrogen than we did previously. **On average, the decrease is c.70% in annual global green H2 demand by 2060 between the two scenarios**, impacted by lower total hydrogen demand and a smaller share of green hydrogen in clean hydrogen, in particular.

Exhibit 40: We are reflecting the market slowdown in our global hydrogen demand forecasts and now estimate that the hydrogen market could increase fivefold by 2060, to >470 Mtpa

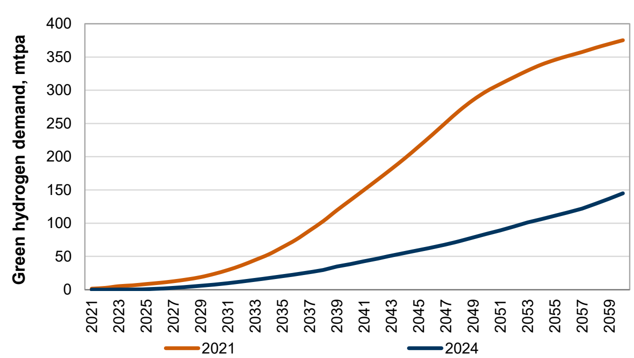
Changes in hydrogen demand by sector in 2024 2.0 degrees scenario vs 2021 GS <2 degrees, mtpa



Source: Goldman Sachs Global Investment Research

Exhibit 41: The average decrease is c.70% in annual global green H2 demand by 2060 between the two scenarios

Green hydrogen demand, mtpa



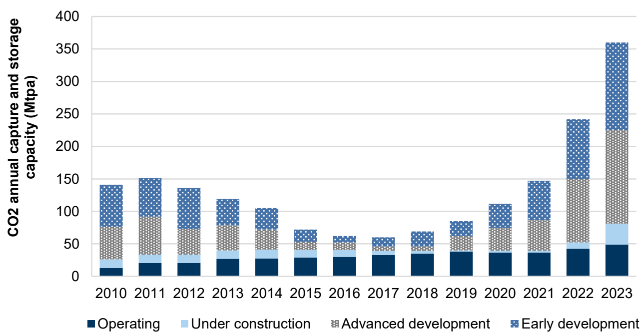
Source: IEA, Goldman Sachs Global Investment Research

CCUS

In the 2021 GS <2.0°C scenario, we estimated that carbon captured volumes would reach 140 mn t by 2023 and increase to 7.7 Gt by 2060. So far, we have seen slower CCUS capacity ramp-up, reaching c.50 mn t in 2023, significantly below our 2021 expectation of 140 mn t and representing only a modest increase from c.46 mn t CCUS capacity in 2020, according to the IEA. At the same time, the pipeline of commercial CCS facilities in development, construction and operation increased to 361 mtpa in 2023 from c.110 mtpa in 2020 (c.50% 3Y CAGR), according to the Global CCS Institute, with rapid escalation in the development of new projects, although relatively few have yet advanced to operation given a c.7-year average development time. We continue to believe CCUS technology will play a meaningful role in reaching net zero, especially in hard-to-abate industries (cement, steel, chemicals), but we moderate the pace of adoption to account for the slower growth seen so far. We now forecast c.200 mtpa of carbon captured by 2030 (vs 690 mtpa before), 2 Gt by 2040 (4 Gt before) and 4 Gt by 2050 (6.7 Gt before).

Exhibit 42: The pipeline of commercial CCS facilities in development, construction and operation increased to 361 mtpa in 2023

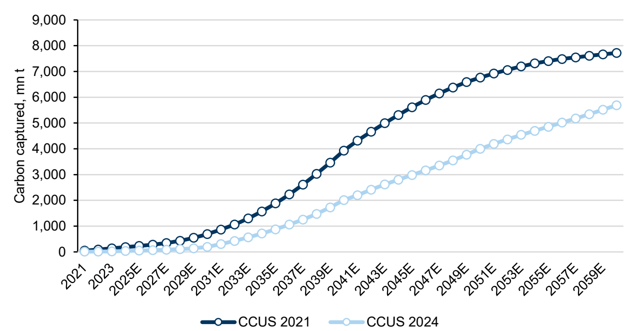
Annual CO2 capture & storage capacity from large-scale CCS facilities



Source: Global CCS Institute Status Report 2023

Exhibit 43: We moderate the pace of adoption to account for the slower growth seen so far

CCUS captured, mtpa



Source: Goldman Sachs Global Investment Research

Increased role of fossil fuels in the energy mix

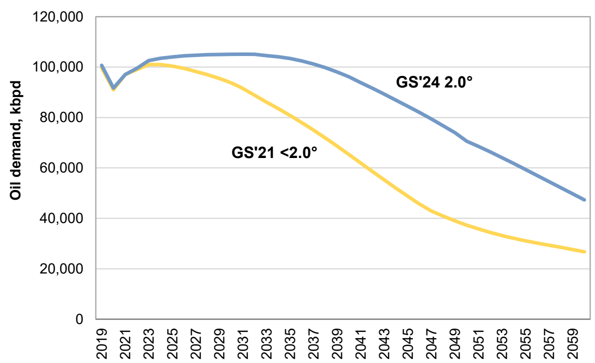
In the exhibits that follow, we present the total oil, natural gas and coal demand under the two paths we focus on here (2021 GS <2.0° and 2024 GS 2.0°). In the case of oil, our 2024 GS 2.0° scenario envisions significantly higher oil demand until 2060 compared with the 2021 GS <2.0° scenario (Exhibit 44), primarily driven by higher oil product consumption in light-duty vehicles (Exhibit 45) as we revise up our ICE fleet forecast (see *Transport* section for more details). We now expect oil demand to peak in the early 2030s compared with 2023 before.

The case of natural gas on the other hand is different, with total demand for natural gas lower in the 2024 GS 2.0° scenario than the 2021 GS <2.0° scenario until 2043, mainly on the back of lower demand in power generation due to the increased role of coal-fired power generation, as well as the smaller role of carbon-capture in reducing emissions from fossil fuel power plants given the lack of new projects. However, we see a reversal of the trend from the early 2040s, with total natural gas demand surpassing our previous estimates in the 2021 GS <2.0° path given both the larger carbon budget and the extra available decade to achieve global net zero, which enables a smoother and less abrupt transition. Such a transition appears more realistically achievable under the current economic and policy frameworks in place globally, compared with the 2021 GS <2.0° scenario.

In the case of coal, overall demand is higher in our 2024 GS 2.0° scenario, with this scenario allowing the flexibility for a slower demand decline compared with the 2021 GS <2.0° scenario. The increase in coal demand between the two scenarios is predominantly driven by a higher share of coal in the power generation mix.

Exhibit 44: The 2024 GS 2.0° scenario allows the flexibility for a slower oil demand decline compared to the 2021 GS <2.0° scenario; peak oil demand moves to the early 2030s vs our previous estimate of 2023

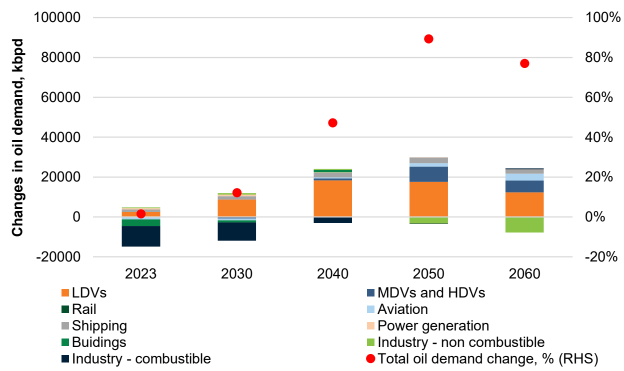
Oil demand (kbpd) under the two paths



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 45: The higher demand for oil is mainly driven by a higher share of traditional ICES and HEVs in the car fleet mix

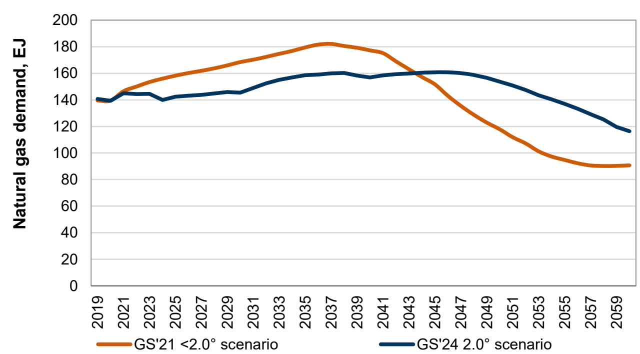
Changes in oil demand in our 2024 2.0° scenario vs 2021 GS <2.0, kbpd



Source: Goldman Sachs Global Investment Research

Exhibit 46: Natural gas demand is lower in our 2024 GS 2.0° scenario until 2043, mainly on the back of lower demand in power gen due to the increased role of coal-fired power generation...

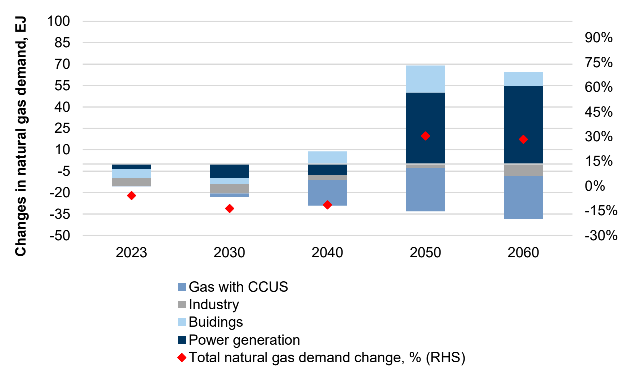
Natural gas demand (EJ) under the two paths



Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

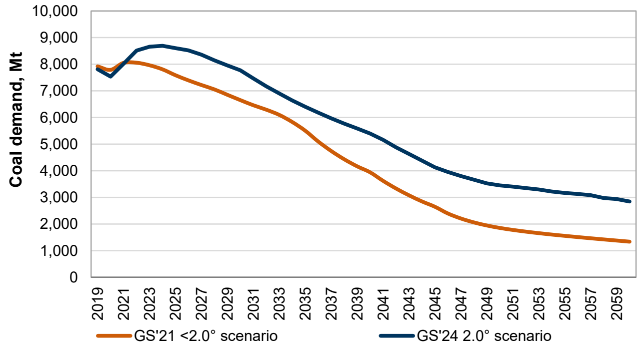
Exhibit 47: ...however, we see a reversal of the trend from the early 2040s, with total natural gas demand surpassing our previous estimates

Changes in natural gas demand, EJ



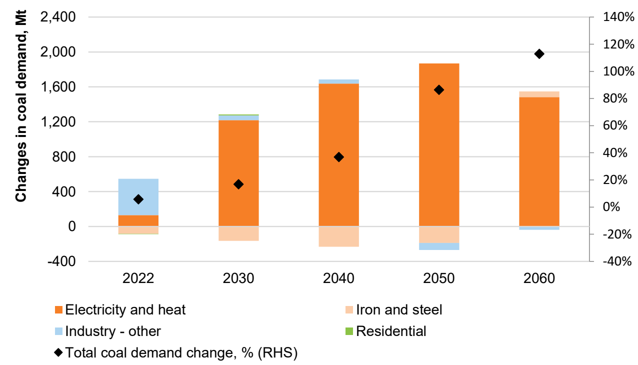
Source: Goldman Sachs Global Investment Research

Exhibit 48: In the case of coal, overall demand is higher in our 2024 GS 2.0° scenario, with this scenario allowing the flexibility for a slower demand decline
Coal demand (Mt) under the two paths



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 49: The increase in coal demand between the two scenarios is predominantly driven by a higher share of coal in the power generation mix
Changes in coal demand, Mt

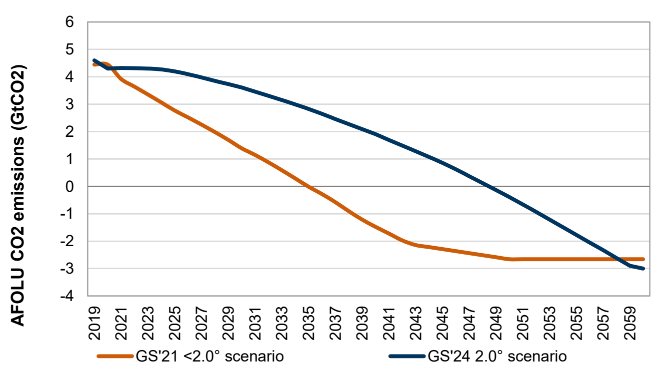


Source: Goldman Sachs Global Investment Research

AFOLU: Reaching a natural net emissions sink by 2050 vs 2035 in the 2021 GS <2.0°C scenario

Historically, carbon emissions from AFOLU have been very volatile, fluctuating in the range of 4.3-5.8 GtCO2 since 2000. We project AFOLU emissions (including LULUCF) to show an average annual decline rate of c.13% between 2023 and 2050 and reach a natural net emissions sink from 2050 thanks to reforestation, soil carbon sequestration, agroforestry and other ways of carbon dioxide removals. In the 2021 GS <2.0°C scenario, we projected a higher annual reduction rate of c.19%, reaching a carbon sink in 2035. The trend for AFOLU remains more uncertain due to the multitude of drivers that affect emissions and removals for land use, land-use change and forestry.

Exhibit 50: We forecast AFOLU to reach a natural net emissions sink by 2050 vs 2035 previously
AFOLU emissions (GtCO2): 2024 vs 2021 2.0° scenario comparison



Source: GCB, Goldman Sachs Global Investment Research

Comparing our updated 3 global carbon neutrality scenarios: 2.0°C, <2.0°C and 1.5°C

We have constructed **three global emission paths** for **carbon neutrality:**

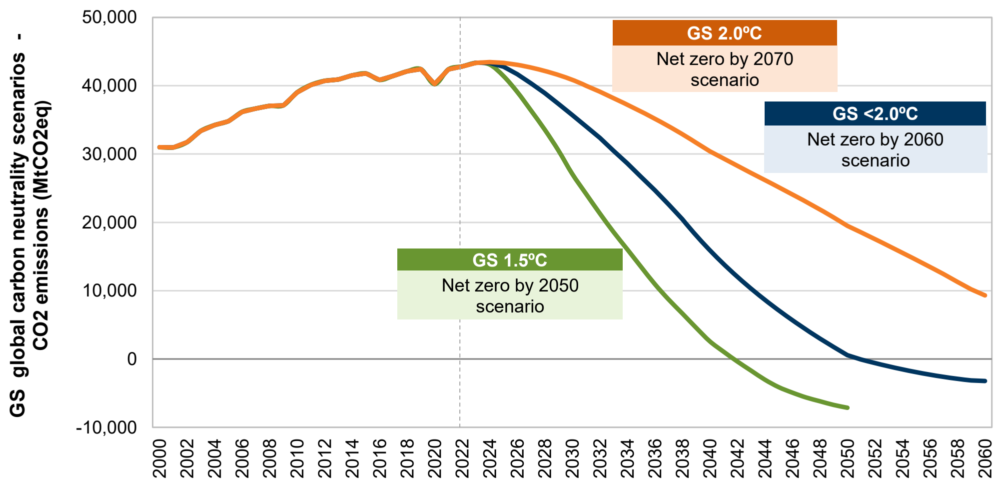
- **GS more realistic, but still ambitious scenario, or 2.0°:** We see this as the most realistic scenario, with **global net zero achieved by 2070** and global warming reaching 2.0°C in 2100, short of the Paris Agreement ambitions.
- **GS <2.0°:** A path consistent with **global net zero by 2060** and in line with **maintaining global warming well below 2.0°C,** consistent with the Paris Agreement ambitions.
- **GS 1.5°:** An aspirational path that aims for **global net zero by 2050,** with a carbon budget that would be **consistent with limiting global warming to 1.5°C with limited overshoot.**

While we focus primarily on outlining in detail our 2.0° scenario (GS 2.0°) in the later sections of this report, in this section we aim to draw some comparisons across the three scenarios.

In this report, we have introduced our less aspirational, but also perhaps more realistically achievable, global net zero scenario in which **global net zero is achieved by 2070,** with global warming reaching 2.0°C in 2100, short of the Paris Agreement ambitions. Exhibit 51 shows a comparison between the three emission paths, GS 2.0°, GS <2.0° and GS 1.5°. The carbon budget for the GS 2.0° scenario is higher than the GS <2.0°and GS 1.5° scenarios, but with a very wide range of carbon budget possibilities found in the literature across different scientific scenarios. For the purposes of this analysis, we define the carbon budget for our GS 2.0° 2.0° scenario to be within the range of the IPCC's RCP4.5 scenario, limiting warming to 2.0° with a likelihood of >50% (a wide range is provided; we choose a budget close to the mid-point), implying a cumulative remaining carbon budget of around 1250 $GtCO_2$ from 2020.

Achieving **net zero by 2050 or 2060, consistent with GS 1.5° and GS <2.0°, represent aspirational scenarios** that would require transformational changes across all key parts of the global energy ecosystem and broader economy, and in our view have a **limited probability of occurring under the current economic and policy frameworks globally.** For the purposes of the analysis presented in this report, we primarily focus on outlining in detail our sectoral approach for achieving global net zero by 2070 – the GS 2.0° scenario. Nonetheless, we also provide a scenario comparison with GS 1.5°and GS <2.0° to showcase some key technological and financial differences between the three paths. The carbon budget for our GS <2.0° scenario is within the range of the IPCC's RCP2.6 scenario (a wide range is provided; we choose a budget close to the mid-point), implying a cumulative remaining carbon budget of around 750 GtCO2 from 2020. In <2.0° scenario we reach net zero in 2051 (first year of negative net emissions thanks to offsets such as natural sinks and DACCS), however the remaining carbon budget is calculated until 2060 in line with the Paris Agreement. For the GS 1.5° scenario, we assume the carbon budget for remaining net cumulative CO2 emissions from all sources from 2020 to be c.500 GtCO2, consistent with limiting warming to 1.5°C with a 50% likelihood. That said, in GS 1.5° scenario, global net zero is achieved already by 2042 (first year of negative net emissions thanks to offsets such as natural sinks and DACCS); the remaining carbon budget is calculated until 2050 in line with Paris Agreement.

Exhibit 51: We have constructed three global carbon neutrality scenarios: one aspirational scenario consistent with 1.5°C global warming by 2100; one consistent with well below 2.0°C global warming, in line with the Paris Agreement ambition; and the scenario we see as most realistic, with global net zero by 2070 and global warming reaching 2.0°C in 2100, short of the Paris Agreement ambitions
GS Global net zero carbon scenarios CO2 emissions (MtCO2)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, Goldman Sachs Global Investment Research, GCB

Carbon budgets

Our GS 2.0° path to global net zero by 2070 addresses all the key emitting sectors: power generation, transport, industry and waste, buildings and AFOLU including agriculture, forestry and other land use emissions. As mentioned in the previous sections, the pace of de-carbonization in each sector and sub-sector included in our path is expected to vary, depending on the carbon abatement cost and readiness of the available de-carbonization technologies. Consequently, we expect the sectoral and sub-sectoral allocation of the carbon budget required to limit global warming within 2.0°C to be different from the current share of emissions of each sector. The sectoral and sub-sector allocations of the remaining carbon budget to 2070 are shown in Exhibit 52. Power generation and industry are the two key sectors with the largest carbon budget allocation to 2070, c.35% and 31%, respectively, reflecting the return of coal-fired power generation in the wake of the 2022 energy crisis and industry being responsible for some of the hardest-to-abate emissions, with the clean technology alternatives relatively costly and in several cases largely undeveloped. Among these are heavy industries (iron & steel, cement, high-temperature heat).

Exhibit 52: Sectoral coverage of CO2 emissions under our GS 2.0° path and sectoral carbon budget allocation to 2070

Sectoral approach emissions analysis	Further sectoral emissions analysis breakdown	GS 2° path: Carbon budget allocation (GtCO2)	GS 2° path: Carbon budget allocation (% of total budget)	
Power Generation	Power Generation	431	35%	35%
Transportation	Aviation	43	3%	25%
	Shipping	39	3%	
	Rail	2	<1%	
	Light-duty road transport	142	11%	
	Heavy-duty road transport	83	7%	
Buildings	Residential buildings	63	5%	7%
	Commercial buildings	31	2%	
Industry (combustion & process), fugitive & waste	Iron & Steel	71	6%	31%
	Cement	71	6%	
	Aluminium*	15	1%	
	Chemicals & petrochemicals, incl. ammonia, methanol, HVCs	50	4%	
	Pulp, paper & packaging	3	<1%	
	Food & tobacco processing	19	2%	
	Other industry incl. fuel extraction/ processing and waste	162	13%	
AFOLU (Agriculture, forestry, other land use)	Agriculture and land use change	87	7%	1%
	Natural sinks, DACCS	-69	-6%	
	Total carbon budget GS 2.0	1,248	100%	

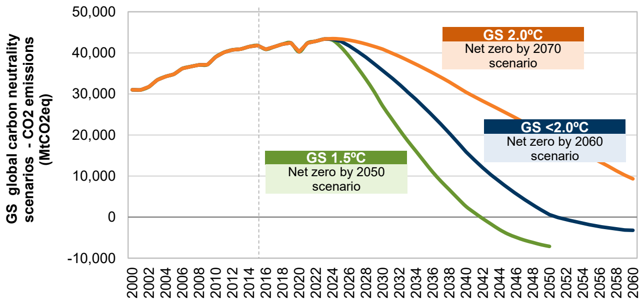
Source: Goldman Sachs Global Investment Research

1) Comparison of sectoral carbon budgets allocation: Under the current economic and policy framework, all sectors, especially power generation, transform at a slower and more achievable pace under the GS 2.0° scenario compared to GS 1.5° and GS <2.0°

We have adopted the **same methodology and sectoral hybrid approach for the construction of all three scenarios**, leveraging our Carbonomics de-carbonization cost curve, and allocating the available carbon budget across different emitting industries on the basis of the current cost and technological readiness. The more aspirational GS 1.5° path has a very strict carbon budget and as such calls for a complete and immediate overhaul of the energy sector that requires transformative changes across all key emitting industries globally. It also aims to achieve global net zero by 2050, while the GS <2.0° path envisages global carbon neutrality by 2060 (a decade later and in line with the ambitions laid out by the world's largest emitter, China). Our newly introduced GS base 2.0° path is a less aspirational, but perhaps more realistically achievable, global net zero path that implies global net zero by 2070, with global warming reaching 2.0°C.

Exhibit 53: In this section of the report, we focus on drawing comparisons between our three global net zero scenarios consistent with 1.5, <2.0 and 2.0 degrees of global warming, respectively...

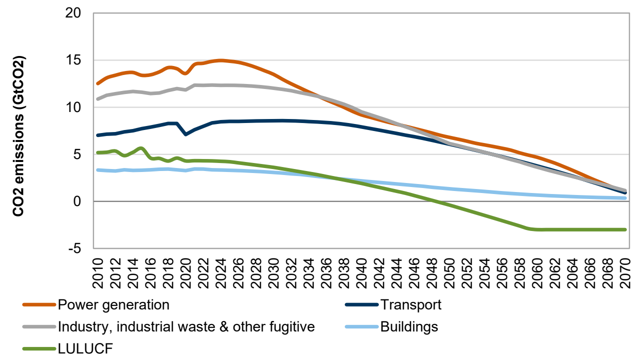
GS global carbon neutrality scenarios CO2 emission (MtCO2)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 54: ...with the three paths...

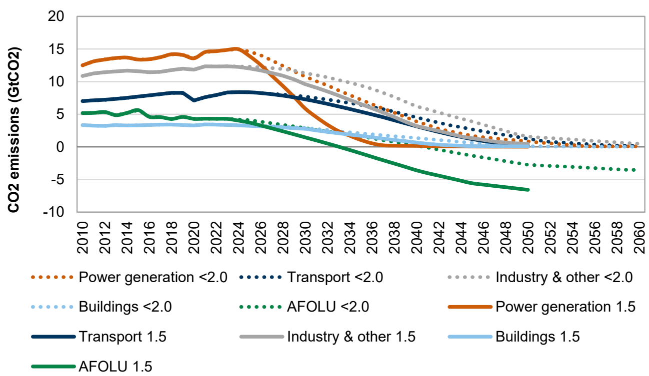
GS 2.0 (base) CO2 emissions by sector (GtCO2)



Source: Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 55: ...showing different sectoral carbon emission allocations

GS 1.5 vs GS <2.0 CO2 emissions by sector (GtCO2)



Source: Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

In Exhibit 53 and Exhibit 55 above, we show a comparison of the emission paths under the three scenarios, both in aggregate and by sector. It is evident that all sectors de-carbonize at a faster pace under the GS 1.5° path compared to the <2.0°or 2.0° path given the lower available carbon budget and the additional decade/two decades to reach net zero. Within this, the most striking difference is the pace of de-carbonization of power generation. Under the more aspirational GS 1.5° path, power generation becomes the first sector to de-carbonize, and does so at a very fast pace. This is because power generation remains the sole key sector where the available clean de-carbonization technologies have been developed at scale and are economic under the current policy framework. In contrast, under the less strict GS <2.0° and more realistic GS 2.0° path, power generation de-carbonizes at a slower pace, enabling a greater role for natural gas as a transition fuel. Notably, the pace of de-carbonization of transport and industry is not too dissimilar under the three scenarios, implying that given the larger carbon budget under the GS <2.0 and GS 2.0 paths, industry and transportation have a relatively lower carbon budget contribution, leaving further space for power generation to de-carbonize.

Exhibit 56: The overall carbon budget and the sectoral carbon budget allocations differ between our three global carbon neutrality scenarios

Sectoral approach emissions analysis	Further sectoral emissions analysis breakdown	GS 1.5° path: Carbon budget allocation (GtCO2, % of total budget)			GS <<2.0° path: Carbon budget allocation (GtCO2, % of total budget)			GS 2.0° path: Carbon budget allocation (GtCO2, % of total budget)		
Power Generation	Power Generation	148	29%	29%	239	32%	32%	431	35%	35%
Transportation	Aviation	21	4%	30%	30	4%	24%	43	3%	25%
	Shipping	18	3%		22	3%		39	3%	
	Rail	2	<1%		2	<1%		2	<1%	
	Light-duty road transport	64	13%		71	9%		142	11%	
	Heavy-duty road transport	44	9%		52	7%		83	7%	
Buildings	Residential buildings	37	7%	10%	38	5%	8%	63	5%	7%
	Commercial buildings	16	3%		24	3%		31	2%	
Industry (combustion & process), fugitive & waste	Iron & Steel	43	8%	40%	52	7%	36%	71	6%	31%
	Cement	45	9%		56	8%		71	6%	
	Aluminium*	6	1%		9	1%		15	1%	
	Chemicals & petrochemicals, incl. ammonia, methanol, HVCs	29	6%		35	5%		50	4%	
	Pulp, paper & packaging	3	1%		3	<1%		3	<1%	
	Food & tobacco processing	9	2%		12	2%		19	2%	
	Other industry incl. fuel extraction/ processing and waste	68	13%		100	13%		162	13%	
AFOLU (Agriculture, forestry, other land use)	Agriculture and land use change	43	8%	-9%	63	8%	0%	87	7%	1%
	Natural sinks, DACCS	-88	-17%		-61	-8%		-69	-6%	
	Total cumulative budget	508	100%		751	100%		1,248	100%	

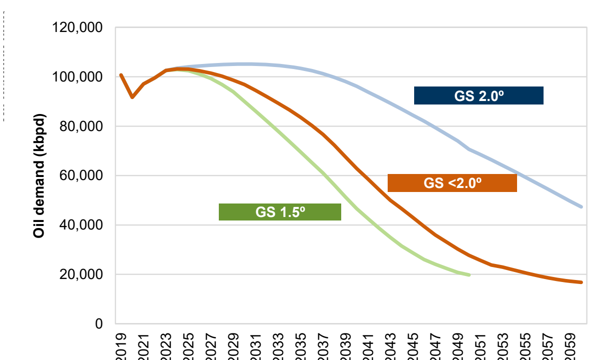
* Direct emissions Negative emissions indicate offsets from natural sinks and DACCS

Source: Goldman Sachs Global Investment Research

2) The role of fossil fuels: Natural gas is most sensitive to the scenarios given its role as a transitional fuel

In the exhibits that follow, we present total oil, natural gas and coal demand under the three paths we have constructed. In the case of oil, the overall path shown in Exhibit 57 looks similar under the three scenarios, with the GS 2.0° path allowing the flexibility for a slower demand decline compared to the GS <2.0° and GS 1.5° scenarios. The case of natural gas on the other hand is different, with the fossil fuel having a critical role as a transition fuel in the GS <2.0° and GS 2.0° paths given both the larger carbon budget and the extra available decade to achieve global net zero, which enables a smoother and less abrupt transition compared to the GS 1.5° path. The GS 2.0° transition appears more realistically achievable under the current economic and policy frameworks in place globally, compared to GS 1.5°. In the case of coal, the overall demand path looks similar under the three scenarios, with the GS <2.0° scenario allowing the flexibility for a slower demand decline compared to the GS 1.5° scenario, while the GS 2.0° scenario envisages a very gradual decrease in coal consumption, predominantly driven by a higher share of coal in the power generation mix.

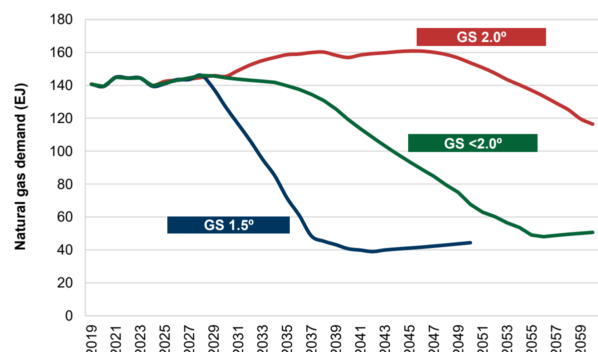
Exhibit 57: Oil demand shows a similar path under the three scenarios, with the key difference being the pace of demand decline for combustible oil...
Oil demand (kbpd) under our three paths



* We use the crude oil energy conversion to find the total energy in EJ without distinguishing between the different oil products

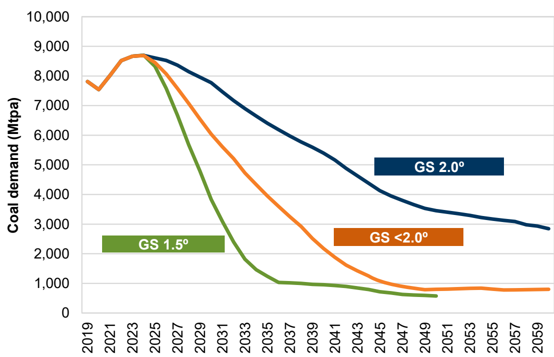
Source: Goldman Sachs Global Investment Research

Exhibit 58: ...while in contrast, the role of natural gas varies notably under the three scenarios, with the GS <2.0° and 2.0 scenarios° incorporating natural gas as a key transition fuel in power generation and industry, a flexibility that is not available under the more constrained GS 1.5° path
Natural gas demand (EJ)



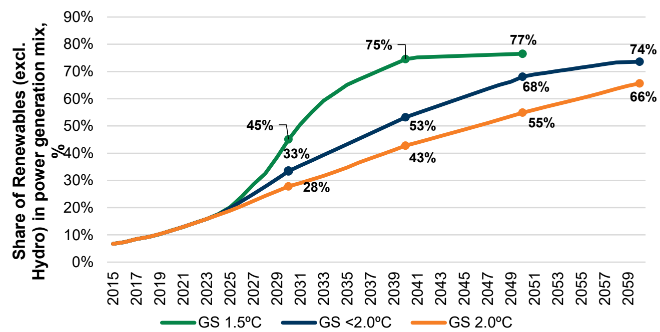
Source: Goldman Sachs Global Investment Research

Exhibit 59: In the case of coal, the overall demand path looks similar under the three scenarios, with the GS <2.0° scenario allowing the flexibility for a slower demand decline compared to the GS 1.5° scenario, while the GS 2.0° scenario envisages a very gradual decrease in coal consumption, predominantly driven by a higher share of coal in the power generation mix.
Coal demand (Mtpa)



Source: Goldman Sachs Global Investment Research

Exhibit 60: Renewables grow their share in the power generation mix significantly in the GS 1.5° scenario, offsetting a steep fall in coal and natural gas consumption
RES share in power generation mix, %



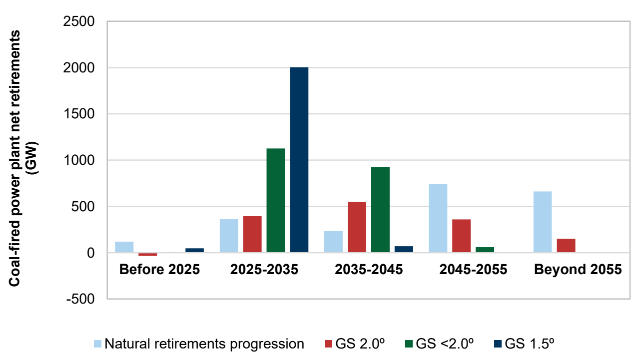
Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

3) Fossil fuel asset retirements: We believe 1.5° is becoming increasingly difficult to achieve due to an estimated $1.1 trn of potentially stranded coal assets

Given the differing pace of the transition of power generation between the three scenarios as described above, the pace of retirements of fossil fuel-based power plants also differs between the three scenarios. Exhibit 61 shows coal power plant retirements by decade on the path to global net zero under four distinct scenarios: (1) the natural retirement progression of existing coal power plant capacity based on the current age distribution of existing plants, (2) the net retirement of coal power plants in the GS 2.0° path, (3) the net retirement of coal power plants in the GS <2.0° path and (4) the net retirement of coal power plants in the stricter, more aspirational GS 1.5° path. As shown in the exhibit, both the GS <2.0° and GS 1.5° de-carbonization scenarios call for a faster pace of coal power plant retirements than the natural progression would suggest (given the relatively young coal power plant fleet in Asia, with the majority being <20 years old), but the GS <2.0° path shows a smoother retirement profile than GS 1.5°, which requires the vast majority of coal power plants to be retired by 2035. Unlike the two more strict scenarios, our base GS 2.0° path implies a pace of coal power plant retirements similar to the natural progression of retirements. The average operational lifetime of a coal-fired power plant in this analysis is assumed to be around 45 years. In the GS 1.5° scenario, many coal-fired power plants would not run for their anticipated life-expectancy. This would be likely to result in 'stranded assets', making coal an increasing financial risk. Our analysis suggests that if global action aligns to limit warming to 1.5°, early retirements required by 2035 would strand assets to the value of US$1.7 trn (assuming a value of US$2bn/ 1GW plant).

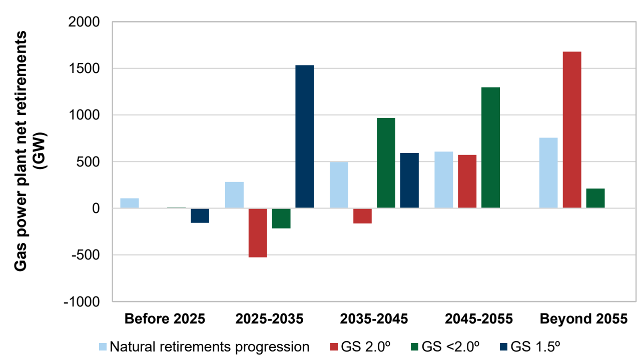
Exhibit 62 shows a similar analysis for natural gas power plants. The aspirational GS 1.5° path calls for net capacity additions before 2025, since the renewables capacity additions are not enough to offset the fast pace of coal retirements, thus requiring additional natural gas as a swing producer. However, after 2025, the GS 1.5° path calls for the retirement of all natural gas-fired plants by 2045, whilst in contrast the GS <2.0° path calls for net capacity additions over 2025-35 – with natural gas being a key transition fuel, particularly in emerging markets – and a more gradual pace of retirements based on the current age distribution of global gas power plants. In our GS 2.0° 2.0° scenario, natural gas plays a significant role, with net capacity additions continuing until 2045 due to the slower phase-out of gas and slower adoption of clean electricity sources, with natural gas plants still not retired by the end of 2070. The operational lifetime of a gas power plant in this analysis is assumed to be around 35 years, the average operating life of gas plants today.

Exhibit 61: While all of our global net zero scenarios assume a phase-out of coal power plants, the coal-fired plant retirement profiles under the GS <2.0 and 2.0 paths are smoother
Coal-fired power plant net retirements (GW)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 62: As natural gas is very sensitive to scenarios, the retirement schedule differs a lot across scenarios
Gas power plant net retirements (GW)



Source: Goldman Sachs Global Investment Research, Global Energy Monitor

The investment path: c.US$75 tn infrastructure investment opportunity on the path to carbon neutrality

The global path to net zero by 2070 requires, on our estimates, US$1.5-2 tn pa of infrastructure investments, representing c.1-1.5% of global GDP

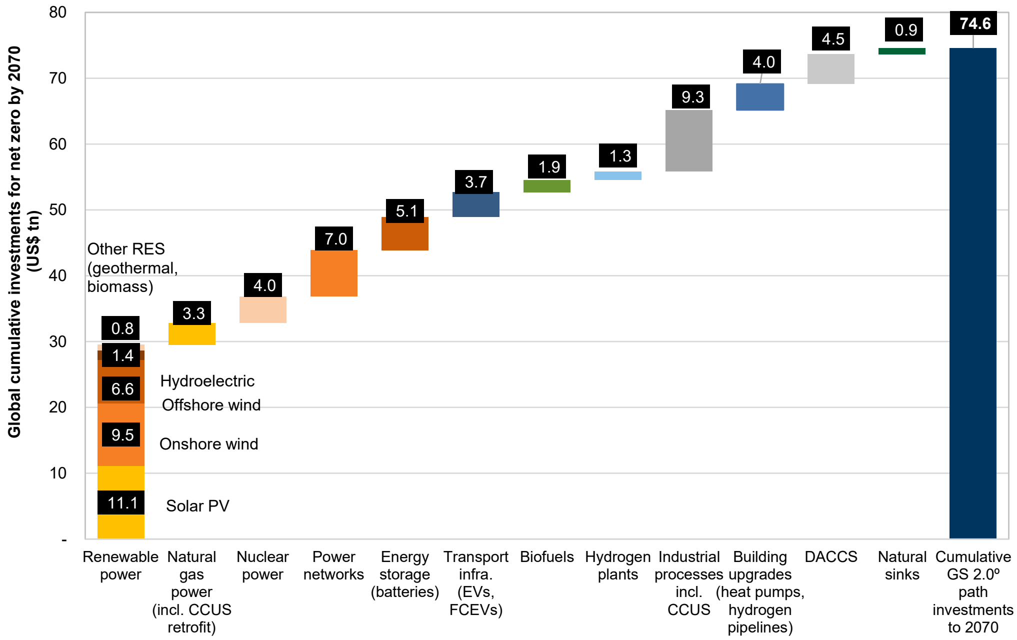
Our GS net zero carbon scenarios have the potential to transform not only the global energy ecosystems but also the economy and society's standard of living. Exhibit 63 shows the wide range of investment opportunities associated with what we believe are the key infrastructure milestones required to achieve net zero emissions by 2070. These include, among others, the increasing uptake of renewable energy and bioenergy, an increasing focus on infrastructure investments for networks and charging stations that will enable a new era of electrification, an upgrade and/or retrofit of industrial plants (the cleanest available alternative technology), retrofitting of buildings and other existing heating infrastructure, enabling greater uptake of cleaner fuels such as electrification and/or clean hydrogen, and finally a greater focus on carbon sequestration (natural sinks and carbon capture).

In aggregate, we estimate a total investment opportunity of around US$75 tn by 2070 in a scenario consistent with the path to net zero we have outlined above, which **implies an average annual green infrastructure investment opportunity of c.US$1.5-2 tn, representing c.1-1.5% of global GDP.** We note that this figure focuses solely on **incremental infrastructure investments** and does not include maintenance and other end-use capex.

Versus the previous edition, we see divergent cost dynamics across different technologies impacting our investment path projections: cost inflation and higher cost of capital have been most prominent in offshore wind, while solar power generation has been relatively less prone to cost inflation with solar module prices declining versus our previous estimates. Battery storage pace of ramp-up in power generation exceeded our 2021 expectations aided by falling battery prices. China is the global leader in the development of energy storage with battery energy storage capacity having surged to 30 GW in 2023 from c.5GW in 2021. Direct air capture costs overshot our 2021 expectations, with current cost estimates at c.$1,100/t CO_2 versus $400/t before. Overall, we estimate **a total investment opportunity of around US$75 tn by 2070 versus c.US$62tn by 2060 previously,** given our 2.0° scenario now envisages net zero by 2070 vs 2060 before.

Exhibit 63: We estimate that there exists in aggregate a c.US$83.4 tn investment opportunity across sectors on the path to global net zero by 2070

Cumulative investment opportunity across sectors for our GS 2.0° scenario global net zero by 2070 scenario (US$ tn)



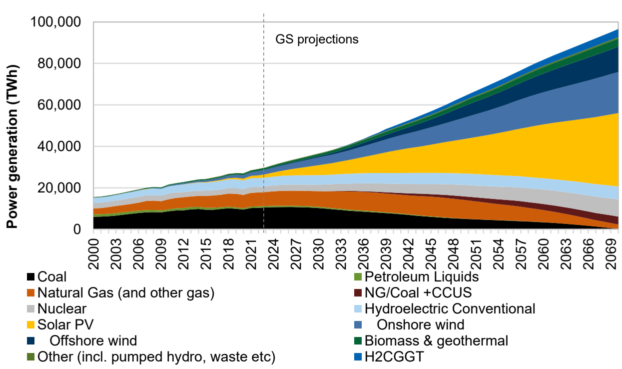
Source: Goldman Sachs Global Investment Research

Power generation: The critical component in global carbon neutrality

Power generation is the most vital component for any net zero scenario, with the sector contributing c.35% of global anthropogenic CO_2 emissions (incl. AFOLU), cumulative in our net zero path as a % of total emissions. The role of power generation is, in our view, only likely to increase in the coming decades, as the penetration and pace of electrification are rapidly increasing across sectors that are progressively following their own de-carbonization path (including, amongst others, road transport, building heating, industrial manufacturing processes and low-temperature industrial heat). Overall, we expect total demand for power generation in a global net zero scenario by 2070 to **increase threefold (vs. the level of 2023) and reach c.97,000 TWh as the de-carbonization process unfolds.**

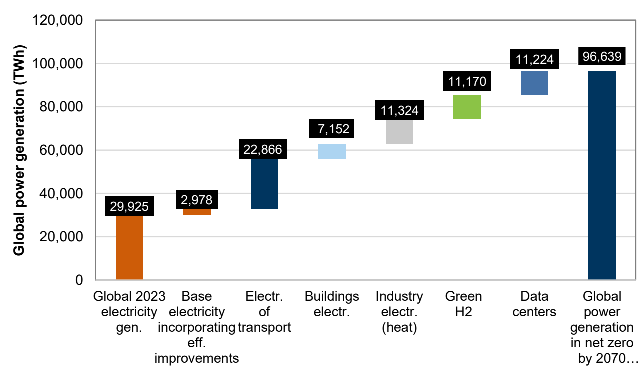
Based on our Carbonomics cost curve analysis, power generation currently dominates the low end of the carbon abatement cost spectrum, with renewable power technologies already developed at scale and costs that have fallen rapidly over the past decade, making them competitive with fossil fuel power generation technologies in many regions globally. Based on our GS 2° scenario, although power generation emissions decline rapidly, decreasing by c.94% by 2070 vs 2022 and reducing reliance on fossil fuels, we model some emissions in 2070 due to the unabated fossil fuels such as coal and natural gas consumed in emerging markets and developing economies, which still account for c.7% of the power generation mix (incl. fossil fuels equipped with CCUS). The total carbon budget allocation to the sector is 431Gt, representing c.35% of the total carbon budget to 2070, a portion that is equal to its current emissions share. The rapid acceleration of power demand leads to a critical need to accelerate the rise in share of carbon-free generation, in order to meet a carbon budget consistent with 2°C global warming.

Exhibit 64: Based on our global net zero by 2070 path, power generation demand increases threefold to 2070...
Global electricity generation (TWh)



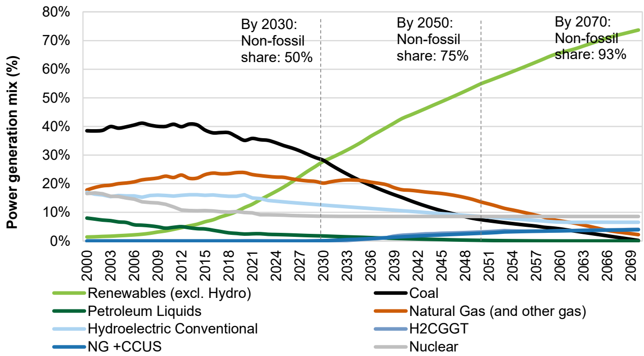
Source: Energy Institute Statistical Review of World Energy, Goldman Sachs Global Investment Research

Exhibit 65: ...as it forms a critical part of the de-carbonization route for other sectors, such as the electrification of transport, buildings, heat in industry, production of green hydrogen and more
Global electricity generation bridge to 2070E (TWh)



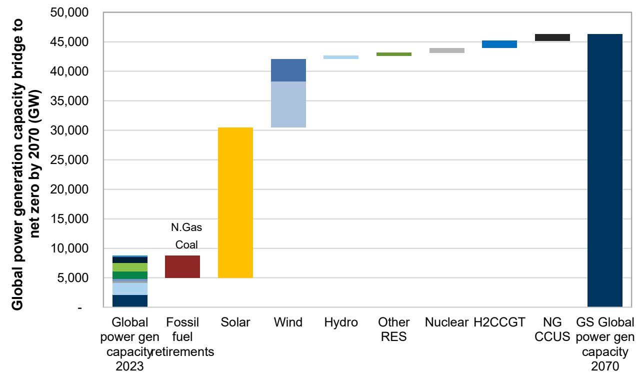
Source: Goldman Sachs Global Investment Research, Ember

Exhibit 66: A path consistent with net zero by 2070 requires transformational changes to the global power generation mix, with the non-fossil fuel share in our base GS 2.0 path rising from c.39% currently to >93% by 2070...
Global power generation fuel mix (%)



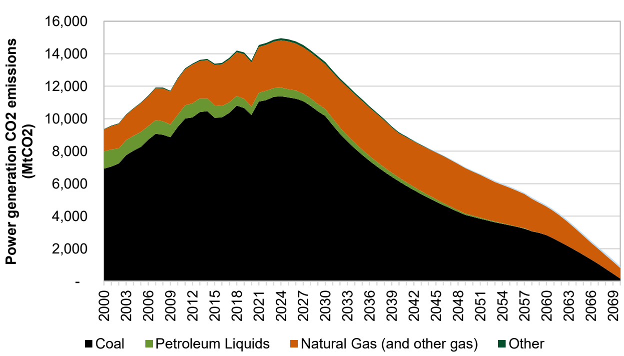
Source: Goldman Sachs Global Investment Research, Energy Institute Statistical Review of World Energy

Exhibit 67: ...leading to >25,000 GW of solar and >11,000 GW of wind net power generation capacity additions to 2070
Global net power generation capacity bridge to 2070 (GW)



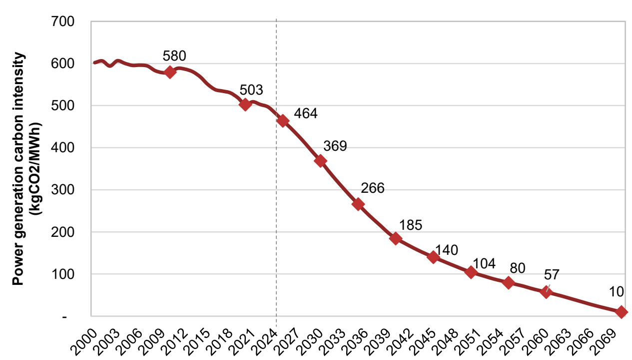
Source: Goldman Sachs Global Investment Research, Ember

Exhibit 68: Based on our GS 2° scenario, although power generation emissions decline rapidly, decreasing c.94% by 2070 vs 2022 and reducing reliance on fossil fuels, we model some emissions in 2070 due to the unabated fossil fuels such as coal and natural gas consumed in emerging markets and developing economies...
Power generation CO2 emissions (MtCO2)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 69: ...achieving close to zero carbon emissions by 2070 and helping to facilitate de-carbonization across other sectors through the uptick of electrification
Power generation carbon intensity (kgCO2/MWh)



Source: Goldman Sachs Global Investment Research, Energy Institute Statistical Review of World Energy

Renewable power: The low-carbon technology dominating 'low-cost de-carbonization', benefiting from economies of scale and a bifurcation in the cost of capital for high- vs. low-carbon energy

Renewable power is the key technology that is envisaged to transform the landscape of the energy industry. It represents one of the most economically attractive opportunities on our de-carbonization cost curve, on the back of lower technology costs as the industry benefits from economies of scale and a lower cost of capital. We estimate that **c.30% of the de-carbonization of global anthropogenic GHG emissions is reliant on access to clean power generation** (as shown in Exhibit 70), including electrification of transport and various industrial processes, electricity used for heating and more.

Renewable power costs have fallen >45% in aggregate across technologies over the past 15 years, thanks to the operational cost reduction that renewable energy has enjoyed over the past decade, owing to economies of scale. However, as we highlight in our report *Carbonomics: Cost curve 2023,* last year saw cost inflation and higher funding costs in renewable power leading to an increase in Levelized Cost of Energy (LCOE) for solar and wind yoy. The weighted average cost of capital (WACC) for new renewable power projects increased to c.4.8% in 2023 from c.3.6% in 2022, driven by the increase in risk-free rates in Europe and in the US. We show in Exhibit 75 how the change in the cost of capital and operational reduction have contributed to the reduction in LCOEs of renewable technologies since 2010. Financial and operational costs decreased until 2020, leading to a decline in LCOE in solar and wind power generation. However, in 2021-2022, the LCOE of off/onshore wind and solar grew, driven by higher financial and operating costs. In 2023, we observed higher equipment costs in renewable energy, although cost inflation has been most prominent in offshore wind, while in solar, module prices have been decreasing. Overall, higher interest rates and cost inflation led to the LCOE of renewable power generation (solar, wind) in Europe increasing by c. 11% yoy and c.40% vs the trough observed in 2020.

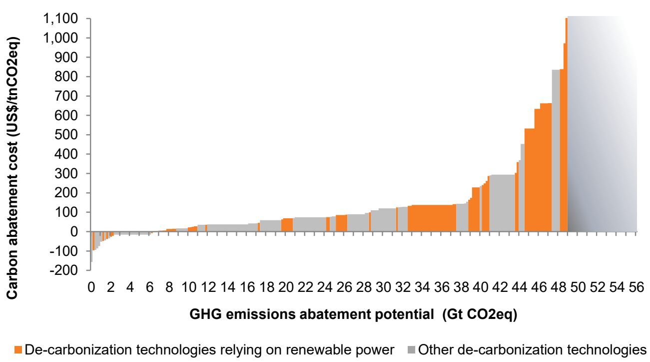
Cost inflation and higher cost of capital most prominent in offshore wind, while solar still offers the most attractive economics

Solar power generation has been relatively less prone to cost inflation, with solar module prices declining significantly since last summer. The ongoing decline in equipment costs, and somewhat stickier PPA prices, suggest better economics for solar: we estimate the solar LCOE at c.€40/MWh in Europe, which is less than half the cost of offshore wind, as a reference. Better relative competitiveness against other renewable technologies, and its high deflationary impact in the context of current power prices (especially in Europe), suggest that solar could gain incremental market share from other technologies. Meanwhile, steep cost inflation has been most evident in offshore wind (especially in the US, owing to an under-developed supply chain). Since its inception in the late 1990s, the offshore wind industry has benefited from a major improvement in economics. In Europe, we estimate that between 2008 and 2020, the LCOE for offshore wind dropped by c.-60%, from c.€200/MWh to a trough of c.€77/MWh. Yet, following a steep, 20-year decline in costs, the more recent cost inflation in raw materials and an unprecedented spike in funding costs have led to a significant increase in offshore's levelized costs. We estimate that the LCOE of offshore wind in Europe and the US increased by c.10% in 2023 yoy.

Capacity expansion

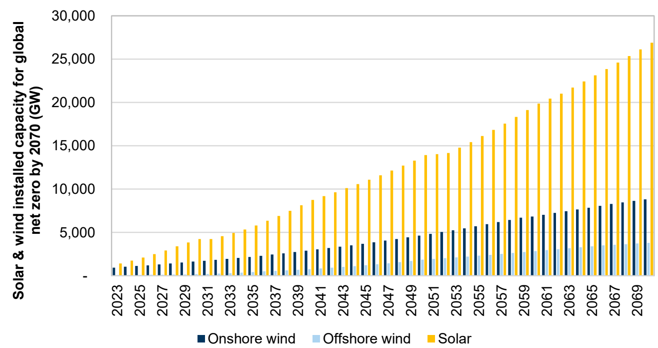
2023 saw a step change in renewable capacity additions, mainly driven by solar capacity expansion. Global net annual renewable capacity additions increased by c.42%, the fastest growth rate over the past two decades. In 2023, China stood at the forefront of the renewables capacity expansion, contributing as much solar PV as the entire world did in 2022, while its wind additions also grew by 66% yoy. Globally, solar PV alone accounted for c.75% of total renewable capacity additions. We expect renewable power capacity additions to continue to accelerate, reaching >550GW by 2030, a c.20% increase compared to 2023. Besides the renewable power capacity expansion, we also expect a revival of nuclear power. During the last two decades, installed nuclear capacity grew by only c.10%, but we expect it to more than double by 2060 vs 2023. At COP28, more than 20 countries launched the Declaration to Triple Nuclear Energy, committing to work collaboratively to advance a global aspirational goal to triple global nuclear capacity by 2050 vs. 2020. The declaration – signed by the US, Canada, France, the UK, South Korea and others – also promises efforts to extend the life of existing plants where appropriate, mobilize investments in nuclear power, and support new technologies such as small modular reactors.

Exhibit 70: Access to renewable power is the most critical component, being broadly vital for the de-carbonization of c.30% of the current global anthropogenic emissions across sectors...
Global anthropogenic GHG emissions de-carbonization cost curve, with orange indicating technologies reliant on access to renewable power



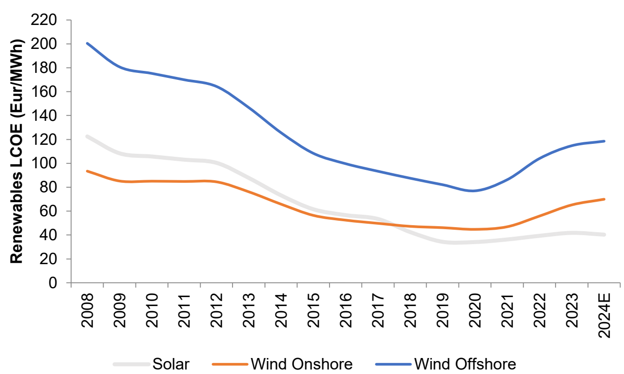
Source: Goldman Sachs Global Investment Research

Exhibit 71: ...and as a result, we expect standout growth in renewable capacity, in particular for wind and solar, for our GS 2 degrees path, consistent with global net zero by 2070
Solar and wind total installed capacity for global net zero (TW)



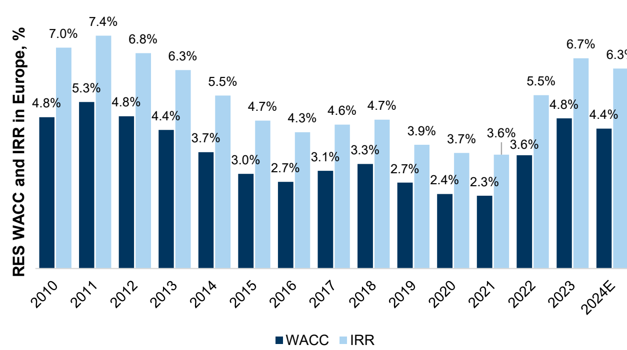
Source: Goldman Sachs Global Investment Research, Ember

Exhibit 72: Renewable power LCOEs have increased across technologies over the last 2 years...
LCOE for solar PV, wind onshore and wind offshore for select regions in Europe (EUR/MWh)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 73: ...on the back of increased financing costs and cost inflation
RES WACC and IRR in Europe,%



Source: IRENA, Goldman Sachs Global Investment Research

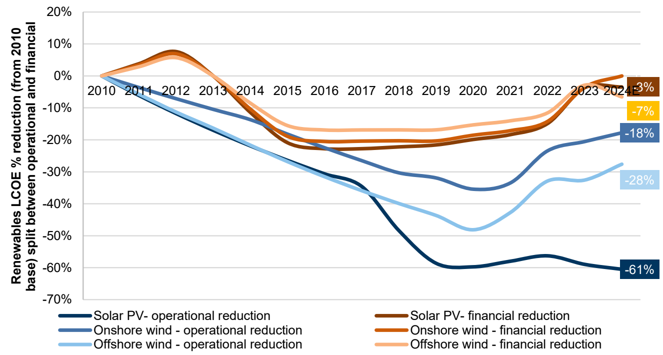
Exhibit 74: Solar module prices have declined significantly since last summer

Global average solar module cost ($/W)

Source: PV Insights

Exhibit 75: Renewable power LCOEs have decreased by >70% in aggregate across technologies, benefiting from a reduction in the cost of capital for these clean energy developments, contributing c.1/3 of the cost reduction since 2010

LCOE for solar PV, wind onshore and wind offshore for select regions, % reduction split by operational and financial

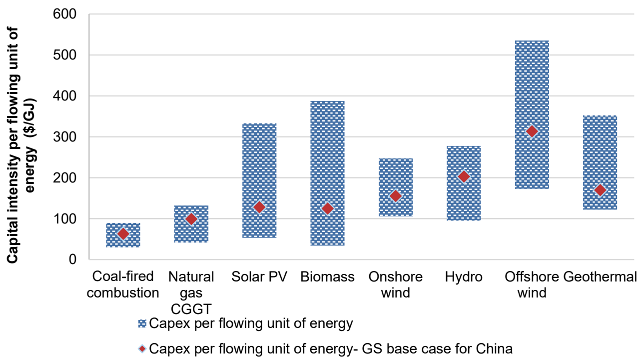


Source: Goldman Sachs Global Investment Research

The power generation investment opportunity: Higher capital intensity of renewable power and the rising importance of energy storage and networks infrastructure pave the way for a c.US$52 tn investment opportunity

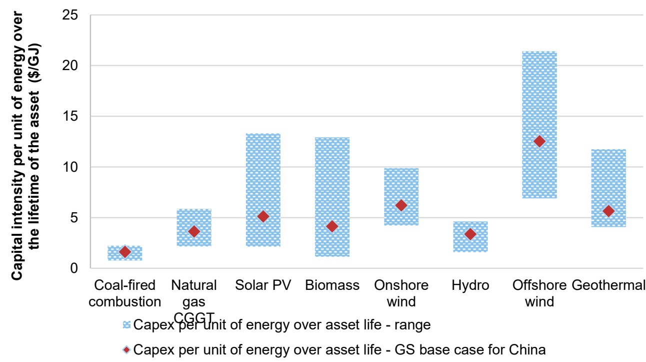
Earlier in this report, we highlighted the substantial potential investment creation opportunity associated with a path consistent with net zero emissions by 2070. Renewable power generation acts as a major contributor to this infrastructure investment opportunity (Exhibit 63). This is mainly due to the higher capital intensity of these technologies and their associated infrastructure, compared with traditional fossil fuel energy developments. In the exhibits that follow, we present the capital intensity (capex) per unit of output energy for each type of power generation technology. We present the results both in units of capex per flowing unit of energy (US$/GJ of peak energy capacity) and per unit of energy over the life of the asset (US$/GJ). This shows higher capital intensity per unit of energy as we move to cleaner alternatives for power generation. However, this does not necessarily translate into higher costs for the consumer, thanks to the availability of cheap financing (under an attractive and stable long-term regulatory framework) and lower opex, compared with traditional hydrocarbon developments.

Exhibit 76: Renewable clean technologies in power generation have higher capital intensity compared with traditional fossil fuel sources, based on per flowing unit of energy...
Capex per flowing unit of energy (US$/GJ)



Source: Company data, Goldman Sachs Global Investment Research

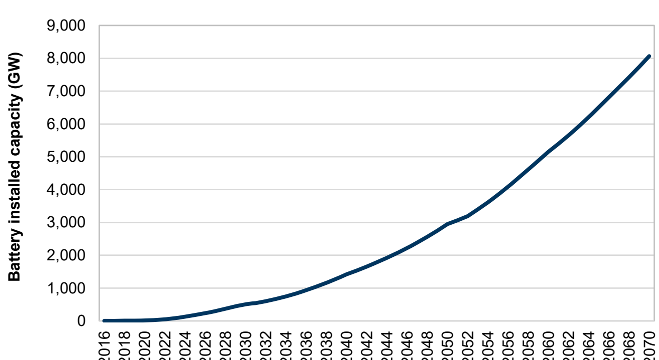
Exhibit 77: ...and over the lifetime of the asset
Capex per unit of energy over the life of the asset (US$/GJ) for each technology



Source: Company data, Goldman Sachs Global Investment Research

As the growth in renewable power accelerates, intraday and seasonal variability has to be addressed through energy storage solutions. To reach full de-carbonization of power markets, we believe two key technologies will likely contribute to solving the energy storage challenge: **utility-scale batteries and hydrogen**, each having a complementary role. We incorporate both of these technologies in our path to net zero and expect utility scale batteries for energy storage to reach c.3,000 GW by 2050 (Exhibit 78, while clean hydrogen-run CGGTs reach c.3.2% in the electricity generation mix in a similar timeframe). **Energy storage and the need for extensive network infrastructure** are particularly **important considerations as demand for power generation growth accelerates, to ensure a resilient global energy ecosystem.**

Exhibit 78: Our GS 2° path incorporates a large acceleration of utility battery energy storage, expected to reach c.3,000 GW by 2050
Power generation battery energy storage (GW)

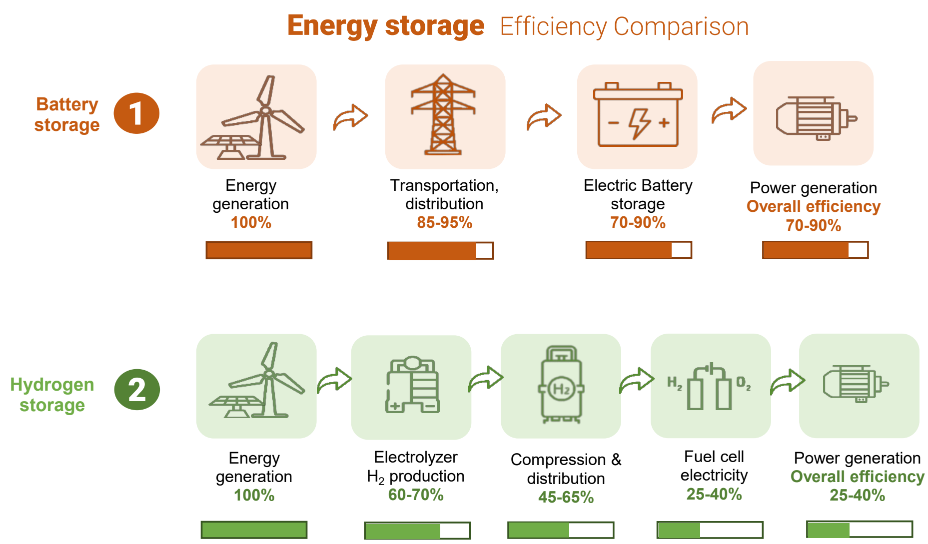


Source: Company data, Goldman Sachs Global Investment Research

While batteries are currently the most developed technology for intraday power generation storage, we consider hydrogen as a more relevant technology for seasonal storage, implying the need for innovation and development of both technologies. Batteries, for instance, are particularly suited to sunny climates, where solar PV production is largely stable throughout the year and can be stored for evening usage.

Hydrogen on the other hand, and the process of storing energy in chemical form and reconverting it to power through fuel cells, could be used to offset the seasonal mismatch between power demand and renewable output. Yet, with fuel cells overall currently having efficiencies that vary between 50% and 65%, the overall efficiency of energy storage becomes a weak point for hydrogen, where we estimate the life-cycle of energy storage efficiency to be in the range of c.25%-40% overall, compared with c.70%-90% for batteries, as shown in Exhibit 79.

Exhibit 79: We see utility scale batteries and hydrogen as the two key complementary technologies to address the energy storage challenge

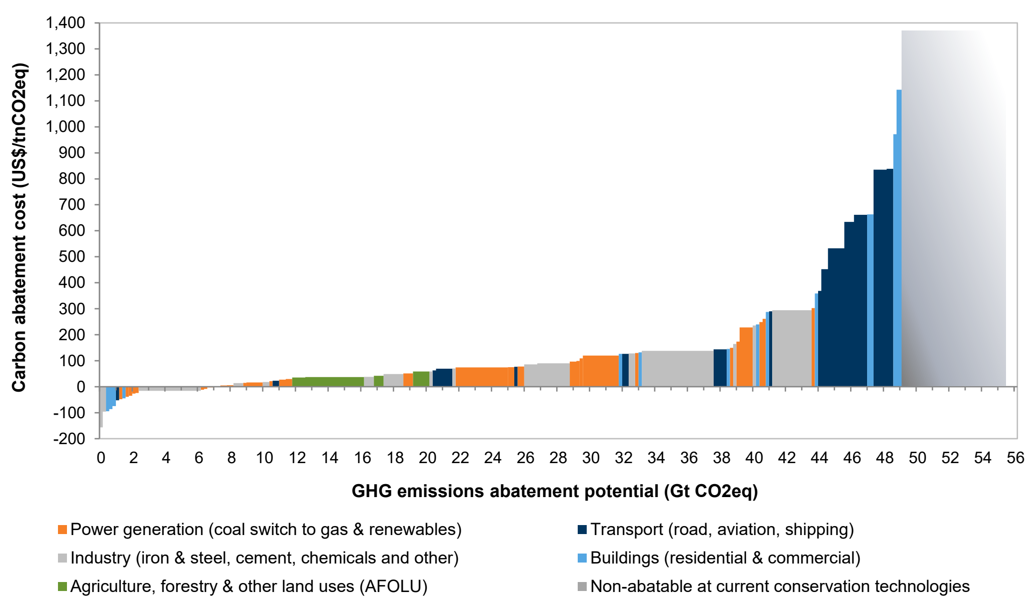


Source: Company data, Goldman Sachs Global Investment Research.

Transportation: The rise of EVs and alternative fuels with different technologies across transport modes

Transportation, in contrast to power generation, **mostly sits in the 'high-cost' area of the de-carbonization cost curve** (Exhibit 80), with the sector responsible for c.20% of global anthropogenic CO_2 emissions (2022, incl. AFOLU). As part of our analysis, we lay out the path to net zero emissions for transportation, as shown in Exhibit 81, addressing all key transportation modes: short- and medium-haul road transport, heavy long-haul transport, rail, aviation and shipping. The speed of de-carbonization varies depending on the transport mode, as shown in Exhibit 82, largely driven by the difference in costs and technological readiness of the available clean alternatives required for each sub-sector. **Light-duty vehicles and rail** (which is already c.33% electrified) are the two transport modes with a **faster relative de-carbonization,** given the readiness and notable cost deflation of clean technologies for both (electrification). On the other hand, **heavy trucks, aviation and shipping de-carbonize at a slower pace,** given the still largely undeveloped or early stage development of de-carbonization alternatives in these areas (sustainable aviation fuels, synthetic fuels, clean hydrogen and ammonia), which we expect to enjoy a large uptake in adoption and account for a notable part of the fleet only post 2030.

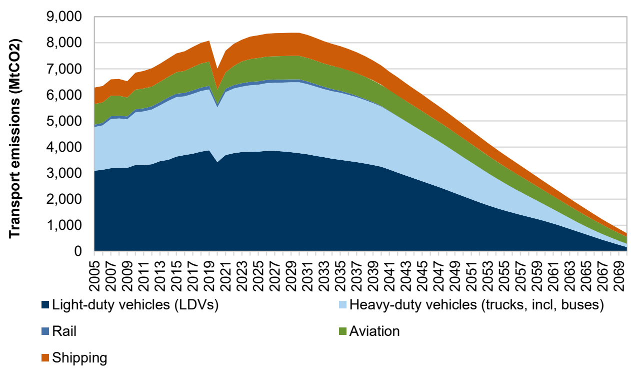
Exhibit 80: Transportation mostly sits in the 'high-cost' area of the de-carbonization cost curve
2023 carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and current costs, assuming economies of scale for technologies in the pilot phase



Source: Goldman Sachs Global Investment Research

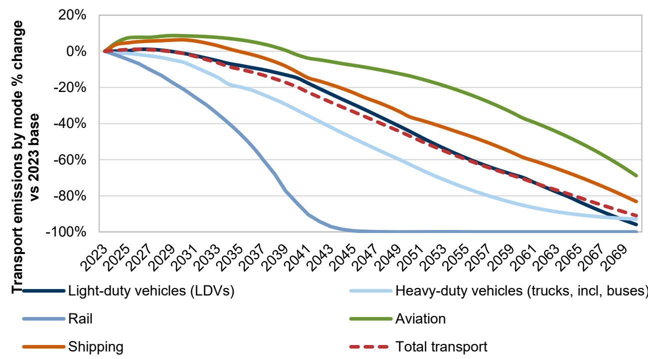
We further address how the fuel mix of the energy consumption of transport evolves over time in our GS 2.0° scenario and present the results both in aggregate and by key transport mode in Exhibit 83 and Exhibit 84. Overall, electricity increases its share in total transport energy consumption to c.45% by 2060 and 60% by 2070, while the fossil fuel share declines from c.95% at present to 30% by 2060 and 5% by 2070. Bioenergy, clean hydrogen & synthetic fuels, and ammonia all emerge as important energy sources for transportation, accounting for c.11%/ 7%/3% respectively by 2060 and 16%/8%/5% by 2070.

Exhibit 81: We model the emissions in the transport sector by mode in our GS 2.0° path...
Transport sector emissions (MtCO2) split by key transport mode



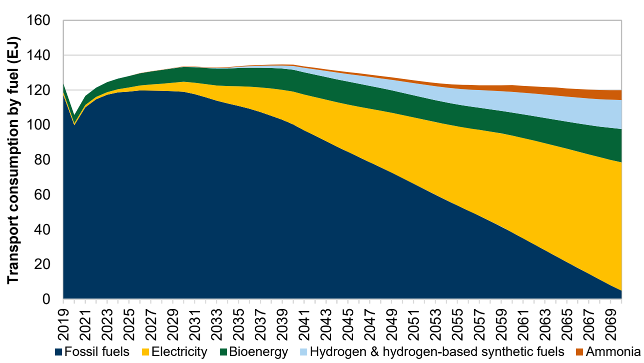
Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

Exhibit 82: ...with the speed of de-carbonization varying across modes depending on the cost and readiness of the respective clean technologies
Transport emissions by mode % change vs. 2023 base



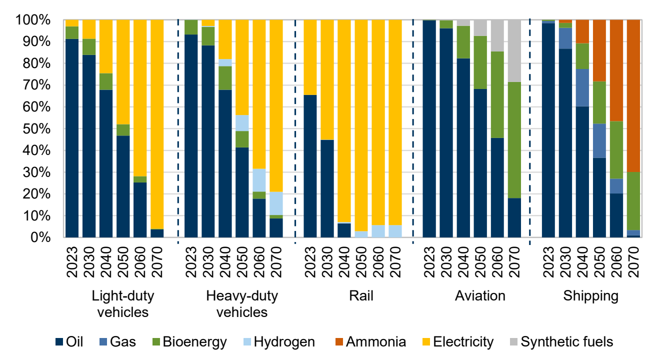
Source: IEA, Goldman Sachs Global Investment Research

Exhibit 83: We expect the energy mix of the transport sector to evolve dramatically over time...
Transport energy consumption by fuel (EJ)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 84: ...with electrification, bioenergy, synthetic fuels, clean hydrogen and ammonia all playing key roles in the transition
Fuel mix of energy consumption in transport by transport mode (%)



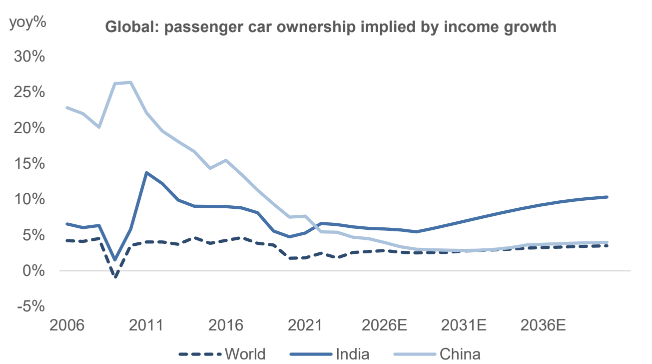
Source: IEA, Goldman Sachs Global Investment Research

Light-duty road transport vehicles: Electrification at the heart of the transport evolution

For light duty vehicles (LDVs) transport (primarily constituting passenger vehicles, commercial vehicles and short/medium-haul trucks), we consider **electrification the key de-carbonization technology. EV share in the global sales mix** in 2023, including battery electric vehicles (BEVs) and plug-in hybrid EV (PHEVs), stood at c.16%, overshooting our 2021 expectation of 10%, primarily owing to faster-than-expected EV sales penetration in China. While in 2024 EV sales momentum has slowed globally, driven by concerns around EV capital costs due to lower prices for used EVs, poor visibility on government policy, and a shortage of rapid-charging stations, we expect the EV sales share to show moderate growth and reach c.18% in 2024. **In our 2.0°**

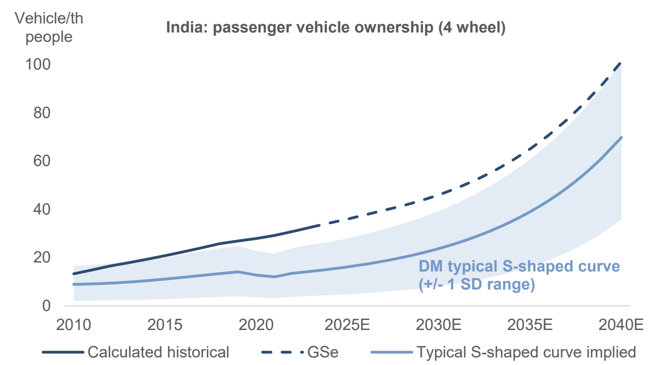
scenario GS 2.0° scenario, we model global EV sales (BEVs and PHEVs) to make up 43% of total sales by 2030 and 71% by 2040, leveraging our Auto team's analysis. Post 2040, we model 85% global EV sales share in 2045 and 100% by 2050 in our 2.0° scenario. We also focus **on the evolution of the LDV fleet** for the purpose of emission accounting in this analysis, with the fleet evolution reliant on both vehicle sales and retirements, as it is ultimately the penetration in the fleet that directly translates into transport emissions. In our 2.0° scenario, the **global LDV fleet grows by a 2.8% CAGR in 2023-2040 and 1.3% CAGR in 2040-2070,** supported by increasing vehicle ownership primarily in emerging markets: our APAC Energy team expect growth in the global passenger vehicle fleet to be mainly supported by India in the coming years, where the adoption of 4-wheel cars is set to accelerate; for China, they embed our Auto team's forecast of slow near-term passenger car sales given tepid consumer demand amid a housing downturn, and expect an eventual convergence to the lower end of the typical vehicle ownership range in the long run. Our GS 2.0° path assumes a major shift in the mix of the fleet of LDVs to 2060, with EVs (including BEVs and PHEVs) making up c.16%/41%/66%/83% of the fleet by 2030/40/50/60E respectively.

Exhibit 85: The global passenger vehicle fleet could continue to grow at a c.3% CAGR in 2024-2030



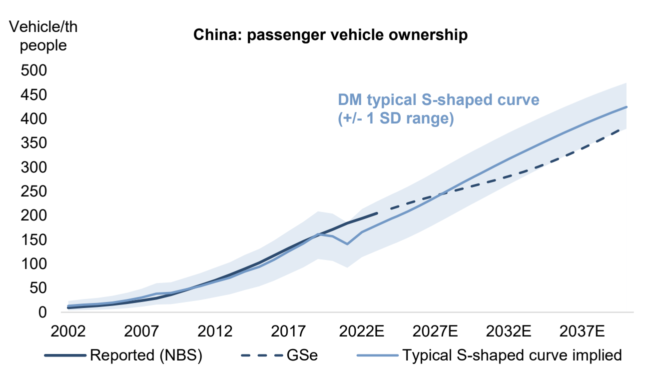
Source: Respective government statistics agencies, World Bank, Goldman Sachs Global Investment Research

Exhibit 86: India's adoption of 4-wheel cars is set to accelerate as income grows...



Source: SIAM, World Bank, Wind, Goldman Sachs Global Investment Research

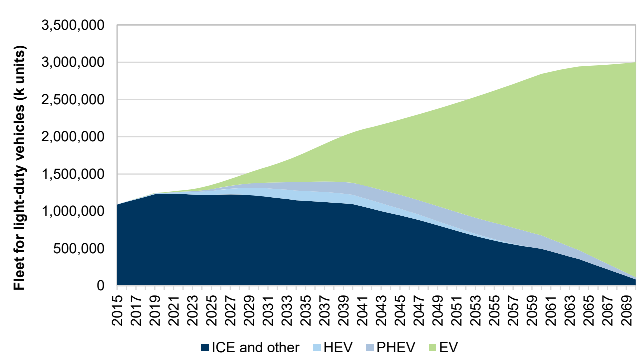
Exhibit 87: ...and the case is similar for China, despite slower domestic passenger car sales in the near term



Source: NBS, World Bank, Goldman Sachs Global Investment Research

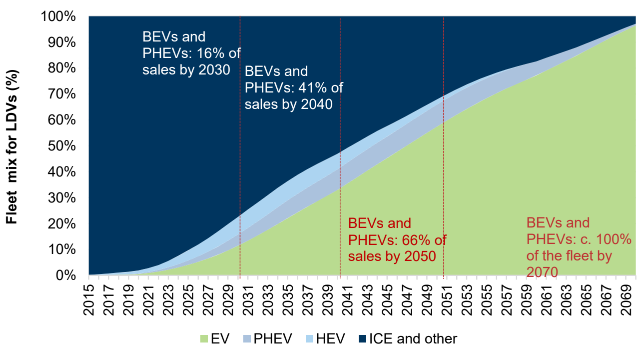
Exhibit 88: Our GS 2.0° path assumes a major shift in the mix of the LDV fleet to 2060...

Light-duty vehicles fleet (k units)



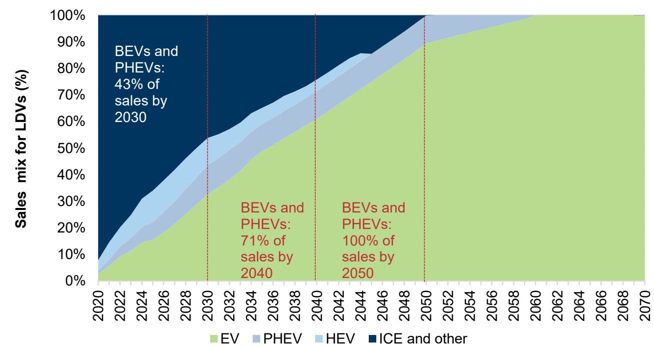
Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 89: ...with EVs (including BEVs and PHEVs) making up c.16%/41%/66%/83% of the fleet by 2030/40/50/60E respectively
Light-duty vehicle fleet mix evolution over time (%)



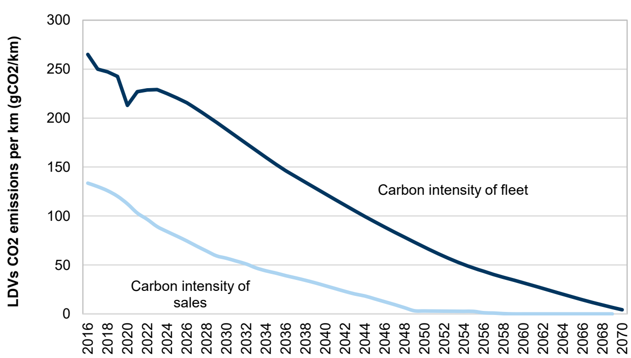
Source: BNEF, IHS Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 90: We now model EVs' (BEVs and PHEVs) share in the global sales mix at 44%/72%/100% by 2030/40/50E...
Light-duty vehicles sales mix (%)



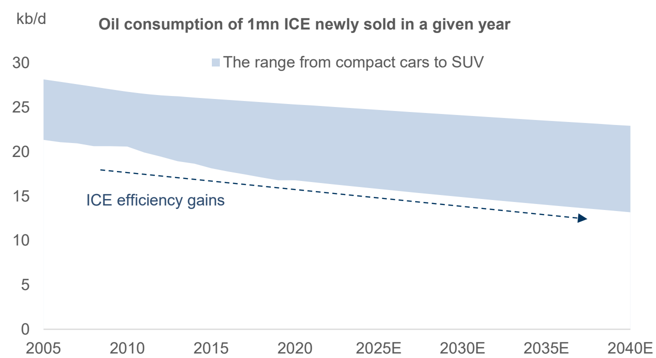
Source: Goldman Sachs Global Investment Research

Exhibit 91: ...and model the carbon intensity of the fleet tracking the carbon intensity of sales, with a c.10-15 year delay
LDVs' CO2 carbon intensity per km travelled (gCO2/km)



Source: Goldman Sachs Global Investment Research

Exhibit 92: Theoretically, 1 million BEVs replacing 1 million ICEs lowers oil demand by c.20 kb/d



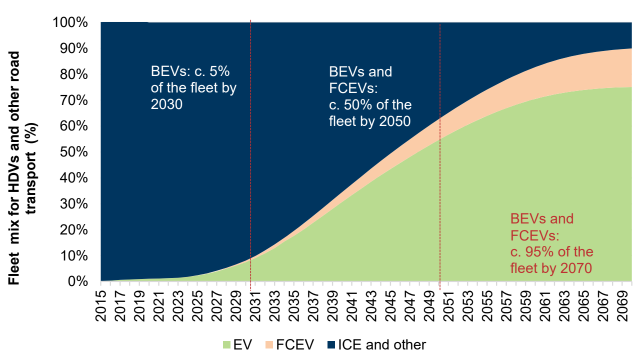
Source: iCET, Arora et al. (2011), Goldman Sachs Global Investment Research

Heavy-duty road transport and other vehicles: Biofuels a near-term viable de-carbonization option, with electrification and clean hydrogen gaining pace post 2030

Electrification and biofuels remain key near-term de-carbonization technologies in trucks and buses, with hydrogen an attractive option for heavy-duty trucks. Penetration of EVs in global sales of trucks and buses has been significantly lower compared to LDV sales so far: in 2023, around 3% of bus sales were EVs and c.1% of medium and heavy trucks. This is driven by the smaller product offering and the need for further technological innovation in the case of long-haul large capacity batteries. While medium-heavy trucks and buses are easier to electrify due to lower daily travel distance, for heavy-duty trucks, we consider clean hydrogen a potentially competitive option, owing to its faster refueling time, lower weight and high energy content. **In our 2.0° scenario GS 2.0° scenario, for heavy trucks,** we model global EV and hydrogen fuel cell vehicles (FCEV) sales making up 5% and 4% in 2030, respectively, and 36% and 16% in 2040, respectively, leveraging our Auto team's analysis. Beyond that, we model 50%/30% global EV and FCEV sales shares in 2050 and 60%/40% by 2060 for heavy trucks. **For buses,** we model the fastest electrification route among heavy vehicles given relatively fixed driving patterns and lower daily travel distances, with global EV share reaching 30%/60%/100% by 2030/40/50, respectively. **For medium-duty trucks,** we model global EV share reaching 20%/55%/85% by 2030/40/50. **We therefore expect the shift in the fleet mix for heavy-duty vehicles to start later than the transition in LDVs,** with EVs and FCEVS making up c.8%/35%/63%/83% of the fleet by 2030/40/50/60E respectively.

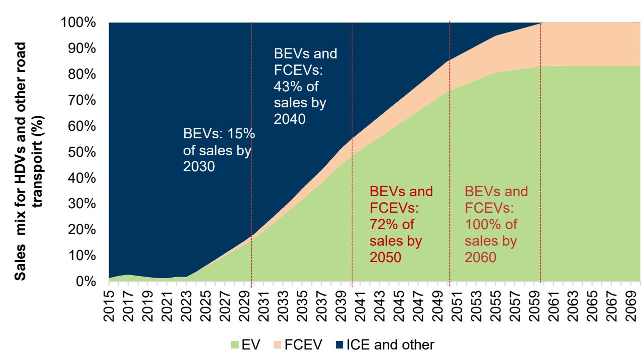
Given this backdrop, **we believe biofuels remain a viable de-carbonization technology in the near and medium term to decarbonize heavy-duty transport.** We leverage our Carbonomics bioenergy report analysis on biodiesel and renewable diesel consumption by 2030 driven by country-specific mandates: biodiesel consumption increases by c.10% by 2030E vs 2023, primarily driven by growing Latam and Asia consumption, resulting in a c.6% blending rate by 2030E globally. Beyond that, we assume an increase in biodiesel consumption to a c.10% blending rate by 2045 globally, which represents a technical limit to blending rates given biodiesel chemical properties (e.g. the presence of oxygen). For renewable diesel, we model c.2 times higher consumption by 2030 driven by growing consumption in Europe and the US, resulting in a c.3.2% blending rate by 2030 globally (from 1.6% in 2023). Beyond that, we assume the blending rate increases to c.5% by 2040 and stays flat from there, with biofuels mandates and long-term waste and residue feedstock limitations representing major areas of uncertainty.

Exhibit 93: Clean hydrogen and electrification are in our view the two key technologies to address long-haul heavy-duty transport emissions...
Fleet mix for heavy-duty vehicles and other road transport (%)



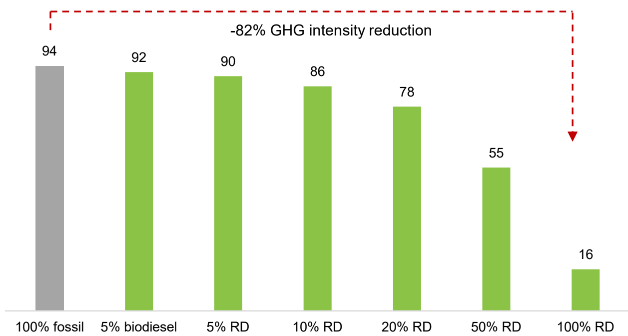
Source: BNEF, IEA, Goldman Sachs Global Investment Research

Exhibit 94: ...with NEVs (FCEVs and EVs) accounting for c.100% of heavy-duty vehicle sales by 2060E
Sales mix for heavy-duty vehicles and other transport (%)



Source: BNEF, IEA, Goldman Sachs Global Investment Research

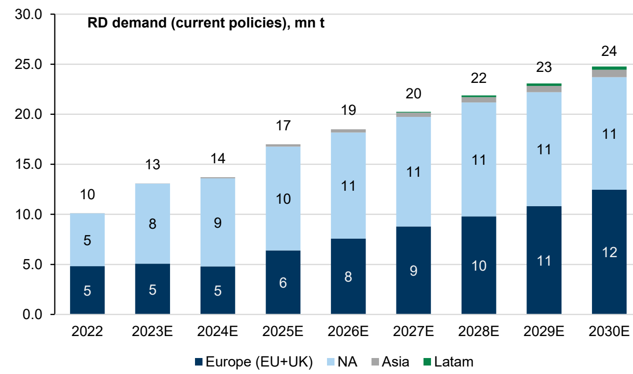
Exhibit 95: Biofuels have potential to de-carbonize transportation within current infrastructure
Liquid fuels GHG intensity, gCO2e/MJ



RD is renewable diesel, GHG intensity is based on used cooking oil feedstock

Source: EU RED II Directive, compiled by Goldman Sachs Global Investment Research

Exhibit 96: For renewable diesel, we model almost 2 times higher consumption by 2030, driven by growing consumption in Europe and the US
RD demand (current policies), mn t



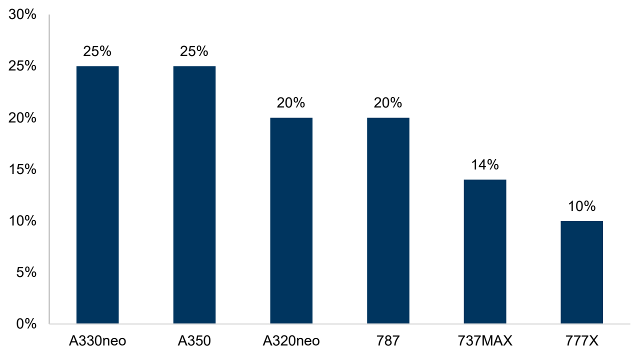
Source: IEA, EPA, Eurostat, Goldman Sachs Global Investment Research

Aviation: One of the harder-to-abate sectors, with new generation aircraft/fleet renewal, sustainable aviation fuels (SAFs) and other new propulsion technologies paving the way for technological transformation

Aviation sits at the top of our Carbonomics cost curve and is one of the toughest sectors to de-carbonize. **Sustainable aviation fuel (SAF), also typically known as biojet (including synthetic e-fuels), improved aircraft efficiency and alternative propulsion systems** are, in our view, all key parts of the solution. In the near term, however, we believe that the **ongoing aircraft fleet renewal – supporting efficiency improvements – and SAF** remain the two scalable solutions for carbon abatement in this industry. While the industry has long recognized the need for a reduction in emissions, in our view, the requirement for energy-dense sources makes the technological development for alternative lower-carbon intensity propulsion systems based on electric, hybrid-electric and hydrogen a lengthy process calling for more technological innovation and scale. **In our 2.0° scenario GS 2.0° scenario,** we leverage our Carbonomics bioenergy report analysis on SAF consumption by 2030 driven by country-specific mandates: an EU-wide mandate of 2% from Jan-1-2025 and 6% by 2030; a UK mandate starting at 2% in 2025 and rising to 10% by 2030, Japan's 10% SAF mandate by 2030; and the US SAF Grand Challenge, targeting 3 bn gallons of domestic SAF production by 2030. Overall, we model c.14 mn t of SAF consumption by 2030 in our 2.0° scenario, representing a c.3.7% blending rate in the total jet fuel pool. Post 2030, we assume SAF blending increases to 15%/24%/40%/53% of total aviation fuel pool by 2040/50/60/70, coupled with the rise of synthetic e-fuels.

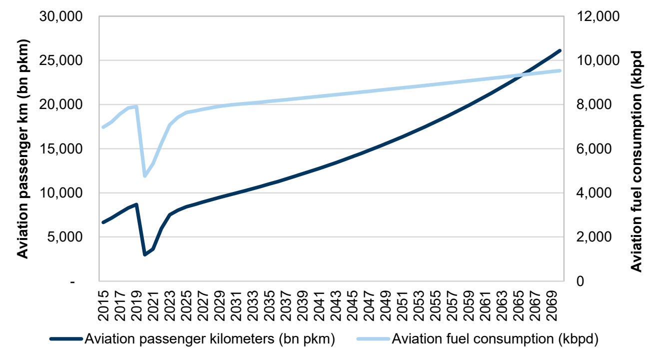
We believe feedstock availability for traditional HEFA process (i.e. waste & residues) might become a bottleneck post 2030, with the total waste & residues pool estimated at 40 mn t globally. Therefore, development of alternative feedstocks and processes is required to de-carbonize aviation. These include alcohol-to-jet (ATJ), FT-gasification technologies which can use a much broader feedstock pool, such as ethanol, forestry and wood residues, municipal waste, and **e-fuels** (a power-to-liquid technology pathway). Key difficulties with e-fuels production currently include low conversion efficiency, a significant amount of cheap renewable electricity needed and the requirement for a stable source of CO2, resulting in 3-6x higher cost of production versus conventional jet fuel. We believe significant technological advancements and cost reductions are needed in the electrolyzer equipment and CCUS space before we see any widespread use of e-fuels. We model c.0.2% synthetic fuels blending in aviation by 2030, with more significant uptake post 2030: we assume the e-SAF blending increases to 3%/7%/15%/30% of total aviation fuel pool by 2040/50/60.

Exhibit 97: The switch to more efficient aircraft has the potential to lead to c.15%-20% fuel burn improvement...
Fuel burn improvement vs. previous generation as per company data



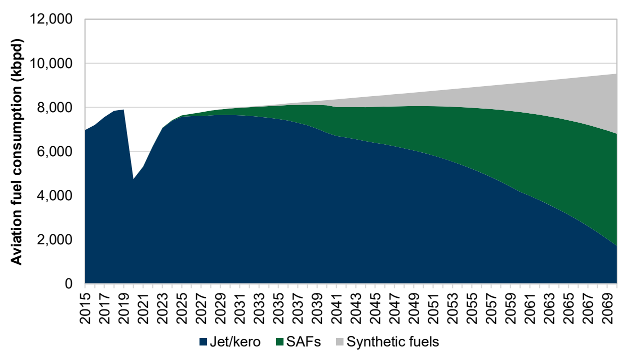
Source: Company data

Exhibit 98: ...and is the key tool in the near and medium term given the ongoing increase in activity we expect in the sector...
Aviation pkm and fuel consumption



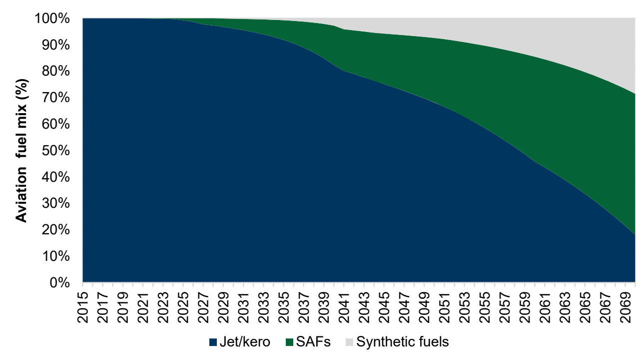
Source: IATA (historical), Goldman Sachs Global Investment Research

Exhibit 99: ...but ultimately, a fuel switch is necessary, with SAFs and synthetic fuels paving the de-carbonization path in the medium and longer term...
Aviation fuel consumption (kbpd)



Source: IATA, IEA, Goldman Sachs Global Investment Research

Exhibit 100: ...accounting for c.53%/30% of the aviation fuel mix respectively by 2070E
Aviation fuel mix (%)



Source: IEA, Goldman Sachs Global Investment Research

Shipping: Alternative low-carbon fuels such as clean ammonia, methanol, biodiesel and LNG all have a role in the de-carbonization process of one of the most challenging areas from a carbon-abatement perspective

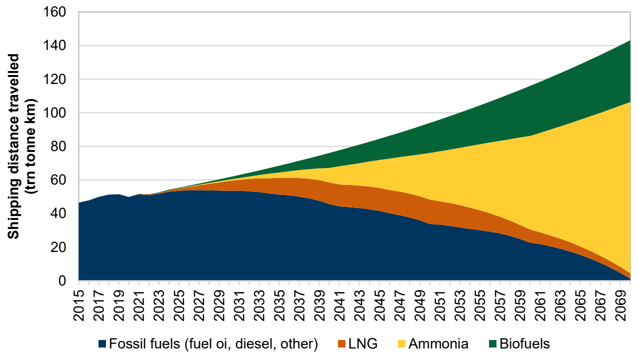
Maritime shipping is responsible for c.0.9 GtCO2eq (2023), accounting for a similar share of the global CO_2 emissions as aviation. Shipping is another sector with hard-to-abate emissions, given a lack of widespread adoption of the available low-carbon de-carbonization technologies at scale, and the relatively long operating life of vessels. The main marine fuels are currently heavy fuel oil and marine diesel oil, with biofuels (primarily FAME biodiesel) and LNG making up less than 2% of the total fuel pool.

We expect **liquefied natural gas (LNG) and biofuels to be key de-carbonization technologies in shipping through 2030. LNG** provides a 20-25% GHG reduction versus low-sulphur fuel oil, and already has an established technological and operational track record and existing shoreside bunkering infrastructure: we expect LNG's share in the shipping fuel mix to increase from c.1% in 2023 to 9.5% in 2030. Longer-term, LNG-fueled engines might also run on bio-methane or synthetic natural gas.

Marine biofuels are currently represented primarily by **FAME biodiesel**, which is used in a 20%/30% blend with fuel oil. Biodiesel produced from animal fats and used cooking oil (UCO) can reduce GHG emissions by up to 80% versus conventional marine diesel, but the feedstock pool for waste & residues is constrained at c.40 mn t and might be used for SAF production in aviation which has fewer de-carbonization alternatives. Therefore, we expect **green methanol to become a primary advanced biofuel post 2030** that can deliver 60-90% GHG emissions savings versus fossil fuels. Biomass-based (bio-methanol) methanol can be produced from a wider biomass feedstock pool (forest residues, agriculture residues) and municipal solid waste through established gasification processes; we note that big shipping companies such as Maersk, Evergreen and Cosco are increasing their methanol-powered ships orderbook, with the first ships to be delivered in 2026/27.

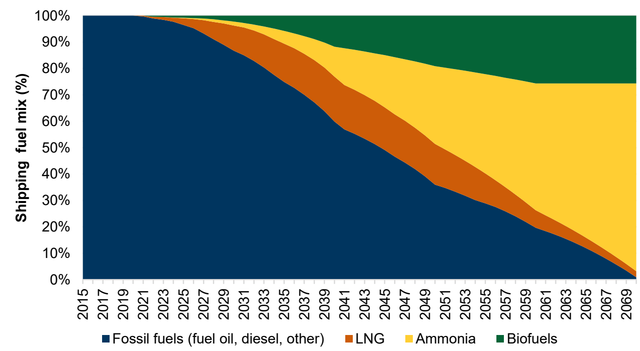
Post 2030, we also expect **low-carbon ammonia (blue and green)** to play a larger role as the ultimate de-carbonization technology for the sector. One of the key advantages of green ammonia is its potential to be a zero-carbon fuel throughout its entire life cycle. Internal combustion engines for ammonia-fueled vessels are currently being developed, and we expect they can be made readily available to the market by 2030. **In our GS 2.0° scenario, low-carbon** ammonia accounts for c.30%/50%/70% of the total energy in shipping in 2050/60/70, sustainable biofuels (incl. green methanol) provide c.20%/25%/25% of total shipping energy needs, and the remaining energy is provided by fossil fuels (oil and LNG).

Exhibit 101: Based on our GS 2.0° path, fuel switching will be key in the de-carbonization of shipping...
Shipping distance travelled in trillion tonne km



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 102: ...with clean ammonia, advanced biofuels and LNG all playing in a role in the energy transition
Shipping energy consumption by fuel (EJ)



Source: IEA, Goldman Sachs Global Investment Research

Rail: Currently the least carbon-intensive transport mode, with further scope for de-carbonization as the electrification process continues and hydrogen for long-haul heavy trips gets added to the mix

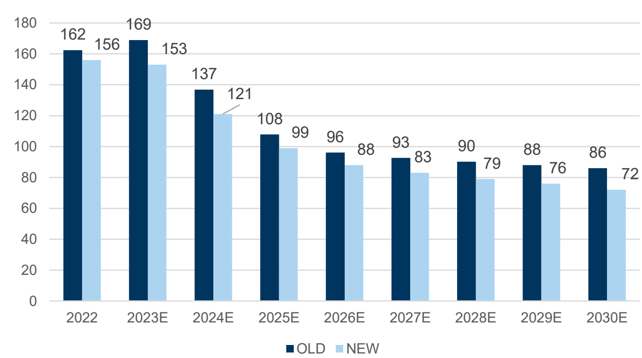
Rail is currently the least carbon-intensive and one of the most energy-efficient transport modes. At present, more than 40% of rail energy is in the form of electricity, with the remaining energy consumption primarily in the form of diesel for heavy long-haul trips. In our 2.0° scenario GS 2.0 degrees, we assume rail activity continues to increase, and that the electrification process continues to unfold until hydrogen fuel cell electric trains (FCEs) unlock the final portion of carbon abatement for those harder-to-abate long-haul rail trips.

Battery technology at the core of the technological and cost evolution of road transport

Battery technology and its evolution play a key role in aiding the de-carbonization of both transport and power generation. The high focus on electric batteries over the past decade has helped to reduce battery costs by over c.30% in the past five years alone, owing to the rapid scale-up of battery manufacturing for passenger electric vehicles (EVs). Nonetheless, the technology is currently not readily available at large, commercial scale for long-haul transport trucks, shipping and aviation, and it remains in the early stages for long-term battery storage for renewable energy.

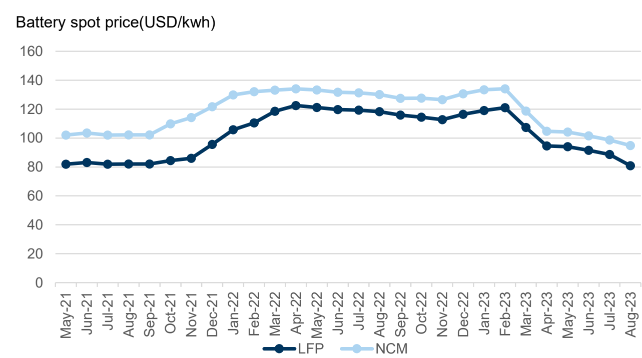
Battery cost deflation and EV economies of scale to drive down EV costs. Our APAC Energy team now see EV cost parity vs ICE vehicles occurring sooner than previously assumed, thanks to a decline in EV costs resulting from lower battery prices. As of 2023, the cost of the EV powertrain was US$11,592, which our APAC Energy team estimate is about twice as high as the US$5,620 ICE powertrain. However, with the decline in battery prices from here, they see the gap shrinking to about 37% in 2025, and **EV powertrain costs possibly falling below ICE powertrain costs in 2030.** Also, in terms of TCO (total cost of ownership), they estimate that the **payback period for EVs will decline to 3.3 years in 2025,** which is close to the level of three years that saw a breakthrough in sales for the Prius. Considering also the lower running costs, EVs should be a competitive option vs ICE vehicles **when battery prices move below US$100/kWh.** TCO is of course not the only factor that determines consumers' purchasing behaviour. EV battery life, range, and charging time will also require technological innovation.

Exhibit 103: Our APAC Energy team expect battery prices to fall to US$99/kWh in 2025
Global battery prices (USD/kWh)



Source: SNE Research, Goldman Sachs Global Investment Research

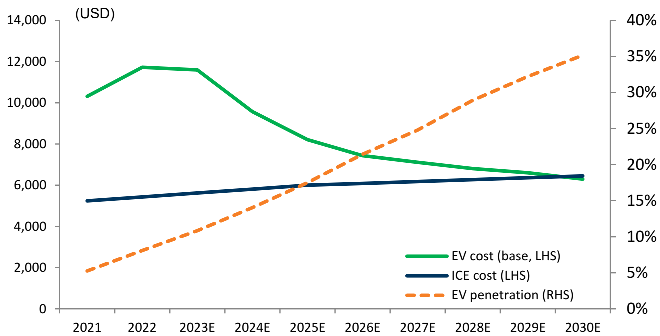
Exhibit 104: Battery prices are already falling in China
Battery spot prices in China



Source: Wind, Goldman Sachs Global Investment Research

Exhibit 105: Our APAC Energy team expect EV costs to fall below ICE costs in 2030

ICE/EV cost comparison and EV market penetration

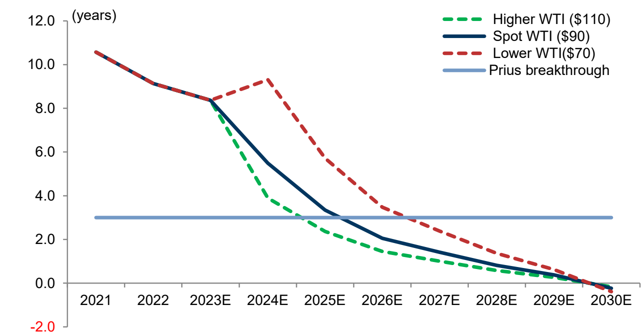


EV cost comprises battery, inverter, drive motor, reducers, cooling equipment. ICE cost comprises engine, transmission, turbo, injection, etc.

Source: SNE Research, Global Insight, MarkLines, Goldman Sachs Global Investment Research

Exhibit 106: They expect the payback period for EVs in 2025 to reach the same level that saw Prius sales take off

TCO simulation



The payback period is the number of years needed for fuel savings from cheaper electricity vs. gasoline to cover the EV cost premium over an ICE vehicle.

Source: SNE Research, FRED, US Department of Energy, US Department of Transportation, Bloomberg, Company data, Goldman Sachs Global Investment Research

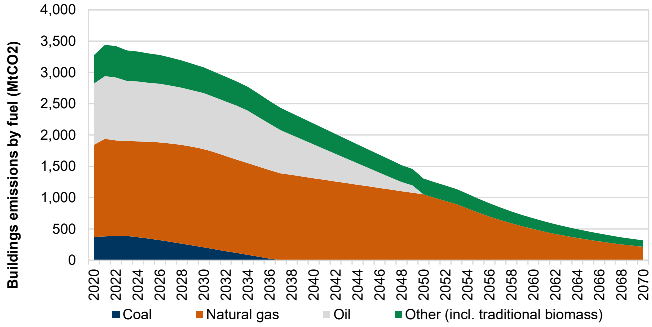
Buildings: Fuel switch and efficiency to govern emissions reduction path

Direct carbon emissions from buildings, both residential and commercial, in 2022 accounted for c.8% of total global CO_2 emissions, primarily attributed to the use of fossil fuels for space and water heating (natural gas and oil predominantly, as shown in Exhibit 107). In our 2.0° scenario scenario, we continue to see global activity in the sector increasing, with the global floor area increasing from 250 bn meters squared to c.630 bn meters squared by 2070. However, we estimate that the transformational energy shift away from fossil fuels to cleaner alternatives, coupled with an acceleration in energy efficiency improvements, could bring the overall carbon intensity of buildings close to zero in the 2060s. While the key technologies that govern the de-carbonization of buildings in the near and medium term are readily available, including electric heat pumps (air and ground source) and residential solar, geothermal, and bioenergy, the long lifespan of buildings makes comparatively costly retrofits essential to achieve net zero emissions by 2070, particularly for residential buildings where the switch is largely reliant on consumer preference. As such, any aspiration for net zero emissions in buildings has to come with the need for an accelerated pace of retrofits.

Our net zero pathway by 2070, GS 2°, requires a step change in the pace of energy efficiency gains, as well as the flexibility of the stock and a shift away from fossil fuels. The first change can be achieved through a combination of measures, including the switch to best-available technology (BAT) across appliances, automation and smart meters, and will largely be governed by underlying building codes and standards. The last factor is largely dependent on the cost of clean fuel alternative technologies. As shown in Exhibit 110, electricity accounts for around one-third of the total final energy consumption of buildings, and we expect its share to almost double, reaching c.59% by 2060, while the share of direct renewable energy such as residential solar, geothermal and bioenergy is also increasing over time, reaching c.22% by 2060E from 6% in 2022.

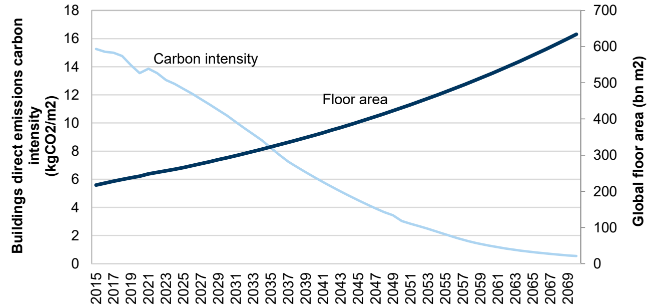
Finally, clean hydrogen could be a key complementary heating technology, given the gas-like properties of the fuel, which could help preserve some of the newer gas pipeline infrastructure and avoid stranded assets. Clean hydrogen could be a key technology in seasonal storage, essential for heating applications that extend beyond buildings into other sectors such as industry.

Exhibit 107: The direct emissions from buildings are currently dominated by the use of natural gas and oil, used primarily for heating applications...
Buildings emissions by fuel (MtCO2)



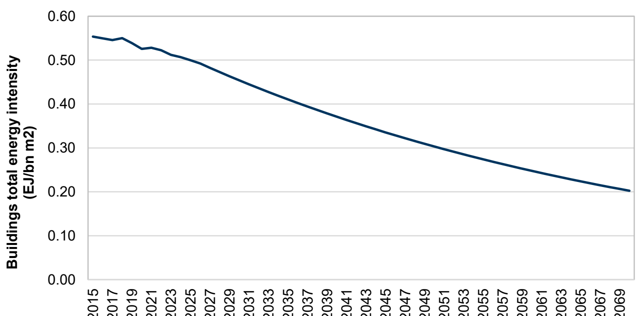
Source: Emission Database for Global Atmospheric Research (EDGAR) release version 8.0, GCB, Goldman Sachs Global Investment Research

Exhibit 108: ...and our base scenario requires the carbon intensity per square meter of global floor area to reduce over time, reaching close to net zero in the 2060s despite the increase in global floor area
Buildings direct emissions carbon intensity (kgCO2/m2)



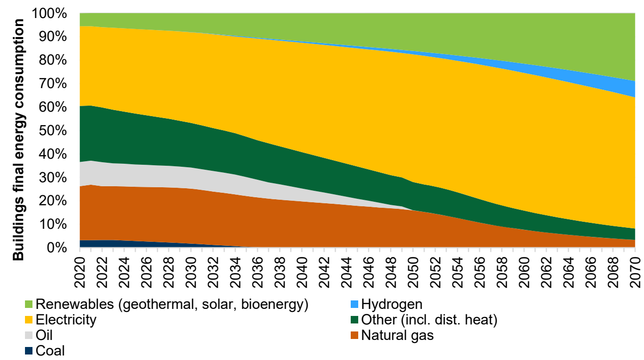
Source: Goldman Sachs Global Investment Research

Exhibit 109: De-carbonization in buildings is primarily driven by an ongoing improvement in energy efficiency, with the energy intensity (both direct and indirect) for buildings halving by 2055E...
Buildings total energy intensity (EJ/bn m2)



Source: Goldman Sachs Global Investment Research

Exhibit 110: ...as well as fuel switching away from fossil fuels and towards electrification, distributed renewable energy and clean hydrogen
Buildings total final energy consumption fuel mix evolution (%)



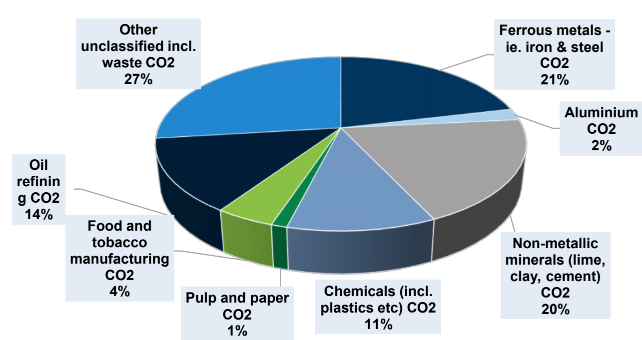
Source: Goldman Sachs Global Investment Research

Industry, waste & other fugitive: Clean hydrogen, CCUS, efficiency, circular economy and electrification setting the scene for a new industrial technology revolution

Industry is the sector with the second largest contribution to global CO2 emissions, accounting for **c.30% of global anthropocentric CO2 emissions in 2023**. Industrial emissions for the purpose of this analysis incorporate all industrial combustion, industrial processes, waste and other fugitive emissions (including those associated with the extraction of fossil fuels). The following discussion covers process emissions but does not include indirect emissions from purchased electricity. While the exact split of all the different industrial sub-sector emissions is subject to uncertainty, with variations between sources, we estimate that **c.65% of global industry & other industrial waste emissions stem from the heavy industries** as shown in Exhibit 115 (ferrous and non-ferrous metals manufacturing, non-metallic minerals such as cement and oil refining & petrochemicals) and are predominantly produced in emerging economies.

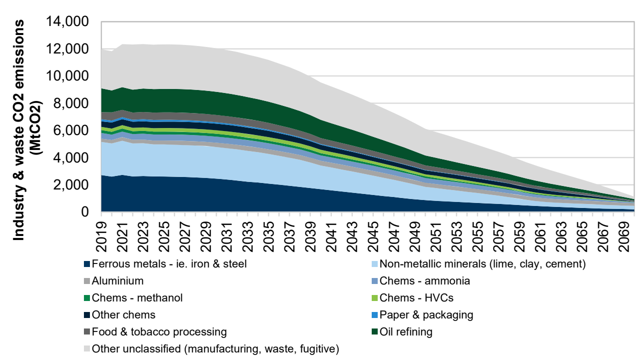
Our GS 2.0° scenario's architecture for heavy industries consists of three main components: **activity projections** (largely dependent on underlying GDP assumptions, material substitution and the circular economy), **technology mix modeling** (the selection of technologies and mix required to meet these activity levels) and finally **emissions modeling**, largely relying on the technology mix and incorporating energy and material efficiency assumptions where appropriate.

Exhibit 111: c.65% of industrial & other waste emissions stems from the heavy industries (iron & steel, cement, chemicals, oil refining)...
Approximate split of global industrial & other waste emissions (%, 2023)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research, IEA, Goldman Sachs Global Investment Research

Exhibit 112: ...with these industries being some of the hardest to de-carbonize given the current lack of large-scale, developed and economic cleaner alternatives
Industry & waste GS 2.0° scenario CO2 emissions (MtCO2eq)



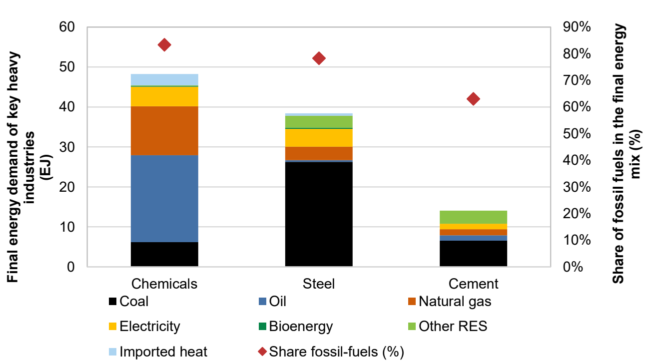
Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

Heavy industries are the key contributors to global industrial emissions, with clean alternatives in need of further technological innovation and large-scale deployment

Iron & Steel: The iron & steel industry accounts for c.2.6 GtCO2 of total emissions (2023), **the single highest emitter among industrial sub-sectors.** A combination of fuel switches and innovative process routes can aid the low-carbon transition path for these ferrous alloys. Our GS 2.0° scenario envisages a technological transformation of the iron & steel sub-sector, largely based on the ongoing shift from coal blast furnace routes, which currently account for c.70% of total steel energy consumption (conventional BF-BOF), to electric arc furnace routes (either through natural gas, clean hydrogen or scrap). Iron & steel is a highly energy-intensive industry, consuming c.35 EJ of energy in 2022 (c.6% of global primary energy consumption) and accounting for c.15% of global primary coal demand. Although the BF-BOF pathway is currently prevalent, another common approach to making steel, which uses recycled materials and employs electric arc furnaces (EAF), is much less carbon- and energy-intensive. The switch **from coal BF-BOF to natural gas DRI-EAF and scrap-based EAF is the key near-term de-carbonization tool for steel,** in our view. Over the past few years, we have seen a number of innovative alternative clean steel production processes being developed, primarily focusing on the increasing use of electricity and clean hydrogen *(see examples of these projects below)*. Post 2030, we assume uptake of the **clean hydrogen process (H2 DRI-EAF)** gathers pace, increasing its share in total steel production from <1% in 2030 to 10%/30%/50%/60% in 2040/50/60/70 in our GS 2.0° scenario. For natural gas DRI-EAF (including that equipped with CCS) and scrap-based EAF paths, we assume the share increases from c.29% in 2023 to c.40% in 2030 and c.60% in 2040 before giving way to the H2 DRI-EAF path and declining to c.55%/40%/30% by 2050/60/70.

Exhibit 113: Final energy consumption of the steel industry is dominated by coal, which accounts for c.70% of the sub-sector's energy mix...

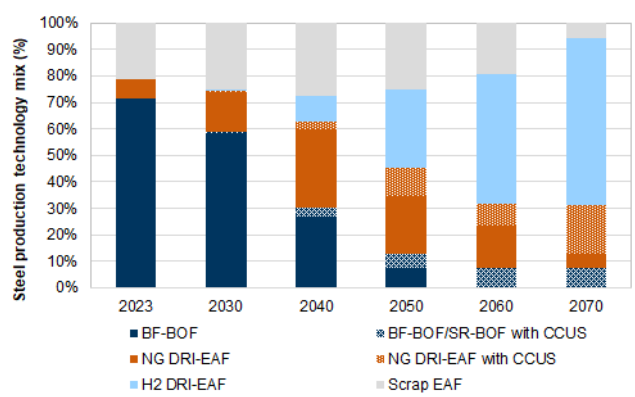
Final energy demand of key heavy industry sub-sectors and share of fossil fuels (2023)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 114: ...and our GS 2.0° path assumes a transformation of the sector, with c.70% of global steel produced in 2050 sourced from hydrogen, scrap EAF and CCUS

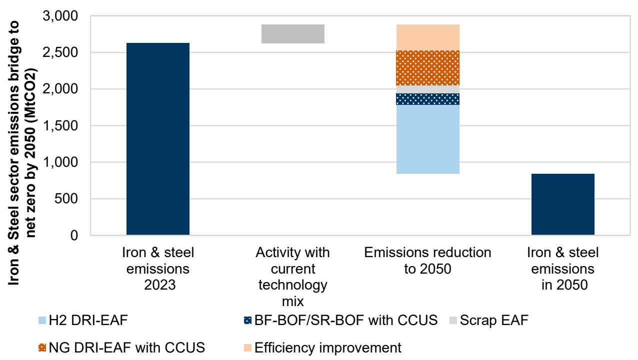
Steel production technology mix (%)



Source: Goldman Sachs Global Investment Research

Exhibit 115: Our GS 2.0 path assumes a combination of technologies in the steel sector will contribute to its de-carbonization by 2050

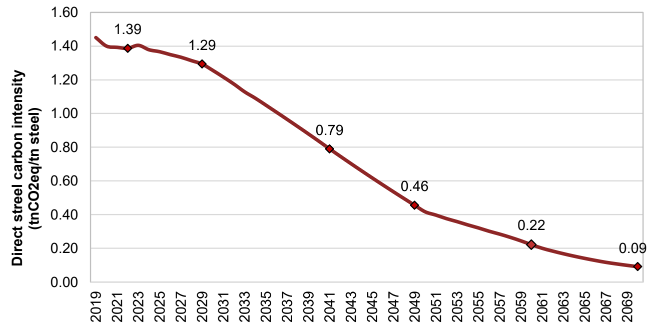
Iron & Steel sector emissions bridge by 2050 (MtCO2)...



Source: Goldman Sachs Global Investment Research

Exhibit 116: ...leading to a notable reduction in overall steel carbon intensity (direct) over time

Steel direct emissions carbon intensity (tnCO2/tn steel)

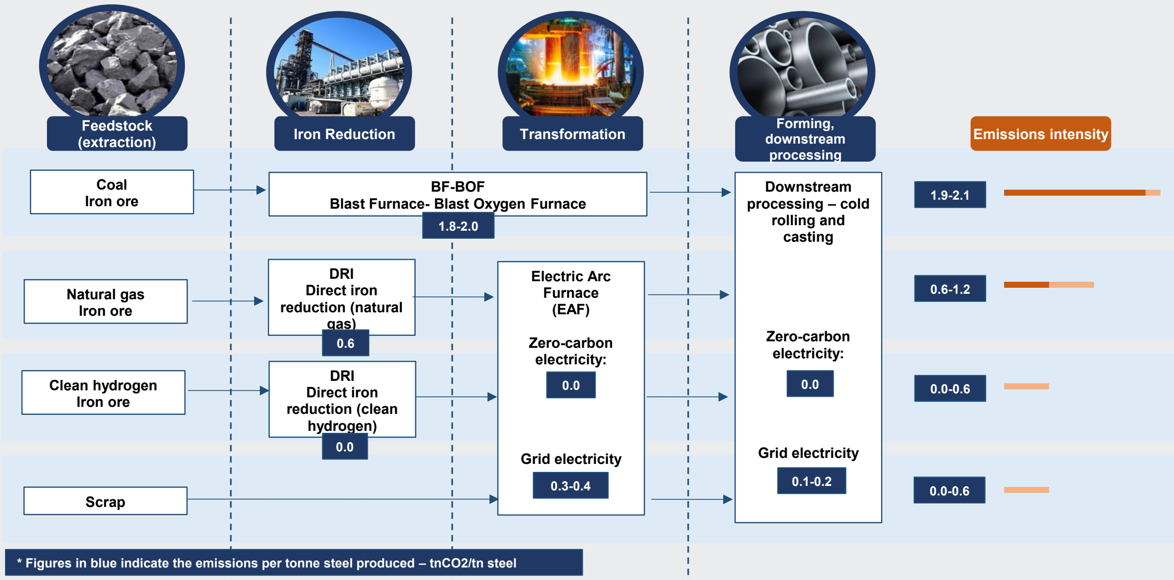


Source: Goldman Sachs Global Investment Research

Clean hydrogen and its role in the de-carbonization of steel

As we highlight in the section above, a key industrial application of clean hydrogen, and one that has recently attracted industry interest, is the production of net zero carbon steel, to help meet growing global steel demand with lower emissions.

Exhibit 117: Schematic summary of possible steel manufacturing routes and associated emissions intensity (tnCO2eq/tn steel)

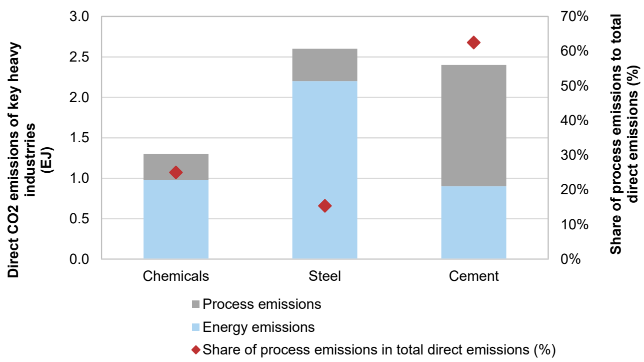


Cement and construction materials: Cement is the second most highly emitting industrial sub-sector, with a tonne of cement today having an average carbon intensity of 0.6 tnCO2, largely attributed to the carbon emitted from the raw materials and processes involved. Energy emissions account for <40% of the total direct emissions of the cement industry, as shown in Exhibit 118, in contrast to other key emitting heavy industries such as steel and chemicals (where energy emissions account for c.70-90% of total direct emissions). Cement is the binding agent for concrete, one of the key inputs to the construction industry, which is itself one of the highest emitting global industries on a Scope 1 and 2 basis.

Central to the process of cement production is the production of the clinker in the kiln, the key active ingredient in cement, which requires large amounts of energy primarily in the form of high-temperature heat. The calcination process is responsible for the vast majority of process emissions. In practice, these emissions can be reduced through **a reduction of the clinker to cement ratio** through blending of clinker with other cementitious materials (such as fly ash, limestone and calcinated clay). Currently, the clinker to cement ratio stands at around 0.7, according to the IEA, and can technically be reduced to 0.5. However, most technologies and innovative materials are still in research and the early stage of development. As a result, a reduction in the clinker to cement ratio alone is not sufficient to achieve net zero in the cement industry. Instead, CCUS is, in our view, the most promising technology for effective de-carbonization of cement. **Our GS 2.0° scenario for net zero by 2070 envisages c.70% of total cement production being retrofitted with CCUS.** Furthermore, cement plants have a typically long operating life, which constrains the pace of replacement using lower-emission technologies in the absence of early retirements, with many of these facilities added to the existing stock in the past decade. Retrofits of existing capacity with CCUS technologies are therefore likely necessary.

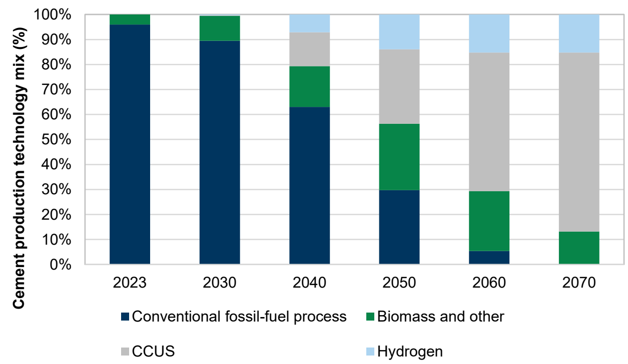
Regarding energy emissions, most are attributed to the use of coal fuel, as shown in Exhibit 113, and currently c.3 GJ of energy are required to produce just one tonne of cement on average. While alternative fuels such as bioenergy and waste are key alternative options, sustainable biomass availability is limited, while the CO2 footprint of non-renewable waste is highly variable. **In our GS 2.0° scenario, we assume c.10% of cement production relies on sustainable biomass as the primary fuel by 2070.** Given the high-temperature heat and the large quantities of energy needed for kilns, switching to direct electrification would be technically challenging and very costly. Clean hydrogen could be a key solution for high-temperature heat, and could aid the de-carbonization of energy emissions in the cement industry: **in our GS 2.0° scenario, it accounts for c.15% of final cement production in 2070.**

Exhibit 118: Cement is one of the hardest-to-abate industrial sub-sectors, primarily owing to the high proportion of direct emissions stemming from processes as opposed to energy...
Direct CO2 emissions and share of process emissions to the total direct emissions (2023)



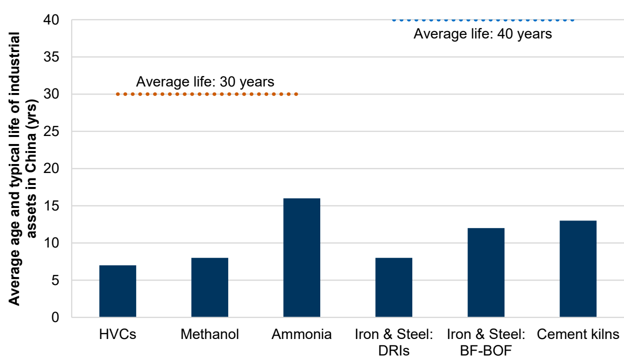
Source: IEA, Goldman Sachs Global Investment Research

Exhibit 119: ...and we expect a major technological mix shift for the industry, primarily in the form of retrofits for CCUS and fuel switch to biomass and clean hydrogen for high-temperature heat
Cement production technology mix (%)



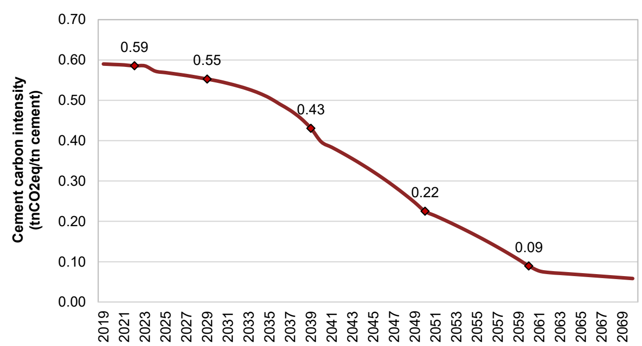
Source: Goldman Sachs Global Investment Research

Exhibit 120: Carbon capture has scope to be a key de-carbonization solution for many hard-to-abate industrial emissions, particularly given the relatively young industrial plant base in emerging economies
Average age and typical life of industrial assets (years)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 121: Based on our GS 2.0° path, the carbon intensity of cement reduces steadily over time, with energy and material efficiency improvements contributing most in the near term, before the acceleration of CCUS retrofits and cleaner fuel adoption begins in the 2030s
Cement direct emissions carbon intensity (tnCO2/tn cement)



Source: Goldman Sachs Global Investment Research

Chemicals: Chemicals is a broad sub-sector including a very large variety of commodity petrochemicals, specialty chemicals and products including plastics, fertilizers, pharmaceuticals, explosives, paints, solvents and more. The resulting carbon intensity varies greatly depending on the final product. In this analysis, we primarily focus on the bulk commodity chemicals, namely ammonia, methanol and high-value-chemicals (HVCs, including ethylene, propylene, benzene and other olefins and aromatics), which together make up the majority of emissions from the chemicals and petrochemicals industry. The chemicals sector is the largest industrial consumer of energy globally, with energy consumption amounting to c.48 EJ in 2023, and with the energy mix primarily consisting of fossil fuels (c.85%) including oil (c.45% of final energy demand), coal (13%), and natural gas (c.25%). Nonetheless, because around half of the energy inputs are used for chemical feedstocks, **a large proportion of the carbon content associated with the energy demand ends up in the final product, rather than being released into the atmosphere,** and as a result, the sector produces fewer CO2 emissions than other key heavy industries such as steel and cement.

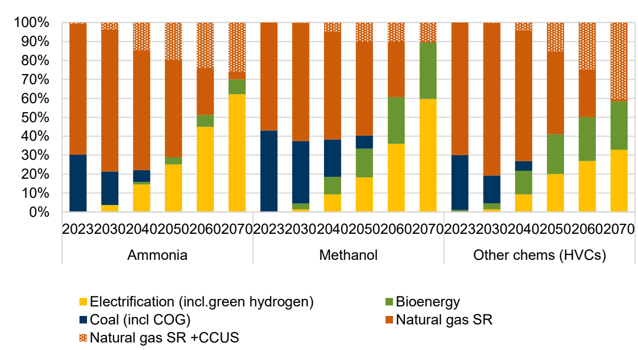
The available clean alternative technologies for chemicals are primarily concerned with a **fuel switch,** given the dominance of energy, as opposed to process direct emissions. **Fuel switch** examples include **from coal and oil to natural gas, bioenergy or electrification** (including the production of green hydrogen). Furthermore, energy efficiency, as well as circular economy (plastics recycling and re-use, more efficient use of nitrogen fertilizers), will also play a critical role in the transition, reducing over time primary chemicals demand. Beyond 2030, further emission reduction could be achieved through CCUS, as well as the accelerated uptick of green electrolytic hydrogen.

Ammonia accounted for c.45% of total chemical emissions in 2023. Ammonia consumes around 2% (8.6 EJ) of total final energy consumption, with c.40% of this energy consumed as feedstock (producing grey hydrogen via steam reforming of natural gas or coal gasification) and the remaining 60% being process energy, for generating heat. About 70% of the ammonia produced by industry is currently used in agriculture as fertilizer, yet it is also a potential candidate as a sustainable fuel for shipping. Just over 70% of ammonia production is currently via natural gas-based steam reforming, while most of the remainder is via coal gasification. Two key paths to de-carbonize ammonia are **carbon capture** applied with steam reforming (blue ammonia) and **electrolysis** to generate green hydrogen (green ammonia). In our GS 2.0° scenario, we assume carbon capture and electrolysis take off after 2030 given the cost gap vs conventional methods: we model the share of the electrolysis path (green ammonia) to increase from 3.6% in 2030 to 15%/25%/45%/60% in 2040/50/60/70, while the share of carbon capture with steam reforming (blue ammonia) increases from 3.6% in 2030 to 15%/20%/24%/26% in 2040/50/60/70. Through 2030, we believe **coal-to-gas-switching** will be the main de-carbonization path, with the share of natural gas-based steam reforming (w/o CCUS) increasing to c.76% by 2030 from 70% in 2023.

Methanol accounted for c.28% of total chemical emissions in 2023. It is currently mainly used for producing chemicals such as formaldehyde, acetic acid and plastics, but current research is focused on the use of methanol as a sustainable marine fuel. Around 60% of methanol production currently uses natural gas as feedstock, while most of the remainder uses coal. Two key paths to de-carbonize methanol are **bio-methanol** production via biomass gasification (forestry and agricultural waste, biogas from landfill, sewage, MSW) and **e-methanol** produced from captured CO2 and green hydrogen. The Methanol Institute estimates the current renewable methanol pipeline at c.27 mn t and projects 7-15 mn t capacity by 2030. In our GS 2.0° scenario, we assume bio-methanol share at 3% (4 mn t) by 2030 and e-methanol share at 1.5% (2 mn t) by 2030. Bio-methanol production costs are currently c.2-3 times higher than fossil-based methanol, while e-methanol can be 5-10 times higher than fossil-based methanol (according to IRENA estimates), which is why we model faster development of bio-methanol initially until 2040, and faster deployment of e-methanol post 2040. In our GS 2.0° scenario, we assume 9%/18%/35%/60% e-methanol share and 9%/15%/25%/30% bio-methanol share in 2040/50/60/70.

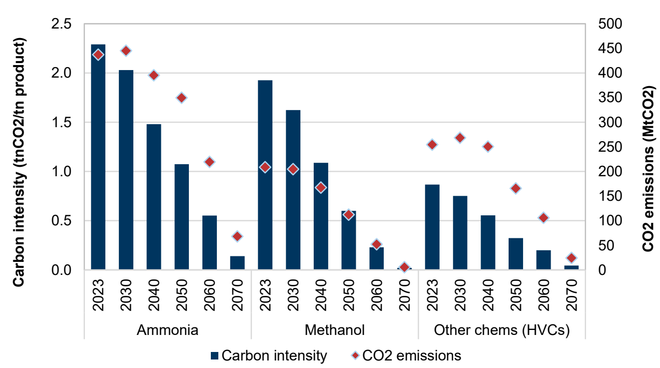
High-value chemicals accounted for c.27% of total chemical emissions in 2023. These primarily include production of petrochemical feedstocks (ethylene, propylene) which are currently produced via a steam cracking process with high heat requirements. We believe de-carbonization paths for high-value chemicals will include carbon capture, clean hydrogen firing, cracker electrification and use of renewable drop-in feedstocks and biomass gasification (HVO and biomass FT naphtha, green and blue methanol). In our GS 2.0° scenario, we assume CCUS in high-value chemicals to increase from <1% in 2030 to 5%/15%/25%/40% in 2040/50/60/70, electrification (incl. green hydrogen) to increase from c.1% in 2030 to 9%/20%/27%/33% in 2040/50/60/70, while for biomass and drop-in feedstocks, we expect an increase from c.3% in 2030 to 12%/21%/23%/25% in 2040/50/60/70.

Exhibit 122: The evolution of the energy mix and circular economy is likely to be key for the emissions abatement of the sector...
Chemicals technology mix across three key categories (%)



Source: Goldman Sachs Global Investment Research

Exhibit 123: ...with varying carbon intensity paths for each chemical product
GS 2.0° key chemicals carbon intensity and CO2 emissions evolution

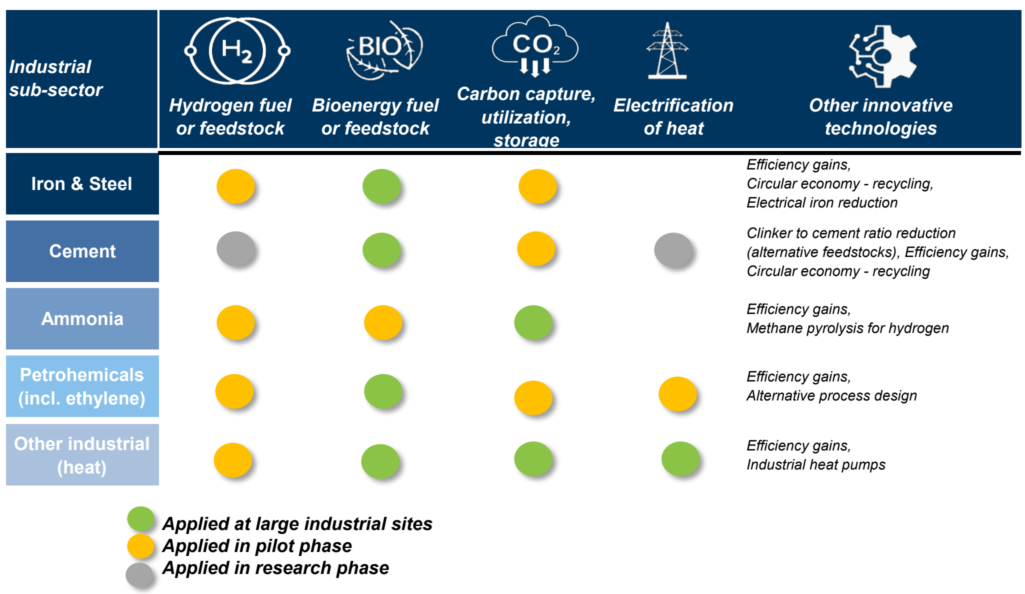


Source: Goldman Sachs Global Investment Research

Other industrial emissions: In our GS 2.0° scenario, we also consider the emissions trajectories of other industrial sub-sectors, including paper & packaging, aluminum and non-ferrous metals, as well as other unclassified broader industrial manufacturing, waste and fugitive emissions. While these segments contribute less direct emissions than the three heavy industries described above, in aggregate, across all sub-categories, they account for the remaining industrial emissions. The lack of thorough disclosure of the emission split and source makes their detailed modeling harder. More broadly, we assume the path of de-carbonization for the broader manufacturing, waste and other unclassified fugitive emissions will be similar, and identify the key technologies that can facilitate that de-carbonization path: electrification and other clean fuel switch, energy and material efficiency and finally carbon capture. Based on our GS 2.0° scenario, emissions from light industries decline by 7%/30%/55%/70%/90% (vs. 2023) by 2030/40/50/60/70 respectively, as in contrast to the heavy industries, the clean alternative technologies for these sectors are readily available.

The ability of processes to be electrified largely depends on the temperature requirements for the supply of heat across them. Low- and medium-temperature heat is assumed to be readily electrified, primarily in the form of industrial heat pumps, while high-temperature heat for heavy industries such as steel and cement, in the absence of further technological innovation, largely relies on alternative fuel switching. Bioenergy, clean hydrogen and natural gas retrofitted with CCUS are all key in facilitating the carbon neutrality path.

Exhibit 124: Summary of key de-carbonization technologies for the major industrial emitting sub-sectors



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 125: Electrification is a promising solution for energy emissions associated with fuel consumption for low- and medium-temperature heat, while CCUS and clean hydrogen are mostly included in our GS 2.0 path to address high-temperature heat

	Heat temperature	Examples of processes	Available clean technologies
c.30%	**Very high-temperature heat >1,000 degrees**	Calcination of limestone for cement production Melting in glass furnace Reheating for slab in hot strip mill	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c.16%	**High-temperature heat 400-1,000 degrees**	Steam reforming and cracking in petrochemicals (ammonia, methanol)	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c.20%	**Medium-temperature heat 100-400 degrees**	Drying, evaporation, distillation activation Broader manufacturing	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c. 15%	**Low-temperature heat < 100 degrees**	Washing, rinsing, food preparation Broader manufacturing	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c.20%	**Other unclassified**		

Source: JRC Scientific and Policy report, McKinsey, Goldman Sachs Global Investment Research

An ecosystem of key transformational technologies

Our GS scenarios for global net zero incorporate our views on the role of key de-carbonization technologies and how these are likely to pave the way for carbon neutrality, leveraging our Carbonomics cost curve. Our path consistent with net zero by 2070 calls for an evolution of the de-carbonization process from one-dimensional (renewable power) to a multi-dimensional ecosystem. Four technologies are emerging as transformational, in our view:

(a) Renewable power: The technology that dominates the 'low-cost de-carbonization' spectrum today and has the potential to support a number of sectors that require electrification, as well as being critical for the production of clean hydrogen longer term ('green' hydrogen).

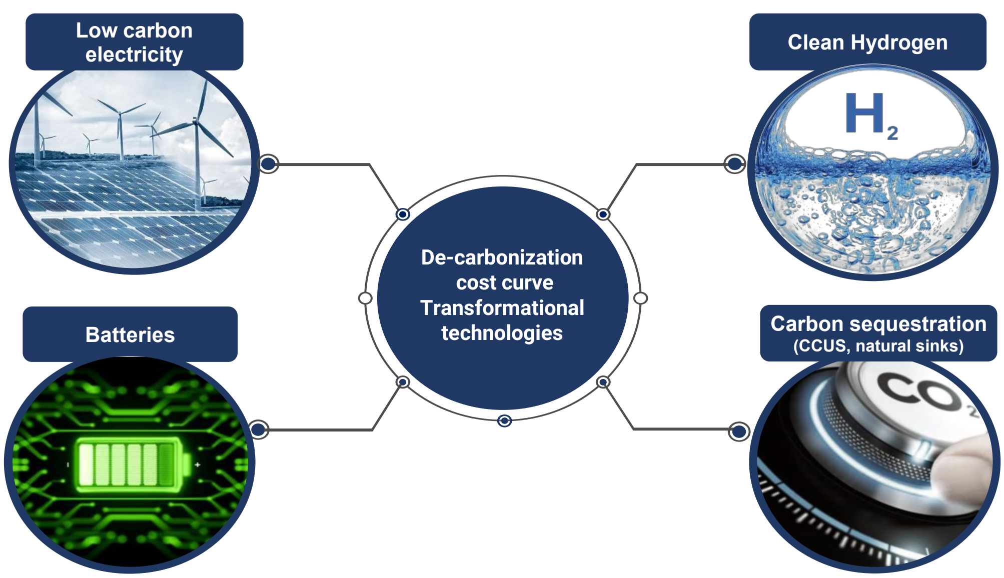
(b) Clean hydrogen: A transformational technology for long-term energy storage, enabling increasing uptake of renewables in power generation, as well as aiding the de-carbonization of some of the harder-to-abate sectors (iron & steel, long-haul transport, heating, petrochemicals).

(c) Battery energy storage: Extends energy storage capabilities, and is critical to the de-carbonization of short-haul transport through electrification.

(d) Carbon capture technologies: Vital for the production of clean ('blue') hydrogen in the near term, while also aiding the de-carbonization of industrial sub segments with emissions that are currently non-abatable under alternative technologies.

We have already addressed in detail the critical need for renewable power and batteries (see Transportation and Power generation sections), and we address clean hydrogen and carbon capture in the sections that follow.

We identify four transformational technologies that we expect to lead the evolution of de-carbonization

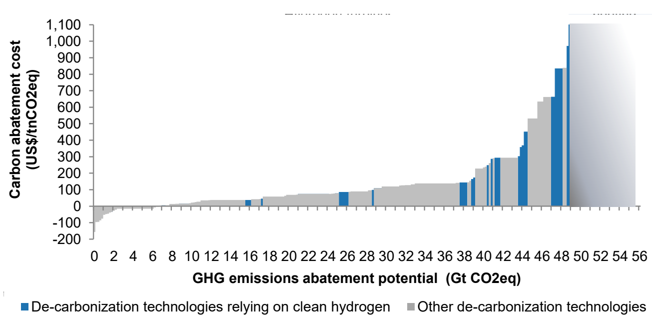


Source: Goldman Sachs Global Investment Research

Clean hydrogen: A rising technology with multiple applications

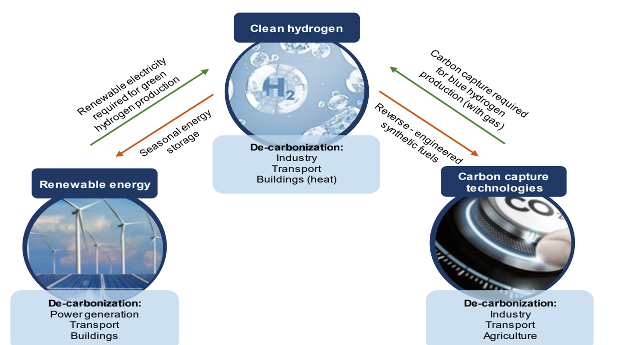
Clean hydrogen has emerged as a critical pillar of any aspiring global net zero path, aiding the de-carbonization of **c.12% of global GHG emissions**. It has a wide range of applications across sectors including, but not limited to, its potential use as an energy storage (seasonal) solution that can extend electricity's reach, an industrial energy source and an industrial process feedstock. Applications in this last area include its potential use in replacing coal in steel mills, serving as a building block for some primary chemicals and providing an additional clean fuel option for high-temperature heat, and long-haul heavy transport. Clean hydrogen is a fuel, but as an energy vector can also be produced by increasingly abundant technologies such as renewables and carbon capture. While the basic scientific principles behind clean hydrogen are well understood, most of these technologies applied in their respective industrial sectors are still at the demonstration or pilot stage. We estimate that hydrogen can contribute c.12% of global de-carbonization, with its **addressable market growing c.6.5x from c.95 Mt in 2022 to c.630 Mtpa on the path to global net zero by 2070.**

Exhibit 126: We estimate that c.12% of global GHG emissions could be abated through technologies that rely on clean hydrogen...



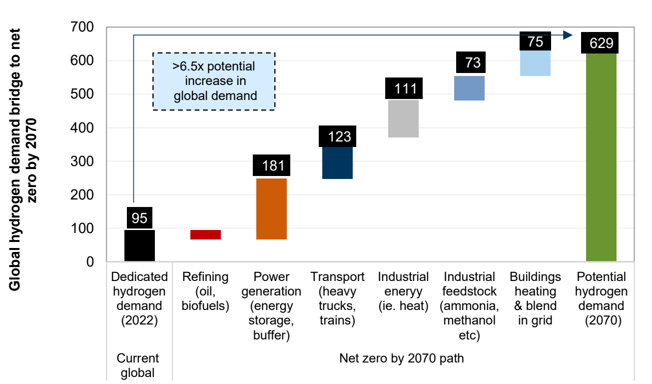
Source: Goldman Sachs Global Investment Research

Exhibit 127: ...with hydrogen forming a key connecting pillar between renewable power and carbon capture



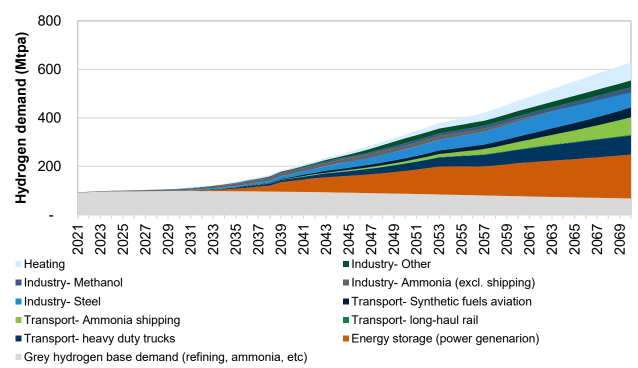
Source: Goldman Sachs Global Investment Research

Exhibit 128: Our GS 2° path of global net zero by 2070 sees total hydrogen demand increasing seven-fold (6.5x) to 2070...
Global clean hydrogen addressable market for net zero by 2070 (Mtpa)



Source: Goldman Sachs Global Investment Research

Exhibit 129: ...with contributions across most key emitting sectors (transport, power generation, industry, buildings)
Total global hydrogen demand (MtH2)



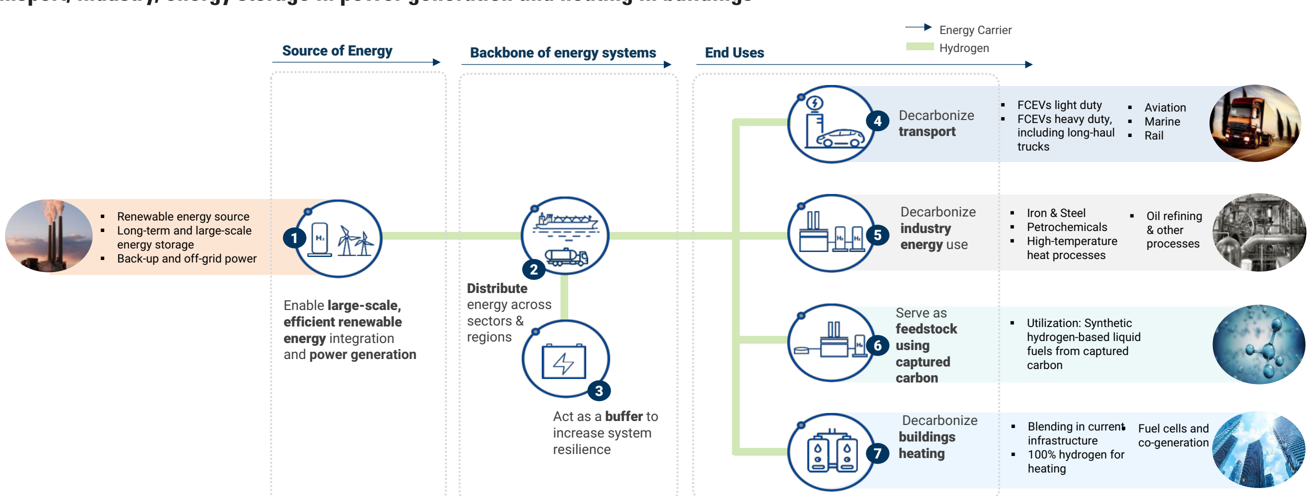
Source: Goldman Sachs Global Investment Research

A critical pillar despite slower-than-expected pace of hydrogen development

As highlighted in our deep-dive report *Carbonomics: The clean hydrogen revolution*, hydrogen as a fuel screens attractively among other conventionally used fuels for its low weight (hydrogen is the lightest element) and high energy content per unit mass, >2.5x the energy content per unit mass of both natural gas and gasoline.

While hydrogen has gone through several waves of interest in the past 50 years, none has translated into sustainably rising investment and broader adoption in energy systems. Nonetheless, the recent focus on de-carbonization and the scaling up and accelerated growth of low-carbon technologies such as renewables have sparked a new wave of interest in the properties and the supply chain scale-up of hydrogen. Over the past few years, the intensified focus on de-carbonization and climate change solutions has led to renewed policy action aimed at the wider adoption of clean hydrogen. Policy support and economic considerations, and the acceleration of low-cost renewables and electrification infrastructure, seem to be converging to **pave the way for potentially more rapid deployment and investment** in hydrogen technologies and the required infrastructure. The renewed interest in hydrogen and policy support observed over the prior two years further accelerated in 2022, and continued in 2023 on the back of REPowerEU and the US IRA. However, during the last year, we have observed a slowdown in the development of the hydrogen market, driven by the high interest rate environment, more expensive renewable power generation and uncertainty associated with the publication of conditions to qualify for 45V incentives under the US IRA, for which a draft was released six months ago. The proposed regulations are still being debated by the industry, with requirements for longer-term hourly matching of renewable energy used for hydrogen production a key area of investor focus. These factors have led to a slow pace of contract awards, which is likely to continue into 2025, given the uncertainties related to the US Presidential election. Despite a slower-than-expected pace of hydrogen projects development, we believe clean hydrogen can develop into a major global market, with global electrolyzer capacity reaching >1100 GW by 2050 and >3200 GW by 2070, on our estimates.

Exhibit 130: Hydrogen could have a critical role in aiding de-carbonization longer term across a wide variety of sectors, including long-haul transport, industry, energy storage in power generation and heating in buildings



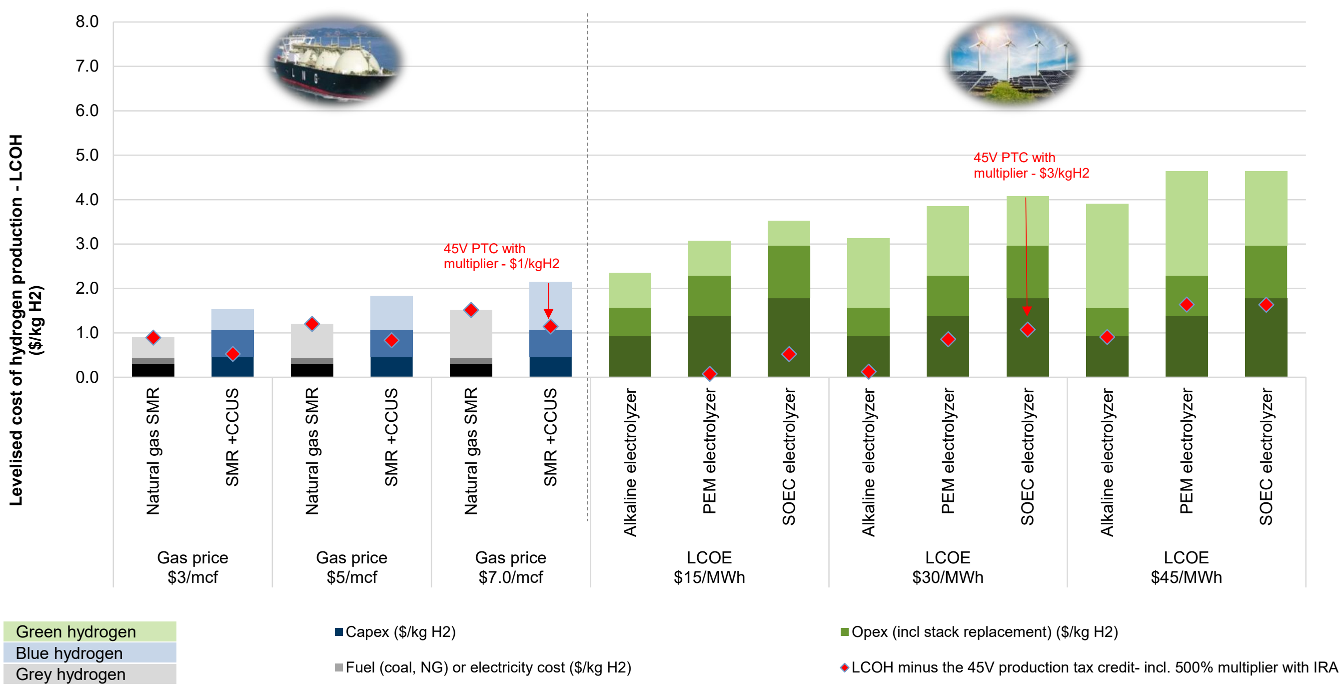
Source: Hydrogen Council, Goldman Sachs Global Investment Research

Clean hydrogen could be the key missing piece of the puzzle to reach net zero, connecting two critical components of the de-carbonization technological ecosystem: carbon sequestration and clean power generation

The low-carbon intensity pathways for hydrogen production and what makes the fuel **uniquely positioned to benefit from two key technologies in the clean tech ecosystem – carbon capture and renewable power generation –** are '**blue**' and '**green**' hydrogen. 'Blue' hydrogen refers to the conventional natural gas-based hydrogen production process (SMR or ATR) coupled with carbon capture, while 'green' hydrogen refers to the production of hydrogen from water electrolysis whereby electricity is sourced from zero carbon (renewable) energies.

While 'blue' and 'green' hydrogen are the lowest-carbon-intensity hydrogen production pathways, our hydrogen cost of production analysis, shown in Exhibit 131, suggests that both of these technologies are more costly when compared with the traditional hydrocarbon-based 'grey' hydrogen production. For 'blue' hydrogen, the cost of production is dependent on a number of technological and economics factors, the price of natural gas being the most critical followed by the additional cost for carbon capture technology integration with the SMR plant.

Exhibit 131: 'Blue' and 'green' hydrogen set the stage for de-carbonization, with 'blue' currently having a lower cost of production compared with 'green' hydrogen, but both being more costly than traditional 'grey' hydrogen

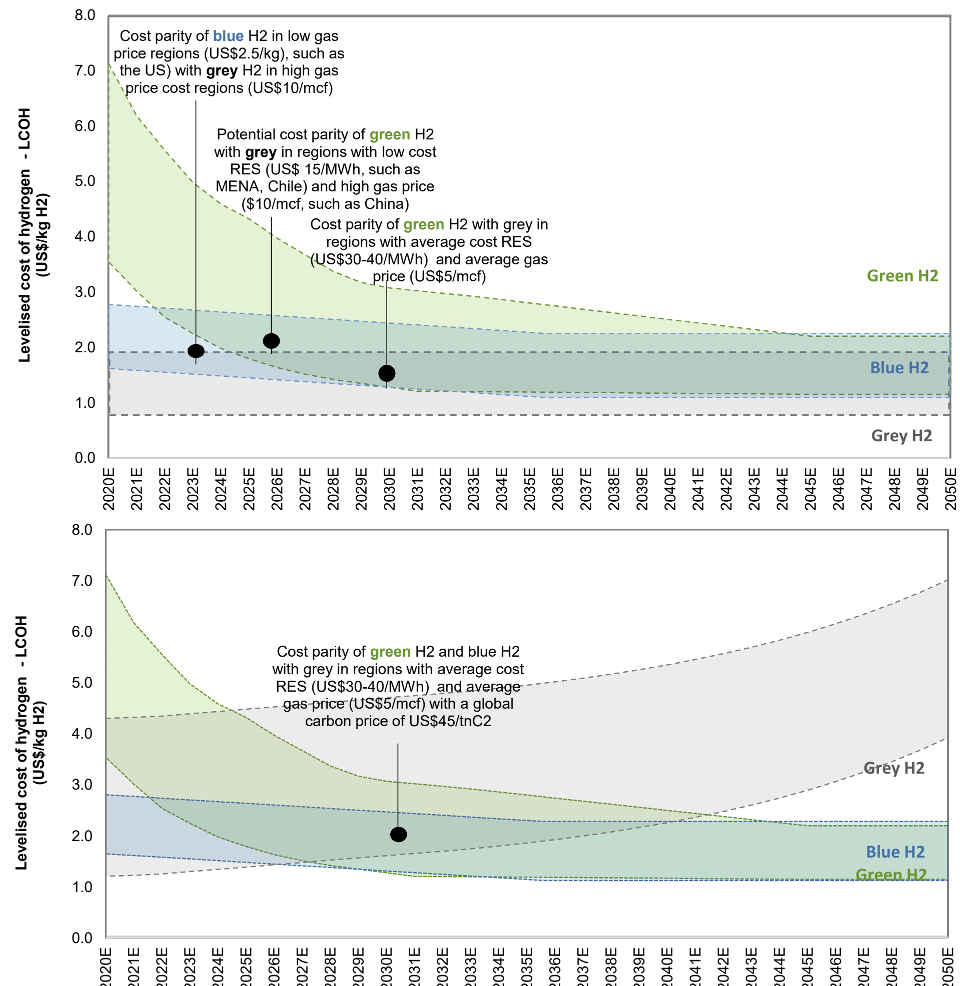


Source: Company data, Goldman Sachs Global Investment Research

Overall, we estimate that under current electricity and electrolyzer costs, the cost of production of green hydrogen is currently c.1.3-5x that of blue hydrogen, depending on the price of natural gas and the LCOE. This leads us to conclude that **both 'blue' and 'green' hydrogen will form key pillars of the low-carbon transition**, but with **'blue' facilitating the near- and medium-term transition** until **'green' reaches cost parity around the end of this decade**. We incorporate the critical role of both blue and green hydrogen in our GS 2° path to carbon neutrality by 2070. The rise of green hydrogen, which we expect to start to accelerate from 2030, should lead to a very strong increase in electrolyzer capacity, which in our GS 2° path reaches >1100 GW by 2050 and >3200 GW by 2070, as well as an increase in power demand of >11,000 TWh, representing c.12% of total power generation in 2070.

Exhibit 132: Green hydrogen could achieve cost parity with grey hydrogen before the end of this decade, depending on the regional gas price. As global carbon prices increase, the path towards cost parity accelerates

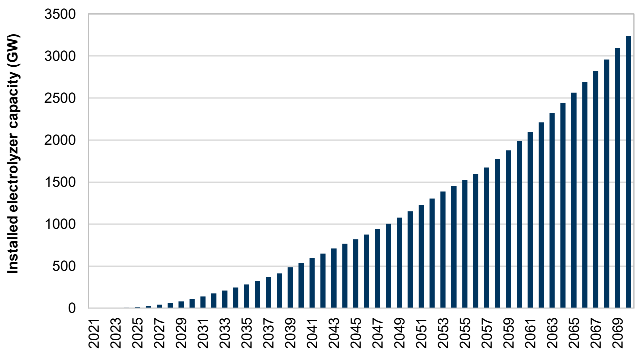
Levelized cost of grey, blue and green hydrogen over time (US$/kg H2)



Source: Goldman Sachs Global Investment Research

Exhibit 133: Given the rising importance of green hydrogen, we see very strong growth in electrolyzer capacity as part of our GS 2° path, reaching c.3,200 GW by 2070...

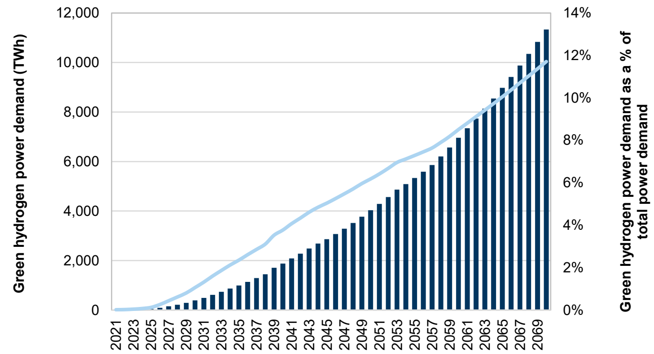
Green hydrogen installed electrolyzer capacity (GW)



Source: Goldman Sachs Global Investment Research

Exhibit 134: ...and >11,000 TWh of power demand stemming from the production of green hydrogen by 2070, representing c.12% of total power demand

Green hydrogen power demand (TWh)



Source: Goldman Sachs Global Investment Research

Carbon sequestration: CCUS, DACCS and natural sinks all key to unlocking net zero emissions

Conservation efforts alone are highly unlikely to achieve net zero carbon by 2070 in the absence of carbon sequestration

We envisage two complementary paths to enable the world to reach net zero emissions: conservation and sequestration. The former refers to all technologies enabling the reduction of gross greenhouse gases emitted and the latter refers to natural sinks and carbon capture, usage and storage technologies (CCUS) that reduce net emissions by subtracting carbon from the atmosphere. The need for technological breakthroughs to unlock the potential abatement of the **emissions that cannot at present be abated** through existing conservation technologies **makes sequestration a critical piece of the puzzle in solving the climate change challenge and leading the world to net zero carbon** emissions at the lowest possible cost. We believe that carbon sequestration can be an attractive competing technology for sectors in which emissions are harder or more expensive to abate, with industry being a prominent example.

The carbon sequestration cost curve

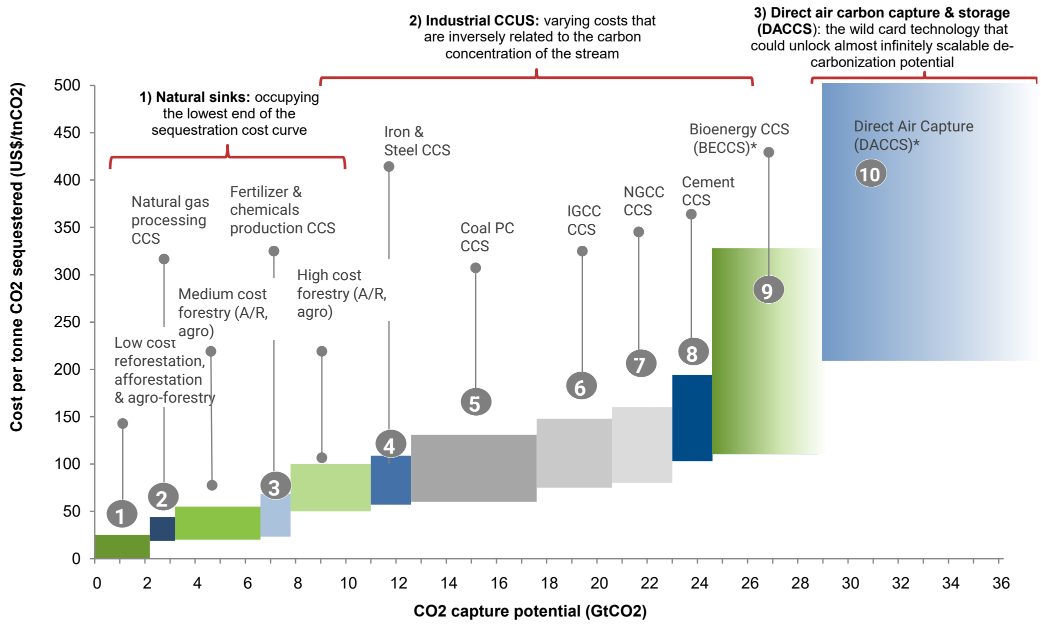
As part of our analysis, we have constructed a carbon abatement cost curve for sequestration (Exhibit 135), although we see a greater range of uncertainty in these technologies, given their under-invested state and the largely pilot nature of the CCUS plants. **Carbon sequestration** efforts can be broadly classified into three main categories:

1) Natural sinks, encompassing natural carbon reservoirs that can remove carbon dioxide. Efforts include reforestation, afforestation and agro-forestry practices.

2) Carbon capture, utilization and storage technologies (CCUS) covering the whole spectrum of carbon capture technologies applicable to the concentrated CO2 stream coming out of industrial plants, carbon utilization and storage.

3) Direct air carbon capture and storage (DACCS), the pilot carbon capture technology that could recoup CO2 from the air, unlocking almost infinite de-carbonization potential, irrespective of the CO2 source.

Exhibit 135: The carbon sequestration curve is less steep vs. the conservation curve but has a higher range of uncertainty given the limited investment to-date and the largely pilot nature of these technologies
Carbon sequestration cost curve (US$/tnCO2eq) and the GHG emissions abatement potential (GtCO2eq)



*Indicates technologies primarily in early development/pilot phase, with wide variability in the estimates of costs.

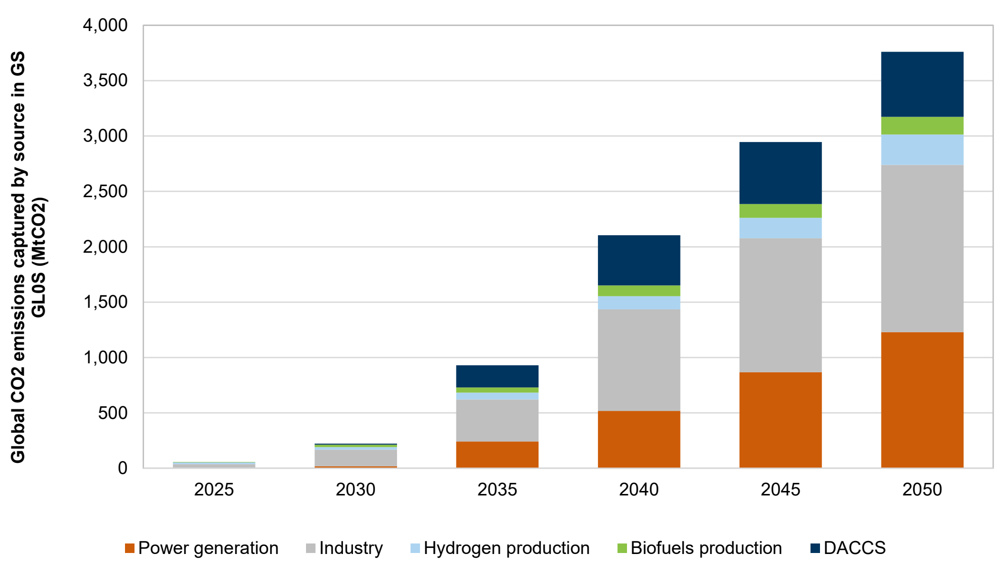
Source: IPCC, Global CCS Institute, Goldman Sachs Global Investment Research

Carbon Capture: A largely under-invested technology coming back after a 'lost decade'

CCUS technologies have scope to be an **effective route to global de-carbonization for some of the 'harder-to-abate' emission sources**: they can be used to significantly reduce emissions from coal and gas power generation, as well as across industrial processes with emissions characterized as 'harder to abate' such as iron & steel, cement and chemicals. CCUS can also facilitate the production of clean alternative fuels such as blue hydrogen, as mentioned in the previous section, as well as advanced biofuels (BECCS).

CCUS encompasses a range of technologies and processes that are designed to capture the majority of CO2 emissions from large industrial point sources and subsequently provide long-term storage solutions or utilization. We have incorporated carbon capture technologies in our GS 2.0° path for carbon neutrality by 2070, **with CCUS across sectors contributing to annual CO2 abatement of c.4 GtCO2 by 2050**, as shown in Exhibit 136 below. The single largest contributor to the CCUS abatement is industry, with sectors such as cement, steel, non-ferrous metals, fugitive and waste emissions all in need of carbon sequestration technologies in the absence of technological breakthroughs. This is followed by the CCUS retrofits required for the production of clean hydrogen from industrial hydrogen plants (blue hydrogen). Finally, CCUS can be retrofitted to the newest gas and coal power plants in power generation, as well as contribute to the full abatement of emissions through the use of biofuels (we assume the use of advanced biofuels in our analysis, but we appreciate the potential availability constraints of waste and other advanced biofuels sources and therefore further incorporate some CCUS to complement the use of bioenergy). DACCS, the potentially infinitely scalable de-carbonization technology, complements process-specific CCUS and contributes c.1 GtCO1 annual abatement by 2050 in our GS 2° scenario.

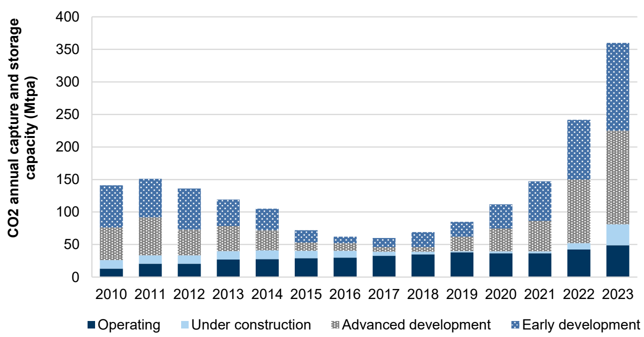
Exhibit 136: Our GS 2.0° path highlights the importance of CCUS, with the annual CCUS abatement reaching c.4 GtCO2 by 2050 and industrial sources being the key contributor
Global CO2 emissions captured by source in GS 2024 2.0° scenario (MtCO2)



Source: Goldman Sachs Global Investment Research

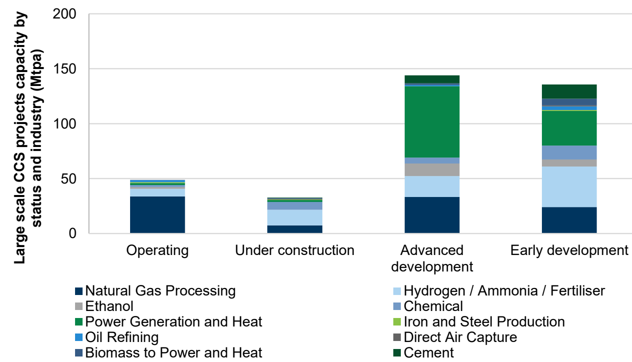
Despite its critical role to any aspirational path aiming to reach net zero by 2070, carbon capture technologies have been largely under-invested to date. We nonetheless expect a revival of interest in the technology following a 'lost decade', with more projects now under development. Currently, we identify more than 39 large-scale CCS facilities operating globally (mostly in the US, Canada and Brazil), with a total capacity of around 50 Mtpa.

Exhibit 137: The pipeline of large-scale CCS facilities is regaining momentum after a 'lost decade'...
Annual CO2 capture & storage capacity from large-scale CCS facilities



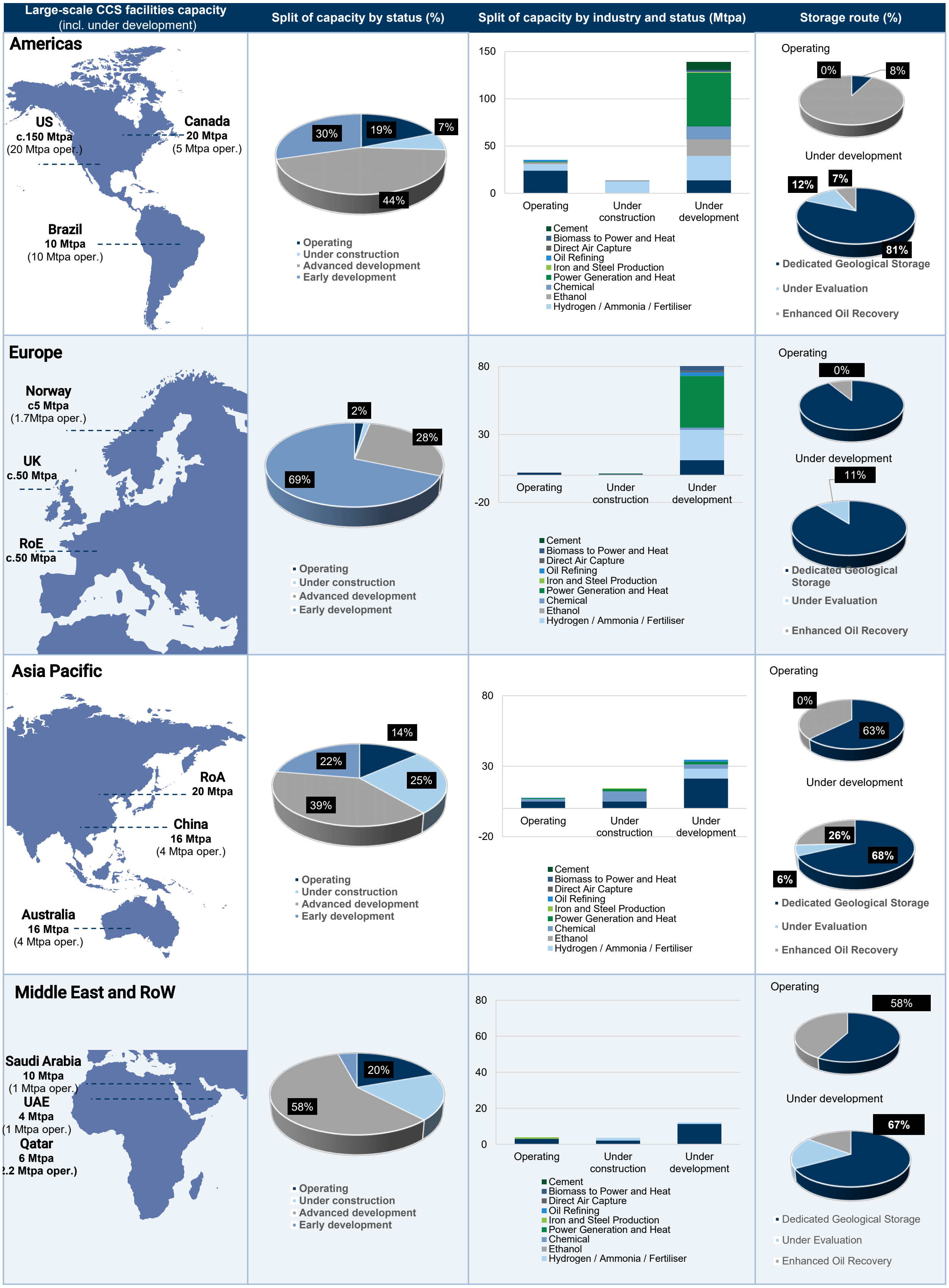
Source: Global CCS Institute Status Report 2023

Exhibit 138: ...as more projects in the development stage start to focus on industries with lower CO2 stream concentrations (industrial processes, such as cement, chemicals, oil refining, hydrogen production & power generation)
Large-scale CCS projects by status and industry of capture (Mtpa, 2023)



Source: Global CCS Institute, Goldman Sachs Global Investment Research

Exhibit 139: Summary of global large-scale CCS projects (capacity >0.4Mtpa) including operating, under construction and under early development projects



Source: Global CCS Institute CO2RE, Data compiled by Goldman Sachs Global Investment Research

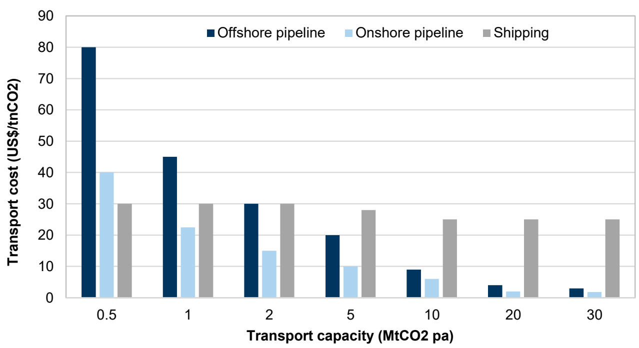
Investment is still needed in CO2 transport infrastructure

Post the capture of the CO2, compression and transport are the two steps that typically follow. The availability of CO2 transport infrastructure is therefore an essential determinant for the deployment of CCUS. The currently large-scale available technologies for the transport of CO2 include pipelines (both onshore and offshore) and shipping. Transport via pipelines is the option that has already been developed at large, commercial scale, while CO2 shipping is still in the early stages of development but could utilize the technological knowledge of shipping of liquefied petroleum gas (LPG) and liquefied natural gas (LNG). There already exists an extensive pipeline network for CO2 transportation in the United States, currently used for enhanced oil recovery (EOR) in onshore depleted shale oil and gas fields, while the launch of the Alberta Carbon Truck Line (ACTL) opens up further possibilities for the formation of an integrated CO2 pipeline transport system. Trucks and rail could also be used for shorter distances but tend to be more economically unattractive options.

For shorter distances, pipelines appear to be the most economically attractive option, yet this is very much dependent on the region and the infrastructure constraints. While the properties of CO2 lead to different design specifications compared with natural gas, CO2 transport by pipeline bears many similarities to high-pressure transport of natural gas. Repurposing existing natural gas or oil pipelines, where feasible, would normally be much cheaper than building a new line. Shipping CO2 by sea may be viable for regional CCUS clusters. In some instances, shipping can compete with pipelines on cost, especially for long-distance transport, which might be needed for countries with limited domestic storage resources. The share of capital in total costs is higher for pipelines than for ships, so shipping can be the cheapest option for long-distance transport of small volumes of CO2.

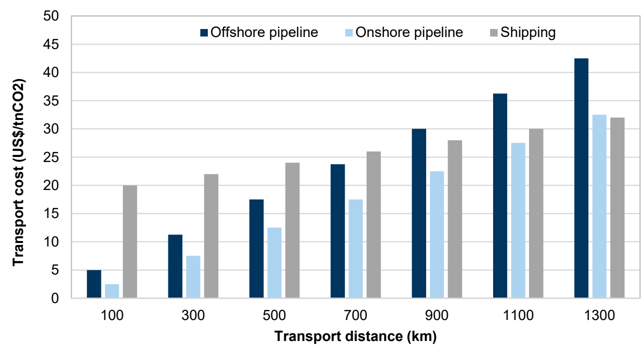
Finally, the CO2 will either be utilized or permanently stored. Storing CO2 involves the injection of captured CO2 into a deep underground geological reservoir of porous rock overlaid by an impermeable layer of rocks, whose purpose is to seal the reservoir and prevent the upward migration of CO2. There are several types of reservoirs suitable for CO2 storage, with deep saline formations and depleted oil and gas reservoirs having the largest capacity. The availability of storage is the key determinant factor influencing the associated storage cost and this varies considerably across regions, with North America, Russia and Australia appearing to hold the largest capacities. Data by the Global CCS Institute suggests that there is sufficient storage potential for what is required to be aligned with the most ambitious climate scenarios.

Exhibit 140: Pipeline transport appears to be the most economically attractive option for large CO2 transport capacity...
Transport cost of CO2 (US$/tnCO2)



Source: Company data, IPCC, Goldman Sachs Global Investment Research

Exhibit 141: ...and for smaller distances, as shipping becomes more economically attractive for distances >1000km
Transport cost of CO2 (US$/tnCO2)

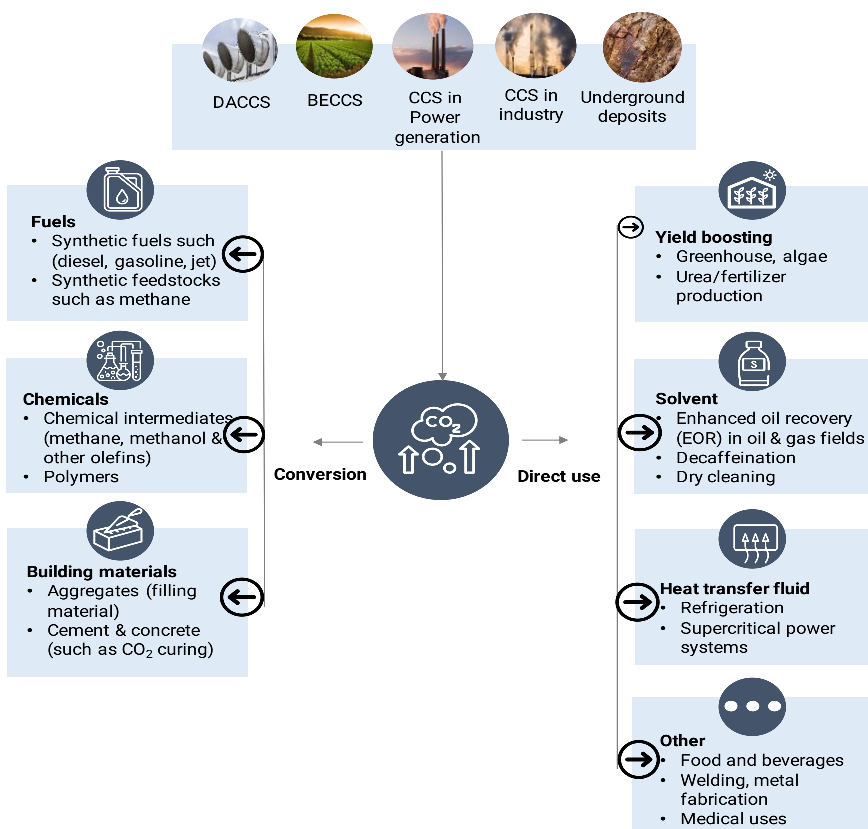


Source: Company data, IPCC, Goldman Sachs Global Investment Research

Captured CO2 Utilization: A potentially valuable commodity in search of new markets

Globally, >200 Mt of CO2 is used every year, with the majority of demand coming from the fertilizer industry, the oil & gas industry for enhanced oil recovery (EOR), and food & beverages. The rising focus on CO2 emissions reduction and carbon capture technologies has sparked further interest in CO2 utilization across a number of applications, involving both direct use (CO2 not chemically altered) and CO2 transformation or conversion. CO2 has, as a molecule, some attractive qualities for utilization purposes, including its stability, very low energy content and reactivity. The most notable examples of those include the use of captured CO2 with hydrogen to produce synthetic fuels and chemicals, the production of building materials such as concrete (replacing water during concrete production, known as CO2 curing, as well as a feedstock to produce aggregates during the grinding phase) and crop yield boosting for biological processes. CO2 utilization can form an important complement to carbon capture technologies, provided the final product or service that consumed the CO2 has a lower life-cycle emission intensity when compared with the product/process it displaces. For CO2 utilization to act as an efficient pathway for emissions reduction, there are therefore a few key parameters that need to be assessed, including: the source of CO2, the energy intensity and the source used in the process (net zero energy is vital in most cases where electricity and heat requirements are large) and the carbon's retention time in the product (this can vary from one year for synthetic fuels to hundreds of years in building materials).

Exhibit 142: There exists a very wide range of potential uses and applications for captured CO2 globally, involving both direct use and conversion



Source: IEA, Goldman Sachs Global Investment Research

The most scalable technology: Direct Air Carbon Capture and Storage (DACCS)

Direct air capture (DAC) is a different form of sequestration, as it does not apply to a specific process (like traditional CCUS), but takes CO_2 from the air in any location and scale. Nascent DAC technologies are capable of **achieving physical and/or chemical separation and concentration of CO_2 from atmospheric air**, unlike CCS, which captures carbon emitted from 'point source' industrial processing streams (flue gas). Carbon captured through DAC can then be repurposed for other uses, for example to make carbon-neutral hydrocarbon fuels. It is early days for DACCS, however, as the technology is still being developed and existing implementation projects are small-scale and very high cost. Nonetheless, we identify this technology as a potential wild card in the challenge of climate change as **it could in theory unlock almost infinitely scalable de-carbonization potential**. A summary of the most prominent DACCS designs to date and the associated details is given below.

Exhibit 143: DACCS: A roadmap of challenges but with unique opportunities ahead

Direct Air Carbon Capture (DACCS)		
Strengths	**Challenges**	**Opportunities**
1) Very large cumulative potential in relation to other carbon removal pathways that could be infinitely scalable	**1)** New concept in need of further technological innovation required to bring energy requirements and costs down to a level that is commercially competitive.	**1)** Primary energy consumption in DACCS is attributed to the heat required for sorbent/solvent regeneration. Identifying sorbents that optimize the binding to CO_2 such that it is strong enough to enable efficient capture but weak enough to reduce heat requirement during regeneration is key.
2) DACCS can be sited in a very wide range of locations including areas near high energy sources and geological storage potential since there is no need to be close to sources of emissions	**2)** The very small concentration of CO_2 in air (c0.04%) compared to industrial streams makes the economics of the capture process unattractive and calls for further innovation.	**2)** Reaction kinetics are important as they impact the rate at which CO_2 can be removed from air. If the rate is low a much larger area for air-sorbent/solvent material contact will be required which translates into a large air contactor area and thus higher capital costs. Optimization of air contactor design through geomtery and pumping strategy is another key technological aspect.
3) There are limited land and water requirements for DAC relative to other pathways such as natural sinks or BECCS.	**3)** Given the high energy intensity of carbon capture technologies, there is an evident need for zero carbon electricity for the most efficient, from a climate change standpoint, operation.	**3)** CO_2 offtake, transport and utilization is a key component for an efficient system operation. Finding new opportunities for CO_2 utilization is therefore vital. Examples include synthetic fuels and petrochemicals.
4) Technological advantages over conventional CCS include the absence of high levels of contaminants present in plants' flue gas streams, and no need for a design targeting the complete CO_2 capture with a single stream pass which is usually the case for CCS applied to industrial flue gas streams.		

Source: ICEF Roadmap, Goldman Sachs Global Investment Research

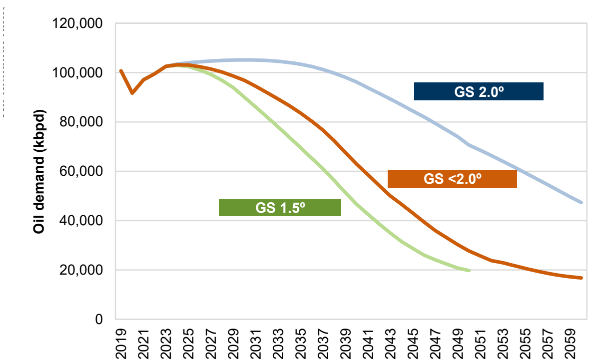
Fossil fuel investments: Investments in oil and natural gas continue to be needed for at least another decade

While global total oil & gas demand eventually declines substantially under our three net zero scenarios, as shown in Exhibit 144 and Exhibit 146, we note a marked divergence between the scenarios. In our GS 2.0° scenario **(GS 2.0°)**, near-term growth and underlying decline rates in the industry support ongoing investments in oil and gas for the next two decades.

Since 2020, the oil & gas industry's increase in capex has mostly been driven by short-cycle projects: US shale, deepwater tie-backs and onshore debottlenecking. The advantage of this capex is that in addition to being shorter-cycle, it tends to be higher return, bringing immediate benefits, on top of improved execution; we estimate it has reduced decline rates to 1% over the past three years. However, these developments also tend to be shorter-life and ultimately increase the industry's decline rates in the longer term. As a result, we estimate the oil reserve life has decreased to 21 years, a 55% reduction over the past decade, painting a tougher long-term supply picture. We outline these supply dynamics in detail in our annual oil & gas industry deep-dive Top Projects report, where our bottom-up analysis suggests that non-OPEC growth reached a peak in 2023-24 and is poised for a slowdown, opening a window for OPEC market share gains, although not before 2027.

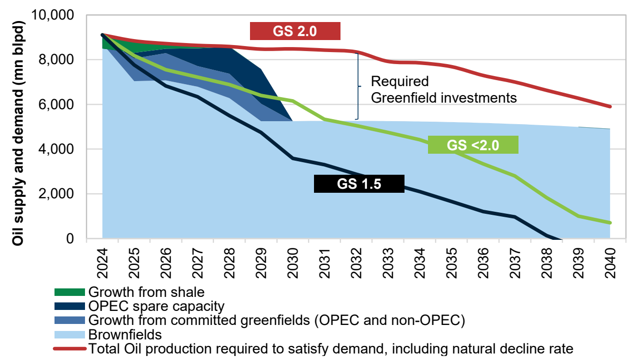
In this section, we look at the implications of the three global net zero scenarios on the need for incremental investments in oil & gas. Our results for oil are presented in Exhibit 145. While in our GS 2.0° scenario **(GS 2.0°)**, near-term growth and underlying decline rates in the industry support ongoing investments in oil for the next two decades, our well below 2°C scenario (**GS <2.0°**) would imply a need for greenfield investment until 2031. Under our 1.5°C scenario (**GS 1.5°**), oil demand could be met with only brownfield investments. For gas, we estimate that investments in natural gas would be needed for the next two decades in our 2.0° scenario, until 2035 in our GS <2.0° scenario and until 2028 in our GS 1.5°C scenario.

Exhibit 144: While oil demand gradually declines under all our global net zero scenarios...
Oil demand (kbpd) under our three global net zero scenarios



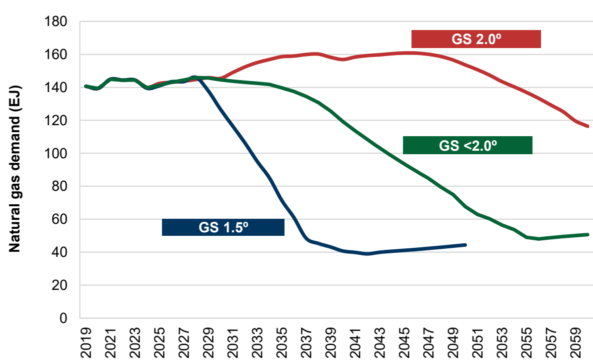
Source: Goldman Sachs Global Investment Research

Exhibit 145: ...we estimate that investments in oil will continue to be needed beyond 2040
Total Oil production required to satisfy demand, including natural decline rate



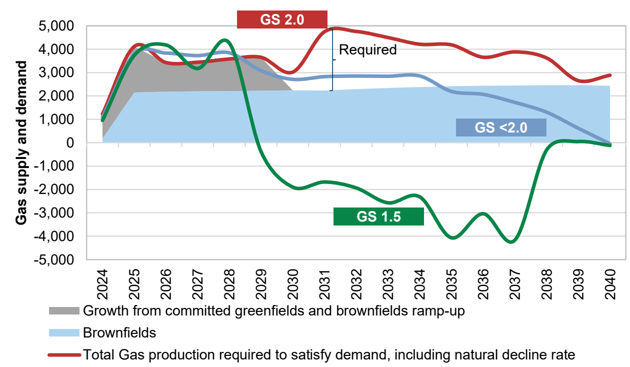
Source: Goldman Sachs Global Investment Research

Exhibit 146: The role of natural gas deviates more between our global net zero scenarios compared to oil...
Natural gas demand (EJ)



Source: Goldman Sachs Global Investment Research

Exhibit 147: ...leading to very different implied needs for natural gas investments in the coming decades
Total Gas production required to satisfy demand, including natural decline rate



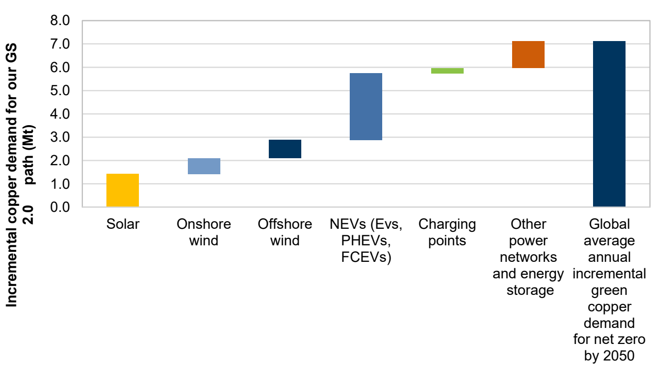
Source: Goldman Sachs Global Investment Research

Natural resources: At the heart of the global net zero evolution

At the heart of any aspirational global path to net zero lies the need for access to clean energy and an accelerated pace of electrification that is likely to drive the next natural resources super-cycle in the coming decades. **Electrification and clean energy are likely to have an impact on total demand for natural resources, and in particular metals** such as aluminium, copper, lithium and nickel, demand for which relies heavily on an acceleration in technologies such as renewables (solar panel, wind turbines manufacturing), power network infrastructure, charging infrastructure, electric vehicles and battery manufacturing. We attempt to quantify the potential impact that the path to net zero by 2070 (GS 2.0°), as laid out in previous sections, will have on the demand for each of these metals, as shown in the exhibits that follow.

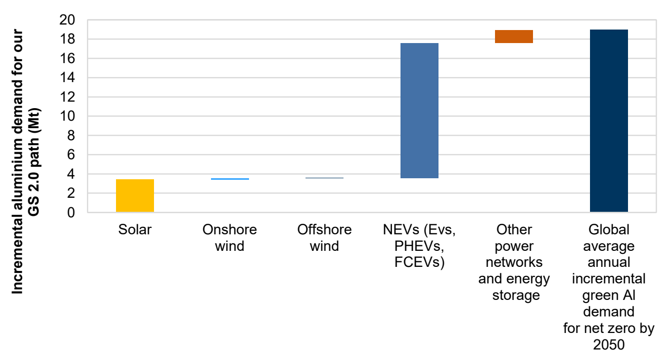
The results of this analysis are calculated on the basis of incremental demand for each clean technology relative to the conventional technology (such as incremental copper demand per electric vehicle compared with conventional ICE vehicles). We find that annual green copper demand in a global net zero path by 2050 will rise by c.7 Mtpa, a c.25% increase from the global copper demand in 2023. Similarly, we estimate the global average incremental green aluminum demand to be around 19Mtpa to 2050, c.30% of the total global aluminium demand in 2023, both suggesting material upside in demand for those metals in our future path to net zero carbon.

Exhibit 148: We estimate c. 7 Mt of average annual incremental copper demand by 2050 for our GS 2.0 ° path, representing a c.25% increase from current annual copper demand...
Incremental green copper demand for global net zero by 2050



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 149: We estimate c.19 Mt of average annual incremental aluminium demand by 2050 for our GS 2.0 ° path, representing a c.30% increase from current annual aluminium demand...
Incremental green aluminium demand for our GS 2.0 ° path

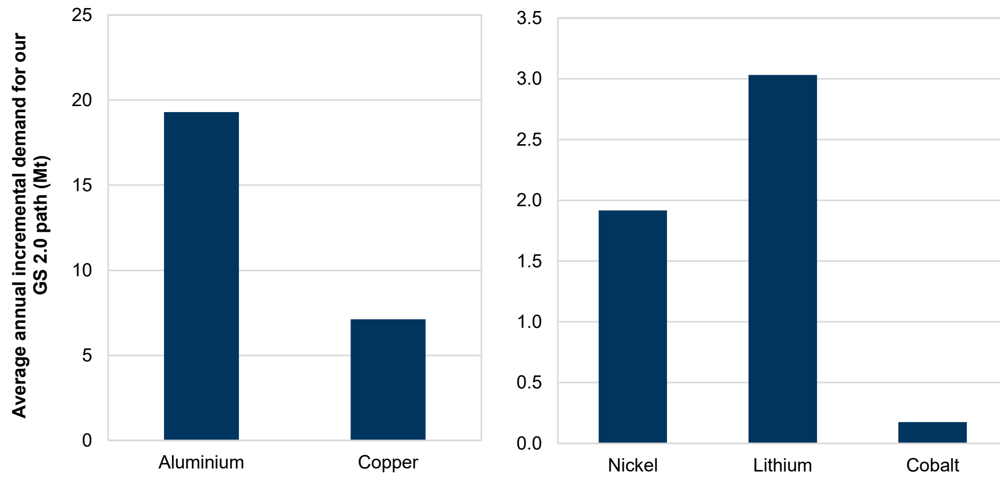


Source: Company data, Goldman Sachs Global Investment Research

Finally, we expect the demand for minerals such as lithium, nickel and cobalt to increase given the standout growth we anticipate in energy storage (both in new energy vehicles and in utility grid storage). Overall, we estimate c.3.0 Mtpa average incremental lithium demand to our GS 2.0° path, c.1.9 Mt of nickel demand and c.0.2 Mt of cobalt demand in a similar timeframe, multi-fold increases for all three metals compared with current demand levels. This is largely underpinned by the new energy vehicles (primarily BEVs) battery mix.

Exhibit 150: We expect multi-fold increases in the demand for minerals such as lithium, nickel and cobalt in the coming decades..

Incremental Li, Ni, Co average annual demand for our GS 2.0 ° path



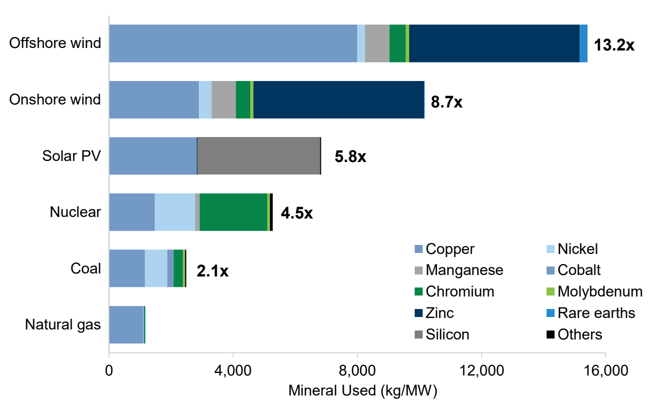
Source: Company data, Goldman Sachs Global Investment Research

The critical raw material crunch and need for a circular economy

The deployment of clean energy technologies is driving a transition towards a materials-intensive energy system from a fuels-intensive one. According to the IEA, an offshore and onshore wind plant requires c.13x and c.9x more mineral resources per MW than a natural gas-fired power plant, respectively. An EV requires 6x the mineral inputs needed for an ICE vehicle.

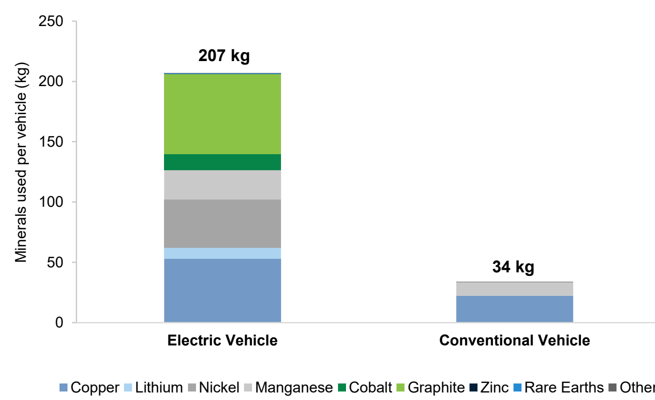
As outlined by our GS SUSTAIN team, key materials are likely to see additional supply constraints given regional concentrations and rising export restrictions. The extraction and production of most energy transition minerals is highly concentrated in certain regions. China controls c.70% of global graphite and rare earths output, and is responsible for the majority of refining of a number of critical materials (100% of graphite, 90% of rare earths, 74% of cobalt, 65% of lithium). Extraction of other key metals also sees high regional concentration: the Democratic Republic of the Congo (DRC) accounts for over 70% of cobalt extraction and Australia is responsible for 47% of lithium extraction.

Exhibit 151: The transition to an electrified renewables economy should drive significant growth in critical materials demand
Minerals used in clean energy tech vs. alternatives, kg/MW



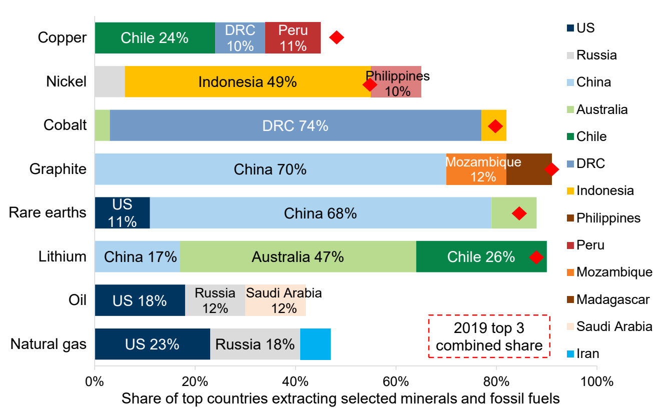
Source: IEA

Exhibit 152: Similarly, a typical EV requires 6x the critical minerals of a conventional car
Minerals used in EVs vs. conventional vehicles, kg/vehicle



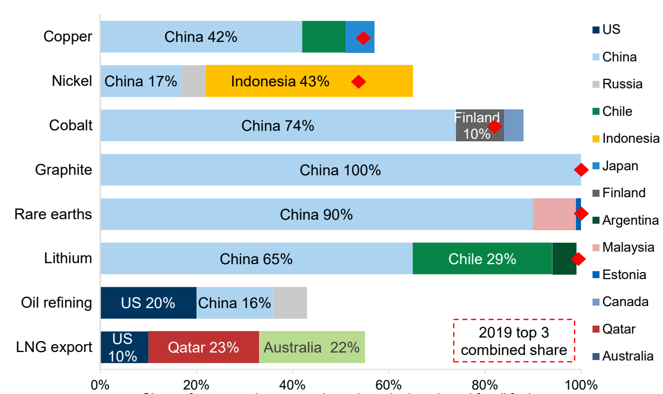
Source: IEA

Exhibit 153: The extraction of several energy transition minerals is highly concentrated and increasing...
Share of top three countries extracting selected minerals in 2022 vs. 2019 and fossil fuels (2019)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 154: ...along with critical mineral refining, where China has the greatest presence
Share of top three countries processing selected minerals in 2022 vs. 2019 and fossil fuels (2019)



Source: IEA, Goldman Sachs Global Investment Research

Assessing climate damage risks

Our GS 2.0° scenario would fall short of the Paris Agreement ambitions to limit global warming to **1.5°. According to the IPCC, a 2.0° scenario would have massive consequences and would cost US$69 trillion to the global economy in terms of adaption costs, an additional US$15 trillion in comparison to a GS 1.5° scenario (AR5, IPCC).** Swiss RE, one of the world's leading providers of reinsurance and insurance, also estimates a global GDP loss of 11% by 2050 in a 2.0°C scenario due to environmental damages, which is 7% higher than its estimated 4% GDP loss by 2050 in a 1.5°C scenario. The 2.0 °C scenario would imply US$15 trn of additional costs, based on our estimates and adjusted for inflation.

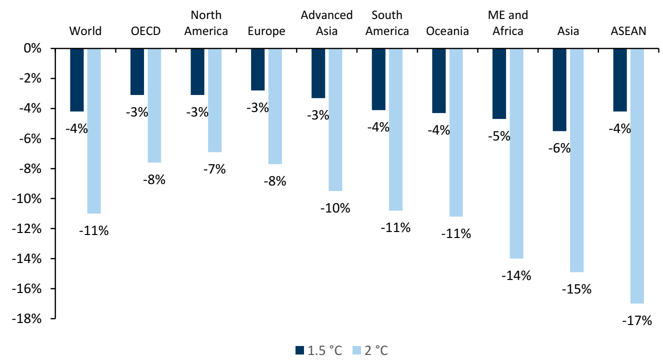
In their note Adaptation: Physical risk, Financial risk, Opportunity, our GS SUSTAIN team outline why they expect a rise in Adaptation investment – both Proactive (investments made in advance of potential physical impacts) and Reactive (investments made after physical impacts have manifested), as they argue that Adaptation will likely be a rising theme regardless of climate outcome. **They believe $400 bn of proactive investment per year this decade would be necessary to fully address Adaptation challenges.**

The relationship between carbon emissions and global temperature increase is well-established and quantified. The IPCC states with high confidence that "Human-induced warming reached c.1°C above pre-industrial levels in 2017, increasing at c.0.2°C per decade. While the impacts of temperature rise on biodiversity and adaptation costs are subject to greater variability and uncertainty, the IPCC notes "robust differences in regional climate characteristics between present-day and global warming of 1.5°C, and between 1.5°C and 2°C" and states that additional warming will increase the magnitude of the changes to the Earth's climate, from rising sea levels to more extreme weather events or biodiversity loss. Every 0.5°C of global temperature rise, for example, will cause clearly discernible increases in the frequency and severity of heat extremes, heavy rainfall events and regional droughts.

- **Extreme weather:** Heatwaves that, on average, arose once every 10 years in a climate with little human influence, will likely occur 4.1 times more frequently with 1.5°C of warming and 5.6 times with 2.0°C – and the intensity of these heatwaves will also increase by 1.9°C/2.6°C respectively. This would imply a frequency and an intensity 1.3/1.6 times higher in a 2.0° scenario than in a 1.5° scenario.
- **Sea level:** Global mean sea level is projected to rise by 0.33-0.61m at 2.0°C compared to 0.28-0.55m at 1.5°C, resulting in a 1.1 times worse impact. Sea level responds to greenhouse gas (GHG) emissions more slowly than global surface temperature, leading to weaker scenario dependence over the 21st century than for global surface temperature.
- **Biodiversity loss:** The percentage of species at high risk of extinction would increase to 18% at 2.0°C from 14% at 1.5°C, making it 1.3 times worse.
- **Drought and food security:** The dry land population exposed to water stress, heat stress, and desertification would increase to 1.15 billion people at 2.0°C from 0.95 billion people at 1.5°C, indicating 200 million more people would be affected.

Exhibit 155: Swiss RE estimates that lost GDP in a 2.0°C scenario vs 1.5°C could be as much as 7% higher by 2050

Simulating for economic loss impacts from rising temperatures in % GDP, relative to a world without climate change (0°C)



Source: Swiss Re Institute

Corporate carbon intensity de-carbonization pathways by industry consistent with 1.5°C, <2.0°C and 2.0°C global warming

As mentioned previously, we have applied our GS 1.5°, <2.0° and 2.0 net zero scenarios to **construct corporate emission reduction paths by industry** for the highest emitting industries globally on Scope 1 and 2, but also on Scope 3 for sectors where Scope 3 emissions are material. That provides a tool to screen corporates against the aspirational net zero by 2050/2060/2070 paths and assessing the suitability of their current emissions intensity reduction targets. We primarily formulate these corporate paths for a carbon intensity measure rather than absolute emissions.

Adopting a sectoral approach for corporate carbon intensity paths:

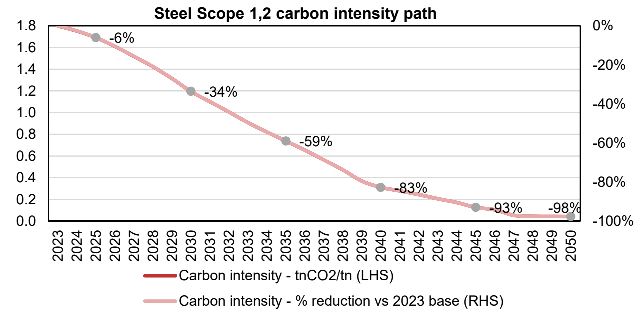
We more broadly classify the major corporate industries into two buckets:

- **Homogeneous industries with a defined unit of production:** Defined as corporate industries whose emissions are homogeneous, and are largely relying on a single activity metric. Examples include the electric utilities sector, where a carbon intensity measure can be derived by dividing the total emissions with the activity metric such as kgCO2/GWh with the power generation (GWh) being the key activity metric, autos sector (gCO2/km), airlines (gCO2/pkm), pure single metal producers and construction materials (tnCO2/tn metal or cement), real estate (gCO2/meter square of floor area) and more.
- **Heterogeneous sectors:** There are sectors where a carbon intensity measure cannot be derived from a single activity metric. Examples include hospitality, household products, food retail, capital goods and more. **For these sectors, instead of an absolute carbon intensity measure, we have constructed an index for emissions reduction based on the current emissions split and emissions sourcing of key corporates in each sector**.

Case Study 1: Examining an example of a homogeneous industry: Steel

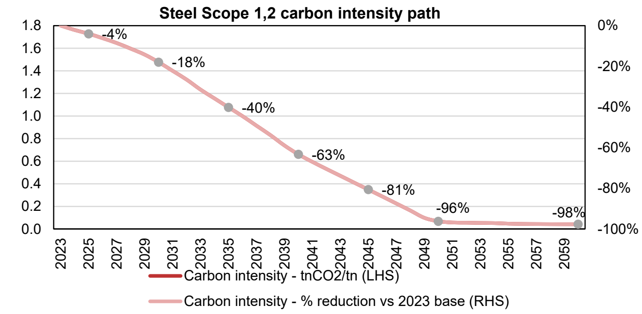
Assuming that corporate carbon intensity levels will converge to the global industry average over time, trending towards zero, the carbon intensity targets for a company in the steel industry are expected to be equal to the sectoral carbon intensity constructed by our global net zero GS 1.5, GS <2.0 and GS 2.0 paths. As part of our bottom-up sectoral global carbon neutrality scenarios, we have modeled the global emissions from the steel industry and the global steel production volumes by technology enabling us to devise a global average carbon intensity measure in tnC02/tn steel. This refers to a direct Scope 1 and indirect Scope 2 (assuming the current global average carbon intensity of power generation for the electrified routes) corporate carbon intensity measure.

Exhibit 156: We have created corporate industry carbon intensity paths consistent with net zero by 2050 (GS 1.5 scenario)...
Carbon intensity for steel (tnCO2/tn steel) and % reduction vs 2023 base



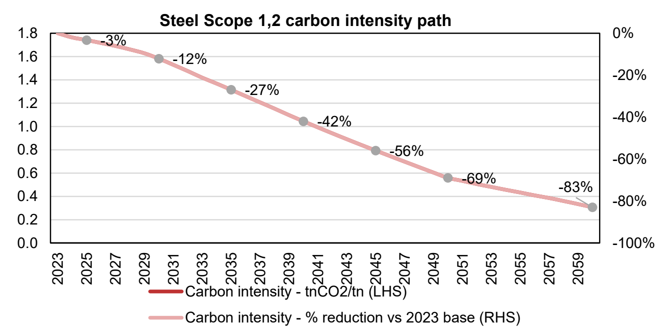
Source: Goldman Sachs Global Investment Research

Exhibit 157: ..and for a path consistent with limiting global warming to below 2 degrees and achieving net zero by 2060 (GS <2.0)
Carbon intensity for steel (tnCO2/tn steel) and % reduction vs 2023 base



Source: Goldman Sachs Global Investment Research

Exhibit 158: ..and for a path consistent with limiting global warming to 2 degrees and achieving net zero by 2070 (GS 2.0)
Carbon intensity for steel (tnCO2/tn steel) and % reduction vs 2023 base

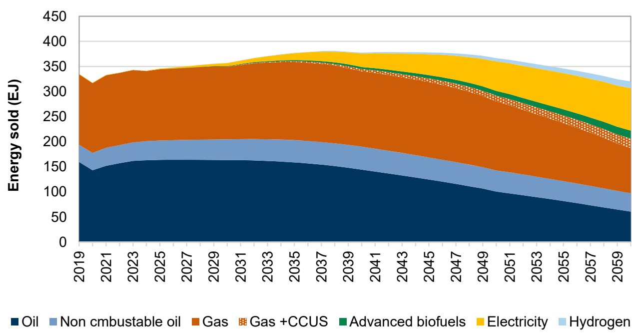


Source: Goldman Sachs Global Investment Research

Case Study 2: Examining an example of a complex homogeneous industry: Oil & gas

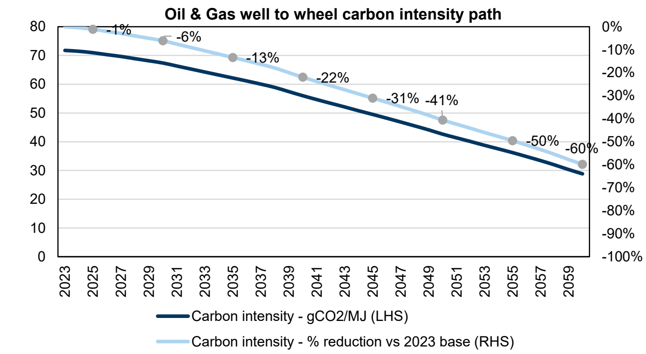
Whilst the oil & gas industry is in theory considered a homogeneous one, with the key activity metric being the amount of energy that is sold in Joules (the universal unit for energy), the wide range of activities and energy products that the integrated oil & gas companies sell makes the carbon intensity evolution analysis more complex than the pure industry example of steel described in Case Study 1. We have constructed a carbon intensity pathway for the oil & gas industry, encompassing all of Scope 1,2 and 3, given the significance of scope 3 emissions for the sector (as shown in Exhibit 159). We have assumed for the purpose of this analysis that the companies maintain their current market share in their respective oil & gas end markets, yet the mix of their energy product offering evolves with the de-carbonization of these markets (such as transport, industry, buildings for oil, power generation, industry and buildings for natural gas). In other words, whilst these companies maintain their current market share when it comes to energy sales, the form of energy sold evolves with the de-carbonization of each respective end market, away from fossil fuels in most cases and towards power, bioenergy, clean hydrogen and more. We note that this analysis does not include carbon offsets (natural sinks) and is solely based on the carbon intensity reduction from a technological evolution perspective.

Exhibit 159: We model the oil & gas industry's sales over time, assuming producers maintain their current share of energy sales...



Source: Goldman Sachs Global Investment Research

Exhibit 160: ...resulting in our overall carbon intensity path for integrated producers consistent with global net zero by 2070
Oil & gas scope 1,2,3 carbon intensity path

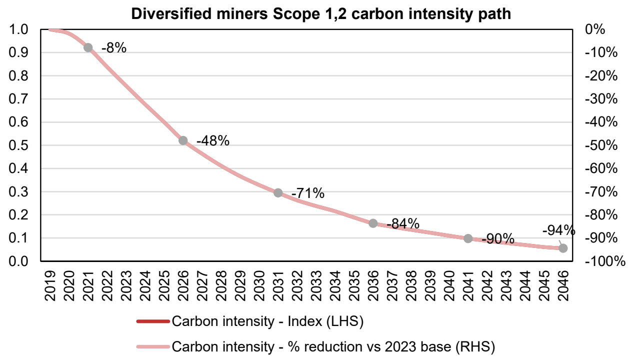


Source: Goldman Sachs Global Investment Research

Case Study 3: Examining an example of a heterogeneous industry: Diversified miners

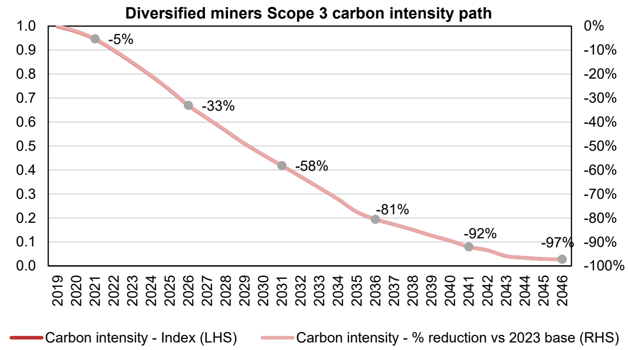
In this case study we focus on a sector which is classified as heterogeneous. As mentioned above, these are sectors where a carbon intensity measure cannot be derived from a single activity metric. **For these sectors, instead of an absolute carbon intensity measure, we have constructed an index for emissions reduction based on the current emissions split and emissions sourcing of key corporates in each sector.** Here we look into the example of diversified miners, where the different product mix of different corporates in the industry makes a single activity metric hard to derive. We have used BHP and Rio Tinto as the two key examples when formulating our suggested carbon intensity path for that sector. Assuming the companies maintain their current (2023) relative product mix (in terms of metals such as coppers, aluminium, iron ore and more and energy such as thermal and met coal) we can form a volume-weighted index for scope 1,2 and 3 emissions (mostly dominated by steel emissions - the scope 3 emissions associated with iron ore). We show the resulting carbon intensity path for diversified miners (average of Rio Tinto and BHP) in the charts that follow.

Exhibit 161: We have constructed carbon intensity reduction pathways for heterogeneous sectors such as diversified miners...
Diversified miners Scope 1,2 carbon intensity for net zero by 2050 (GS 1.5)



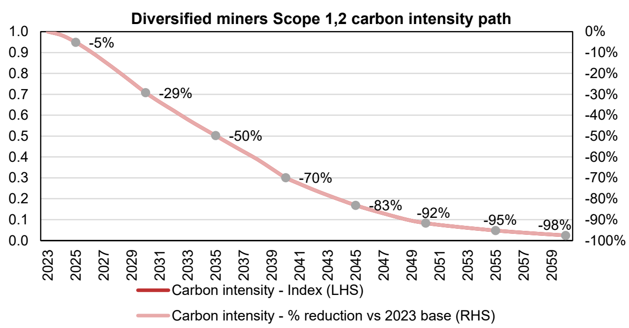
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 162: ...across all 3 scopes for industries where the Scope 3 emissions contribution is material
Diversified miners Scope 3 carbon intensity for net zero by 2050 (GS 1.5)



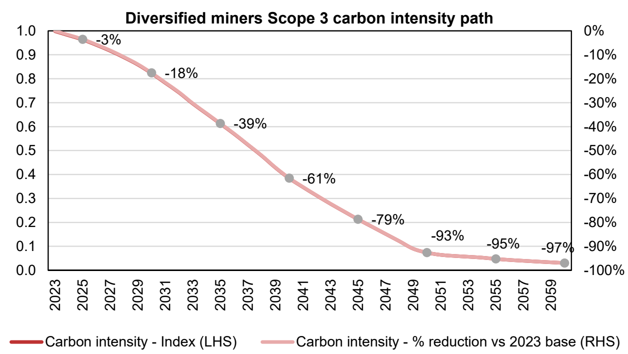
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 163: We have also constructed carbon intensity reduction pathways consistent with Paris Agreement ambitions to maintain global warming below 2 degrees...
Diversified miners Scope 1,2 carbon intensity for net zero by 2060 (GS <2.0)



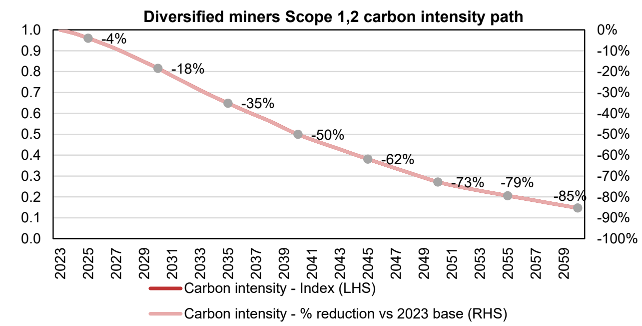
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 164: ...giving perhaps a more gradual and realistic path of emissions reduction compared to the global net zero by 2050
Diversified miners Scope 3 carbon intensity for net zero by 2060 (GS <2.0)



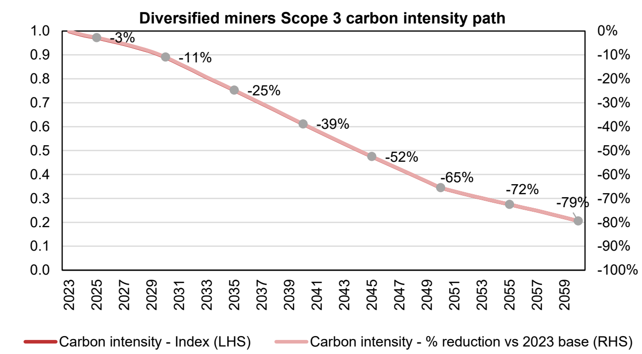
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 165: We have also constructed carbon intensity reduction pathways consistent with global warming of 2 degrees...
Diversified miners Scope 1,2 carbon intensity for net zero by 2070 (GS 2.0)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 166: ...which is the most realistic way of carbon intensity evolution in our view
Diversified miners Scope 3 carbon intensity for net zero by 2070 (GS 2.0)



Source: Company data, Goldman Sachs Global Investment Research

Limitations to our corporate industry carbon intensity paths:

- **Regional differences:** The carbon intensity paths for corporate industries were constructed on the basis of our global net zero scenarios which do not differentiate between regions. Whilst that provides a fair representation of the speed of de-carbonization across sectors on a global basis on average, we note that different regions' de-carbonization process will likely move at different speeds based on the current economic and policy framework in place. Similarly, corporates listed in different regions and with operations across different regions globally may end up de-carbonizing at a pace that differs from the one suggested by our corporate carbon intensity charts. For instance, most corporates in Europe will likely have a carbon intensity that is already well below the global average and therefore may need to move their de-carbonization process at a different pace to converge with the global average carbon intensity path.
- **Absence of carbon offsets:** The carbon intensity paths constructed above do not incorporate the role of carbon offsets such as natural sinks. This implies that for instance the carbon intensity reduction of 40% by 2035 required for integrated oil & gas companies in 1.5 degrees scenario is the one required purely from a technological and energy mix evolution perspective. Once the impact of carbon offsets is incorporated these targets will likely be higher. We do consider carbon offsets as a critical tool for net zero to be plausible and do incorporate natural sinks into our global net zero scenarios (GS 1.5, GS <2.0 and GS 2.0), yet to attribute them amongst sectors poses an additional challenge when it comes to constructing corporate industry carbon intensity pathways. Carbon offsets in the form of natural sinks and DACCS are critical for the path to global net zero, especially for harder-to-abate sectors in the absence of further technological innovation.

- **Heterogeneous sectors:** As we mentioned previously, these are sectors where a carbon intensity measure cannot be derived from a single activity metric. Examples include hospitality, household products, food retail, capital goods and more. For these sectors, instead of an absolute carbon intensity measure, we have constructed an index for emissions reduction based on the current emissions split and emissions sourcing of key corporates (benchmarks) in each sector. The key issue with this approach is of course that it cannot be readily applied to all corporates within each industry. For instance, following on from our Case study 3 above, Rio Tinto and BHP are not representative of the whole diversified miners corporate universe and may have different product splits (dictating the pace of de-carbonization of Scope 1 emissions as well as different relative emission contributions from Scope 1,2,3). Indeed more heterogeneous sectors also have a wider variety of corporates in each, a prominent example being capital goods with different companies exposed to different end markets and with different emissions composition.

Disclosure Appendix

Reg AC

We, Michele Della Vigna, CFA, Anastasia Shalaeva, Yulia Bocharnikova, Quentin Marbach, Alberto Gandolfi and Nikhil Bhandari, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

Unless otherwise stated, the individuals listed on the cover page of this report are analysts in Goldman Sachs' Global Investment Research division.

GS Factor Profile

The Goldman Sachs Factor Profile provides investment context for a stock by comparing key attributes to the market (i.e. our coverage universe) and its sector peers. The four key attributes depicted are: Growth, Financial Returns, Multiple (e.g. valuation) and Integrated (a composite of Growth, Financial Returns and Multiple). Growth, Financial Returns and Multiple are calculated by using normalized ranks for specific metrics for each stock. The normalized ranks for the metrics are then averaged and converted into percentiles for the relevant attribute. The precise calculation of each metric may vary depending on the fiscal year, industry and region, but the standard approach is as follows:

Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

Financial Returns and Multiple use the Goldman Sachs analyst forecasts at the fiscal year-end at least three quarters in the future. Growth uses inputs for the fiscal year at least seven quarters in the future compared with the year at least three quarters in the future (on a per-share basis for all metrics).

For a more detailed description of how we calculate the GS Factor Profile, please contact your GS representative.

M&A Rank

Across our global coverage, we examine stocks using an M&A framework, considering both qualitative factors and quantitative factors (which may vary across sectors and regions) to incorporate the potential that certain companies could be acquired. We then assign a M&A rank as a means of scoring companies under our rated coverage from 1 to 3, with 1 representing high (30%-50%) probability of the company becoming an acquisition target, 2 representing medium (15%-30%) probability and 3 representing low (0%-15%) probability. For companies ranked 1 or 2, in line with our standard departmental guidelines we incorporate an M&A component into our target price. M&A rank of 3 is considered immaterial and therefore does not factor into our price target, and may or may not be discussed in research.

Quantum

Quantum is Goldman Sachs' proprietary database providing access to detailed financial statement histories, forecasts and ratios. It can be used for in-depth analysis of a single company, or to make comparisons between companies in different sectors and markets.

Disclosures

Distribution of ratings/investment banking relationships

Goldman Sachs Investment Research global Equity coverage universe

	Rating Distribution			Investment Banking Relationships		
	Buy	Hold	Sell	Buy	Hold	Sell
Global	49%	34%	17%	63%	57%	40%

As of October 1, 2024, Goldman Sachs Global Investment Research had investment ratings on 2,988 equity securities. Goldman Sachs assigns stocks as Buys and Sells on various regional Investment Lists; stocks not so assigned are deemed Neutral. Such assignments equate to Buy, Hold and Sell for the purposes of the above disclosure required by the FINRA Rules. See 'Ratings, Coverage universe and related definitions' below. The Investment Banking Relationships chart reflects the percentage of subject companies within each rating category for whom Goldman Sachs has provided investment banking services within the previous twelve months.

Regulatory disclosures

Disclosures required by United States laws and regulations

See company-specific regulatory disclosures above for any of the following disclosures required as to companies referred to in this report: manager or co-manager in a pending transaction; 1% or other ownership; compensation for certain services; types of client relationships; managed/co-managed public offerings in prior periods; directorships; for equity securities, market making and/or specialist role. Goldman Sachs trades or may trade as a principal in debt securities (or in related derivatives) of issuers discussed in this report.

The following are additional required disclosures: **Ownership and material conflicts of interest:** Goldman Sachs policy prohibits its analysts, professionals reporting to analysts and members of their households from owning securities of any company in the analyst's area of coverage. **Analyst compensation:** Analysts are paid in part based on the profitability of Goldman Sachs, which includes investment banking revenues. **Analyst as officer or director:** Goldman Sachs policy generally prohibits its analysts, persons reporting to analysts or members of their households from serving as an officer, director or advisor of any company in the analyst's area of coverage. **Non-U.S. Analysts:** Non-U.S. analysts may not be associated persons of Goldman Sachs & Co. LLC and therefore may not be subject to FINRA Rule 2241 or FINRA Rule 2242 restrictions on communications with subject company, public appearances and trading securities held by the analysts.

Distribution of ratings: See the distribution of ratings disclosure above. **Price chart:** See the price chart, with changes of ratings and price targets in prior periods, above, or, if electronic format or if with respect to multiple companies which are the subject of this report, on the Goldman Sachs website at https://www.gs.com/research/hedge.html.

Additional disclosures required under the laws and regulations of jurisdictions other than the United States

The following disclosures are those required by the jurisdiction indicated, except to the extent already made above pursuant to United States laws and regulations. **Australia:** Goldman Sachs Australia Pty Ltd and its affiliates are not authorised deposit-taking institutions (as that term is defined in the Banking Act 1959 (Cth)) in Australia and do not provide banking services, nor carry on a banking business, in Australia. This research, and any access to it, is intended only for "wholesale clients" within the meaning of the Australian Corporations Act, unless otherwise agreed by Goldman Sachs. In producing research reports, members of Global Investment Research of Goldman Sachs Australia may attend site visits and other meetings hosted by the companies and other entities which are the subject of its research reports. In some instances the costs of such site visits or meetings may be met in part or in whole by the issuers concerned if Goldman Sachs Australia considers it is appropriate and reasonable in the specific circumstances relating to the site visit or meeting. To the extent that the contents of this document contains any financial product advice, it is general advice only and has been prepared by Goldman Sachs without taking into account a client's objectives, financial situation or needs. A client should, before acting on any such advice, consider the appropriateness of the advice having regard to the client's own objectives, financial situation and needs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests and a copy of Goldman Sachs' Australian Sell-Side Research Independence Policy Statement are available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Brazil:** Disclosure information in relation to CVM Resolution n. 20 is available at https://www.gs.com/worldwide/brazil/area/gir/index.html. Where applicable, the Brazil-registered analyst primarily responsible for the content of this research report, as defined in Article 20 of CVM Resolution n. 20, is the first author named at the beginning of this report, unless indicated otherwise at the end of the text. **Canada:** This information is being provided to you for information purposes only and is not, and under no circumstances should be construed as, an advertisement, offering or solicitation by Goldman Sachs & Co. LLC for purchasers of securities in Canada to trade in any Canadian security. Goldman Sachs & Co. LLC is not registered as a dealer in any jurisdiction in Canada under applicable Canadian securities laws and generally is not permitted to trade in Canadian securities and may be prohibited from selling certain securities and products in certain jurisdictions in Canada. If you wish to trade in any Canadian securities or other products in Canada please contact Goldman Sachs Canada Inc., an affiliate of The Goldman Sachs Group Inc., or another registered Canadian dealer. **Hong Kong:** Further information on the securities of covered companies referred to in this research may be obtained on request from Goldman Sachs (Asia) L.L.C. **India:** Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (India) Securities Private Limited, Research Analyst - SEBI Registration Number INH000001493, 951-A, Rational House, Appasaheb Marathe Marg, Prabhadevi, Mumbai 400 025, India, Corporate Identity Number U74140MH2006FTC160634, Phone +91 22 6616 9000, Fax +91 22 6616 9001. Goldman Sachs may beneficially own 1% or more of the securities (as such term is defined in clause 2 (h) the Indian Securities Contracts (Regulation) Act, 1956) of the subject company or companies referred to in this research report. Investment in securities market are subject to market risks. Read all the related documents carefully before investing. Registration granted by SEBI and certification from NISM in no way guarantee performance of the intermediary or provide any assurance of returns to investors. Goldman Sachs (India) Securities Private Limited Investor Grievance E-mail: india-client-support@gs.com. Compliance Officer: Anil Rajput |Tel: + 91 22 6616 9000 | Email: anil.m.rajput@gs.com. **Japan:** See below. **Korea:** This research, and any access to it, is intended only for "professional investors" within the meaning of the Financial Services and Capital Markets Act, unless otherwise agreed by Goldman Sachs. Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (Asia) L.L.C., Seoul Branch. **New Zealand:** Goldman Sachs New Zealand Limited and its affiliates are neither "registered banks" nor "deposit takers" (as defined in the Reserve Bank of New Zealand Act 1989) in New Zealand. This research, and any access to it, is intended for "wholesale clients" (as defined in the Financial Advisers Act 2008) unless otherwise agreed by Goldman Sachs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests is available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Russia:** Research reports distributed in the Russian Federation are not advertising as defined in the Russian legislation, but are information and analysis not having product promotion as their main purpose and do not provide appraisal within the meaning of the Russian legislation on appraisal activity. Research reports do not constitute a personalized investment recommendation as defined in Russian laws and regulations, are not addressed to a specific client, and are prepared without analyzing the financial circumstances, investment profiles or risk profiles of clients. Goldman Sachs assumes no responsibility for any investment decisions that may be taken by a client or any other person based on this research report. **Singapore:** Goldman Sachs (Singapore) Pte. (Company Number: 198602165W), which is regulated by the Monetary Authority of Singapore, accepts legal responsibility for this research, and should be contacted with respect to any matters arising from, or in connection with, this research. **Taiwan:** This material is for reference only and must not be reprinted without permission. Investors should carefully consider their own investment risk. Investment results are the responsibility of the individual investor. **United Kingdom:** Persons who would be categorized as retail clients in the United Kingdom, as such term is defined in the rules of the Financial Conduct Authority, should read this research in conjunction with prior Goldman Sachs research on the covered companies referred to herein and should refer to the risk warnings that have been sent to them by Goldman Sachs International. A copy of these risks warnings, and a glossary of certain financial terms used in this report, are available from Goldman Sachs International on request.

European Union and United Kingdom: Disclosure information in relation to Article 6 (2) of the European Commission Delegated Regulation (EU) (2016/958) supplementing Regulation (EU) No 596/2014 of the European Parliament and of the Council (including as that Delegated Regulation is implemented into United Kingdom domestic law and regulation following the United Kingdom's departure from the European Union and the European Economic Area) with regard to regulatory technical standards for the technical arrangements for objective presentation of investment recommendations or other information recommending or suggesting an investment strategy and for disclosure of particular interests or indications of conflicts of interest is available at https://www.gs.com/disclosures/europeanpolicy.html which states the European Policy for Managing Conflicts of Interest in Connection with Investment Research.

Japan: Goldman Sachs Japan Co., Ltd. is a Financial Instrument Dealer registered with the Kanto Financial Bureau under registration number Kinsho 69, and a member of Japan Securities Dealers Association, Financial Futures Association of Japan Type II Financial Instruments Firms Association, The Investment Trusts Association, Japan, and Japan Investment Advisers Association. Sales and purchase of equities are subject to commission pre-determined with clients plus consumption tax. See company-specific disclosures as to any applicable disclosures required by Japanese stock exchanges, the Japanese Securities Dealers Association or the Japanese Securities Finance Company.

Ratings, coverage universe and related definitions

Buy (B), Neutral (N), Sell (S) Analysts recommend stocks as Buys or Sells for inclusion on various regional Investment Lists. Being assigned a Buy or Sell on an Investment List is determined by a stock's total return potential relative to its coverage universe. Any stock not assigned as a Buy or a Sell on an Investment List with an active rating (i.e., a stock that is not Rating Suspended, Not Rated, Coverage Suspended or Not Covered), is deemed Neutral. Each region manages Regional Conviction lists, which are selected from Buy rated stocks on the respective region's Investment lists and represent investment recommendations focused on the size of the total return potential and/or the likelihood of the realization of the return across their respective areas of coverage. The addition or removal of stocks from such Conviction lists are managed by the Investment Review Committee or other designated committee in each respective region and do not represent a change in the analysts' investment rating for such stocks.

Total return potential represents the upside or downside differential between the current share price and the price target, including all paid or anticipated dividends, expected during the time horizon associated with the price target. Price targets are required for all covered stocks. The total return potential, price target and associated time horizon are stated in each report adding or reiterating an Investment List membership.

Coverage Universe: A list of all stocks in each coverage universe is available by primary analyst, stock and coverage universe at https://www.gs.com/research/hedge.html.

Not Rated (NR). The investment rating, target price and earnings estimates (where relevant) are not provided or have been suspended pursuant to Goldman Sachs policy when Goldman Sachs is acting in an advisory capacity in a merger or in a strategic transaction involving this company, when there are legal, regulatory or policy constraints due to Goldman Sachs' involvement in a transaction, when the company is an early-stage biotechnology company, and in certain other circumstances. **Rating Suspended (RS).** Goldman Sachs Research has suspended the investment rating and price target for this stock, because there is not a sufficient fundamental basis for determining an investment rating or target price. The previous investment rating and target price, if any, are no longer in effect for this stock and should not be relied upon. **Coverage Suspended (CS).** Goldman Sachs has suspended coverage of this company. **Not Covered (NC).** Goldman Sachs does not cover this company. **Not Available or Not Applicable (NA).** The information is not available for display or is not applicable. **Not Meaningful (NM).** The information is not meaningful and is therefore excluded.

Global product; distributing entities

Goldman Sachs Global Investment Research produces and distributes research products for clients of Goldman Sachs on a global basis. Analysts based in Goldman Sachs offices around the world produce research on industries and companies, and research on macroeconomics, currencies, commodities and portfolio strategy. This research is disseminated in Australia by Goldman Sachs Australia Pty Ltd (ABN 21 006 797 897); in Brazil by Goldman Sachs do Brasil Corretora de Títulos e Valores Mobiliários S.A.; Public Communication Channel Goldman Sachs Brazil: 0800 727 5764 and / or contatogoldmanbrasil@gs.com. Available Weekdays (except holidays), from 9am to 6pm. Canal de Comunicação com o Público Goldman Sachs Brasil: 0800 727 5764 e/ou contatogoldmanbrasil@gs.com. Horário de funcionamento: segunda-feira à sexta-feira (exceto feriados), das 9h às 18h; in Canada by Goldman Sachs & Co. LLC; in Hong Kong by Goldman Sachs (Asia) L.L.C.; in India by Goldman Sachs (India) Securities Private Ltd.; in Japan by Goldman Sachs Japan Co., Ltd.; in the Republic of Korea by Goldman Sachs (Asia) L.L.C., Seoul Branch; in New Zealand by Goldman Sachs New Zealand Limited; in Russia by OOO Goldman Sachs; in Singapore by Goldman Sachs (Singapore) Pte. (Company Number: 198602165W); and in the United States of America by Goldman Sachs & Co. LLC. Goldman Sachs International has approved this research in connection with its distribution in the United Kingdom.

Goldman Sachs International ("GSI"), authorised by the Prudential Regulation Authority ("PRA") and regulated by the Financial Conduct Authority ("FCA") and the PRA, has approved this research in connection with its distribution in the United Kingdom.

European Economic Area: GSI, authorised by the PRA and regulated by the FCA and the PRA, disseminates research in the following jurisdictions within the European Economic Area: the Grand Duchy of Luxembourg, Italy, the Kingdom of Belgium, the Kingdom of Denmark, the Kingdom of Norway, the Republic of Finland and the Republic of Ireland; GSI - Succursale de Paris (Paris branch) which is authorised by the French Autorité de contrôle prudentiel et de resolution ("ACPR") and regulated by the Autorité de contrôle prudentiel et de resolution and the Autorité des marches financiers ("AMF") disseminates research in France; GSI - Sucursal en España (Madrid branch) authorized in Spain by the Comisión Nacional del Mercado de Valores disseminates research in the Kingdom of Spain; GSI - Sweden Bankfilial (Stockholm branch) is authorized by the SFSA as a "third country branch" in accordance with Chapter 4, Section 4 of the Swedish Securities and Market Act (Sw. lag (2007:528) om värdepappersmarknaden) disseminates research in the Kingdom of Sweden; Goldman Sachs Bank Europe SE ("GSBE") is a credit institution incorporated in Germany and, within the Single Supervisory Mechanism, subject to direct prudential supervision by the European Central Bank and in other respects supervised by German Federal Financial Supervisory Authority (Bundesanstalt für Finanzdienstleistungsaufsicht, BaFin) and Deutsche Bundesbank and disseminates research in the Federal Republic of Germany and those jurisdictions within the European Economic Area where GSI is not authorised to disseminate research and additionally, GSBE, Copenhagen Branch filial af GSBE, Tyskland, supervised by the Danish Financial Authority disseminates research in the Kingdom of Denmark; GSBE - Sucursal en España (Madrid branch) subject (to a limited extent) to local supervision by the Bank of Spain disseminates research in the Kingdom of Spain; GSBE - Succursale Italia (Milan branch) to the relevant applicable extent, subject to local supervision by the Bank of Italy (Banca d'Italia) and the Italian Companies and Exchange Commission (Commissione Nazionale per le Società e la Borsa "Consob") disseminates research in Italy; GSBE - Succursale de Paris (Paris branch), supervised by the AMF and by the ACPR disseminates research in France; and GSBE - Sweden Bankfilial (Stockholm branch), to a limited extent, subject to local supervision by the Swedish Financial Supervisory Authority (Finansinpektionen) disseminates research in the Kingdom of Sweden.

General disclosures

This research is for our clients only. Other than disclosures relating to Goldman Sachs, this research is based on current public information that we consider reliable, but we do not represent it is accurate or complete, and it should not be relied on as such. The information, opinions, estimates and forecasts contained herein are as of the date hereof and are subject to change without prior notification. We seek to update our research as appropriate, but various regulations may prevent us from doing so. Other than certain industry reports published on a periodic basis, the large majority of reports are published at irregular intervals as appropriate in the analyst's judgment.

Goldman Sachs conducts a global full-service, integrated investment banking, investment management, and brokerage business. We have investment banking and other business relationships with a substantial percentage of the companies covered by Global Investment Research. Goldman Sachs & Co. LLC, the United States broker dealer, is a member of SIPC (https://www.sipc.org).

Our salespeople, traders, and other professionals may provide oral or written market commentary or trading strategies to our clients and principal trading desks that reflect opinions that are contrary to the opinions expressed in this research. Our asset management area, principal trading desks and investing businesses may make investment decisions that are inconsistent with the recommendations or views expressed in this research.

The analysts named in this report may have from time to time discussed with our clients, including Goldman Sachs salespersons and traders, or may discuss in this report, trading strategies that reference catalysts or events that may have a near-term impact on the market price of the equity securities discussed in this report, which impact may be directionally counter to the analyst's published price target expectations for such stocks. Any such trading strategies are distinct from and do not affect the analyst's fundamental equity rating for such stocks, which rating reflects a stock's return potential relative to its coverage universe as described herein.

We and our affiliates, officers, directors, and employees will from time to time have long or short positions in, act as principal in, and buy or sell, the securities or derivatives, if any, referred to in this research, unless otherwise prohibited by regulation or Goldman Sachs policy.

The views attributed to third party presenters at Goldman Sachs arranged conferences, including individuals from other parts of Goldman Sachs, do not necessarily reflect those of Global Investment Research and are not an official view of Goldman Sachs.

Any third party referenced herein, including any salespeople, traders and other professionals or members of their household, may have positions in the products mentioned that are inconsistent with the views expressed by analysts named in this report.

This research is not an offer to sell or the solicitation of an offer to buy any security in any jurisdiction where such an offer or solicitation would be illegal. It does not constitute a personal recommendation or take into account the particular investment objectives, financial situations, or needs of individual clients. Clients should consider whether any advice or recommendation in this research is suitable for their particular circumstances and, if appropriate, seek professional advice, including tax advice. The price and value of investments referred to in this research and the income from them may fluctuate. Past performance is not a guide to future performance, future returns are not guaranteed, and a loss of original capital may occur. Fluctuations in exchange rates could have adverse effects on the value or price of, or income derived from, certain investments.

Certain transactions, including those involving futures, options, and other derivatives, give rise to substantial risk and are not suitable for all investors. Investors should review current options and futures disclosure documents which are available from Goldman Sachs sales representatives or at https://www.theocc.com/about/publications/character-risks.jsp and https://www.fiadocumentation.org/fia/regulatory-disclosures_1/fia-uniform-futures-and-options-on-futures-risk-disclosures-booklet-pdf-version-2018. Transaction costs may be significant in option strategies calling for multiple purchase and sales of options such as spreads. Supporting documentation will be supplied upon request.

Differing Levels of Service provided by Global Investment Research: The level and types of services provided to you by Goldman Sachs Global Investment Research may vary as compared to that provided to internal and other external clients of GS, depending on various factors including your individual preferences as to the frequency and manner of receiving communication, your risk profile and investment focus and perspective (e.g., marketwide, sector specific, long term, short term), the size and scope of your overall client relationship with GS, and legal and regulatory constraints. As an example, certain clients may request to receive notifications when research on specific securities is published, and certain clients may request that specific data underlying analysts' fundamental analysis available on our internal client websites be delivered to them electronically through data feeds or otherwise. No change to an analyst's fundamental research views (e.g., ratings, price targets, or material changes to earnings estimates for equity securities), will be communicated to any client prior to inclusion of such information in a research report broadly disseminated through electronic publication to our internal client websites or through other means, as necessary, to all clients who are entitled to receive such reports.

All research reports are disseminated and available to all clients simultaneously through electronic publication to our internal client websites. Not all research content is redistributed to our clients or available to third-party aggregators, nor is Goldman Sachs responsible for the redistribution of our research by third party aggregators. For research, models or other data related to one or more securities, markets or asset classes (including related services) that may be available to you, please contact your GS representative or go to https://research.gs.com.

Disclosure information is also available at https://www.gs.com/research/hedge.html or from Research Compliance, 200 West Street, New York, NY 10282.