Note: The following is a redacted version of the original report published March 22, 2023 [83 pgs].

Goldman Sachs

EQUITY RESEARCH | March 22, 2023 | 9:10 PM CET

Carbonomics

The third American energy revolution

The **US shale revolution is entering its age of maturity** and eventual decline. The US needs another energy revolution to maintain its energy cost leadership, unmatched outside the Middle East. We estimate that **renewable technologies can deliver twice the scale of energy produced by shale**, unlocking $3 trn of infrastructure investment over the coming decade.

In this report, we leverage our Carbonomics framework to model this renewable revolution, and draw five key conclusions:

1. The US IRA provides the most supportive regulatory environment in clean tech history, unlocking, on our estimates, **$1.2 trn of incentives by 2032**;

2. We expect this to drive **$3 trn of investments across renewable electrons and molecules**, including the **first deployment at large scale of green hydrogen and carbon capture**;

3. This renewables investment programme should **save 22 Gt of emissions through to 2032 at a cost to the government of $52/tonne of CO2...**

4. ...driving **the US Carbonomics cost curve 75% lower over the period...**

5. ...and transforming the need for natural resources - we see a 35%/20% incremental uplift from green capex to copper/aluminium demand by the end of the decade, with oil & gas demand in structural decline.

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

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

Brian Lee, CFA
+1 917 343-3110
brian.k.lee@gs.com
Goldman Sachs & Co. LLC

Neil Mehta
+1 212 357-4042
neil.mehta@gs.com
Goldman Sachs & Co. LLC

The Goldman Sachs Group, Inc.

For full list of authors, please see overleaf

All Authors

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

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

Brian Lee, CFA
+1 917 343-3110
brian.k.lee@gs.com
Goldman Sachs & Co. LLC

Neil Mehta
+1 212 357-4042
neil.mehta@gs.com
Goldman Sachs & Co. LLC

Brian Singer, CFA
+1 212 902-8259
brian.singer@gs.com
Goldman Sachs & Co. LLC

Enrico Chinello, Ph.D.
+1 212 357-3398
enrico.chinello@gs.com
Goldman Sachs & Co. LLC

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

Jerry Revich, CFA
+1 212 902-4116
jerry.revich@gs.com
Goldman Sachs & Co. LLC

Mark Delaney, CFA
+1 212 357-0535
mark.delaney@gs.com
Goldman Sachs & Co. LLC

Joe Ritchie
+1 212 357-8914
joseph.ritchie@gs.com
Goldman Sachs & Co. LLC

Adam Samuelson
+1 212 902-6764
adam.samuelson@gs.com
Goldman Sachs & Co. LLC

Emily Chieng, CFA
+1 917 343-5603
emily.chieng@gs.com
Goldman Sachs & Co. LLC

Ati Modak
+1 212 902-9365
ati.modak@gs.com
Goldman Sachs & Co. LLC

Adam Bubes, CFA
+1 212 357-9824
adam.bubes@gs.com
Goldman Sachs & Co. LLC

Vivek Srivastava
+1 212 902-2603
vishal.vivek@gs.com
Goldman Sachs & Co. LLC

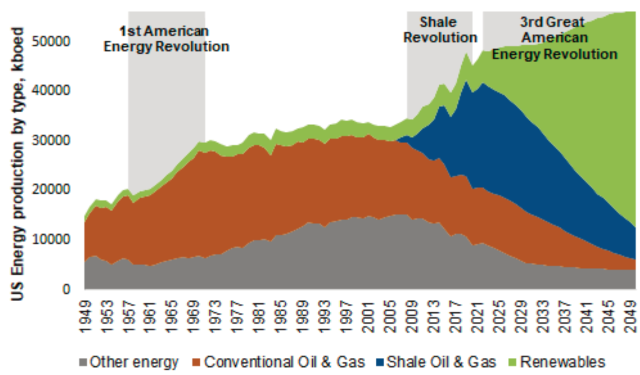
Table of Contents

The following is a redacted version of Goldman Sachs Research's report "Carbonomics: The third American energy revolution" originally published Mar. 22 2023 (83pgs). All company references in this note are for illustrative purposes only and should not be interpreted as investment recommendations.

PM Summary

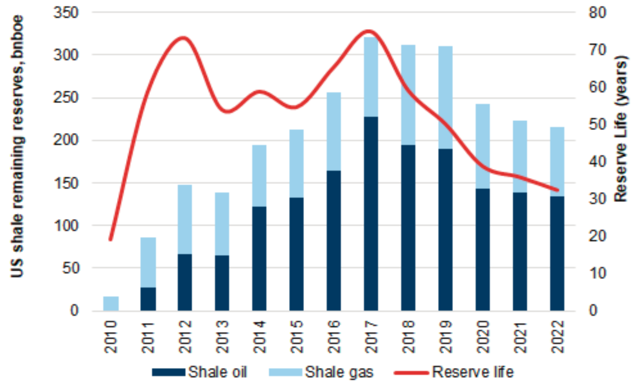
The **US shale revolution started in 2008,** and over the following decade **made the US the world's largest oil & gas producer,** providing American industry and consumers with low-cost energy comparable in scale and cost positioning only to the Middle East. **However, 15 years later, shale is entering its age of maturity** and eventual decline. Using our Top projects data, we estimate that shale reserves have fallen by 33% since 2017, reducing the reserve life of shale (resources/production) by 57%, and that shale production will peak over the next 3-5 years. Shale remains a very valuable asset, but in our view **the USA can no longer rely on it to carry this key cost competitive advantage into the next decade: it needs another energy revolution** to maintain its energy cost leadership. We estimate that **renewable technologies can deliver twice the scale of energy produced by shale**, unlocking the equivalent of 43 mnboe/d through **green electrons** (70%, mostly solar and wind) and **green molecules** (30%, mostly hydrogen and bio-energy) by 2032. In this report, we leverage our Carbonomics framework to model this renewable revolution, unpicking the key technologies that can drive this $3 trn (GSe) infrastructure investment over the coming decade.

Exhibit 1: We are entering the third American post-WW2 energy revolution...
US energy production by type, kboed



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

Exhibit 2: ...with shrinking US shale reserves sealing the end of a decade of oil & gas resource expansion
US shale remaining reserves, bnboe

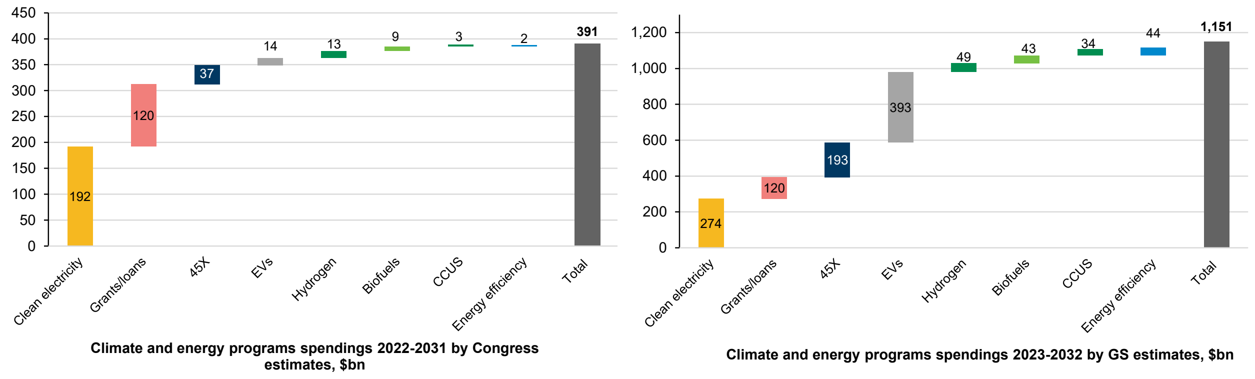


Source: Company data, Goldman Sachs Global Investment Research

The IRA provides the most supportive regulatory environment in clean tech history, unlocking, on our estimates, $1.2 trn of incentives by 2032

The US IRA (approved by the US House of Representatives on August 12 as the "Inflation Reduction Act of 2022") is in our view the most comprehensive and impactful legislation to be implemented on clean tech. It unlocks incentives that make most clean tech technologies profitable at large scale, across both renewable electrons (solar, wind, EVs, energy storage) and renewable molecules (bio-energy, clean hydrogen, carbon capture). We believe that the uptake of these incentives will be much greater than initially expected: on September 7, **the Congressional Budget Office (CBO)** released its final scoring of the Inflation Reduction Act. It **estimated that the budgetary impact from the bill's Energy and Climate provisions would total $391 bn over the 2022-2031 period.** Of this, about $265 bn would come in the form of tax credits that incentivize businesses to invest in and produce renewable energy and low emission fuels, and individuals to make purchases that improve the energy efficiency of their homes and transportation choices. **On our estimates, the IRA could cost the government around $1.2trn through to 2032, three times the CBO estimate**. **This material government contribution would in turn unlock US$3 trn of infrastructure investments to 2032 (a 2.5x multiplier vs c.$1.2trn government incentives).**

Exhibit 3: We note that our government spending estimates are three times higher than the Congress estimate of $391 bn over 2022-2031
Cumulative government spending across sectors for the restructuring of the US energy system by 2032 (USbn)



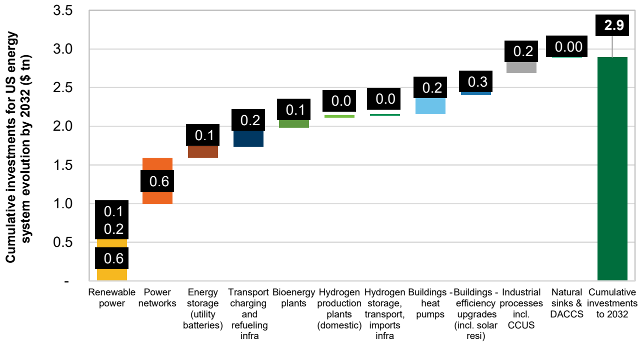
Source: US Treasury, Congressional Budget Office, Goldman Sachs Global Investment Research

This attractive regulatory backdrop drives $3 trn of investments across renewable electrons and molecules, including the first deployment at large scale of green hydrogen and carbon capture

The IRA improves the economics of most clean tech, but has a transformative impact on the economics of renewable molecules (where developments have been very marginal over the past decade), especially for clean hydrogen, carbon capture and the new generation of bio-energy developments. If we dissect the impact by sector, we estimate that **the transport sector – the key emitting sector in the USA – is most impacted by the IRA**. The decreases in costs that we see are primarily driven by the modified tax credit for new EV purchases (a maximum credit of $7,500 per vehicle), tax credit for commercial clean vehicles, with battery capacity of not less than 15 kWh (the credit is capped at $40,000 or $7,500 for vehicles weighing less than 14,000 pounds) and the extension of tax credits for biofuels and the creation of a new sustainable aviation fuel credit. Additionally, the 45V production tax credit (PTC) for clean hydrogen of up to $3/kg of hydrogen introduced in the IRA should also have a positive impact on the US transport carbon cost curve, benefiting FCEVs and hydrogen train adoption. Buildings and Heavy Industry also set to materially benefit from the incentives for electrification, clean hydrogen and carbon capture. **This improvement in project economics will unlock, in our view, $3 trn of infrastructure investments to 2032** and $11 trn by 2050. **We estimate that c.70% of this total investment will be directed to electrification (renewable power, but also considerable investment in power and charging networks) with the remaining c.30% directed to green molecules.**

Exhibit 4: The attractive regulatory backdrop drives $3 trn of investments across renewable electrons and molecules

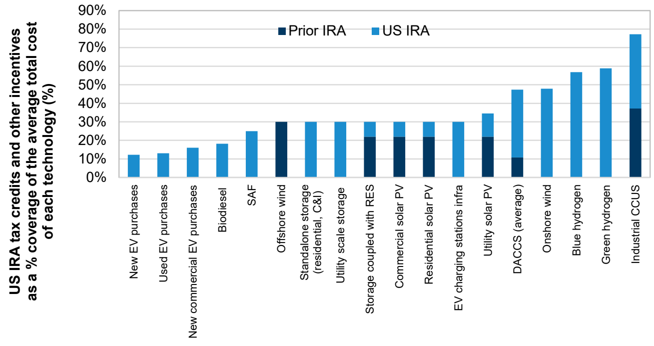
Cumulative investment opportunity across sectors for the restructuring of the US energy system by 2032 (US trn)



Source: Goldman Sachs Global Investment Research

Exhibit 5: The IRA is a breakthrough, especially for carbon capture and clean hydrogen

US IRA tax credits and other incentives as a % of coverage of the average total cost of each clean technology (%)

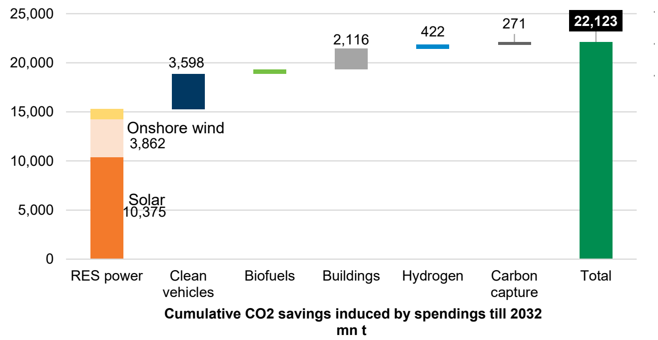


Source: US Treasury, Congressional Budget Office, Goldman Sachs Global Investment Research

The renewable revolution could save 22 Gt of emissions at a cost to the government of $52/tonne of CO2

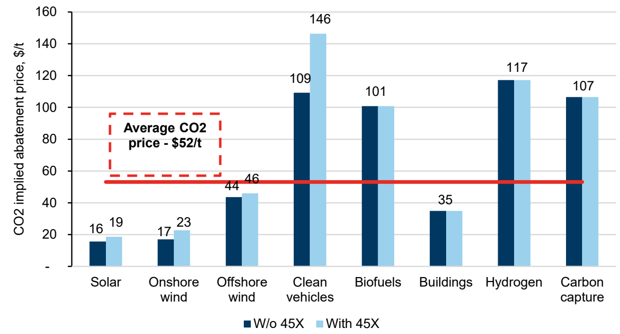
We estimate that CO2 savings from IRA incentives and induced investments to 2032 will amount to 22 gigatonnes, implying a $52/t cost of CO2 abated to the US government. This abatement CO2 price varies by technology: while for solar and onshore wind the CO2 price is less than $25/t, given their 25+ years longevity and the mature nature of the technology, for hydrogen, EVs and biofuels the price exceeds $100/t given the shorter project life (average car life of 15 years) and the immaturity of many of these technologies. We also consider how the IRA changes the cost curve of decarbonization for the USA. The Carbonomics cost curves show the reduction potential and carbon abatement cost for anthropogenic GHG emissions through >100 different applications of GHG conservation and sequestration technologies across all key emitting sectors in the region that the cost curve addresses. **In this report, we introduce the first Carbonomics de-carbonization cost curve for the USA, and show the transformation of the cost curve, incorporating US IRA tax credits and other incentives, moving the cost curve 75% lower**.

Exhibit 6: This $3 trn investment to 2032E can save 22 Gt of CO2 emissions...
Cumulative CO2 savings to 2032E; US, bridge by tech/sector



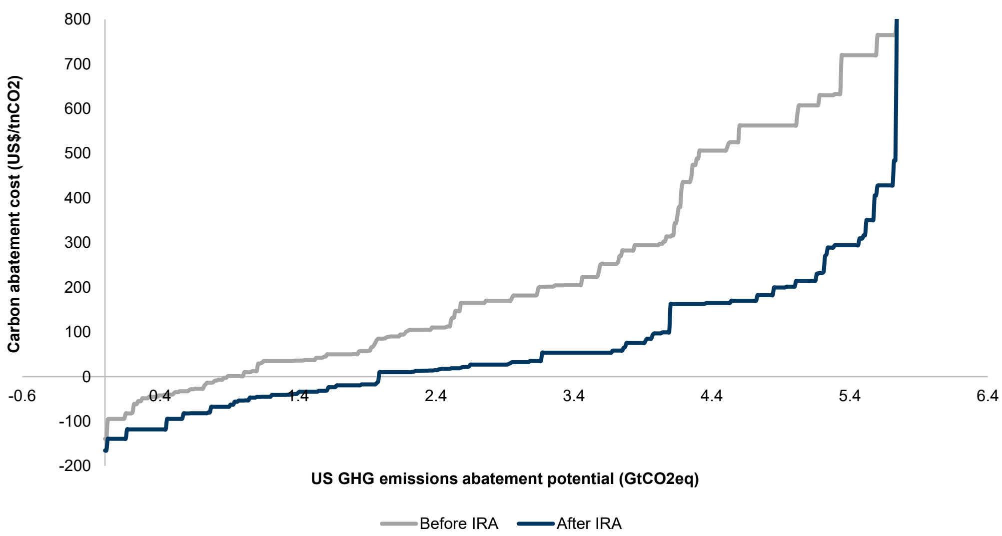
Source: Goldman Sachs Global Investment Research

Exhibit 7: ...implying a CO2 abatement price to the US government of $52/t
Implied CO2 abatement price, US/t



Source: Goldman Sachs Global Investment Research

Exhibit 8: The IRA has transformed the cost curve, pushing it sharply down
US 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 prior to and after IRA

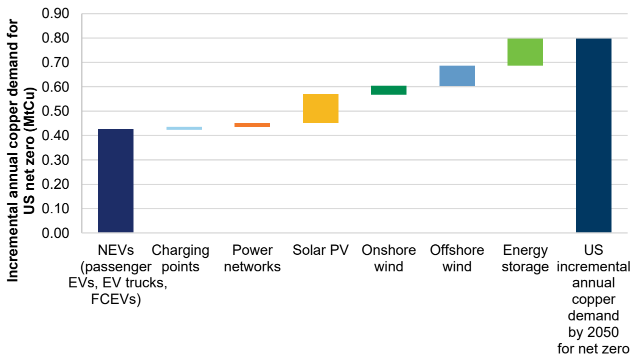


Source: Goldman Sachs Global Investment Research

The renewables revolution transforms the need for natural resources, with 35%/20% uplift to copper and aluminium demand by the end of the decade, and oil & gas demand in structural decline.

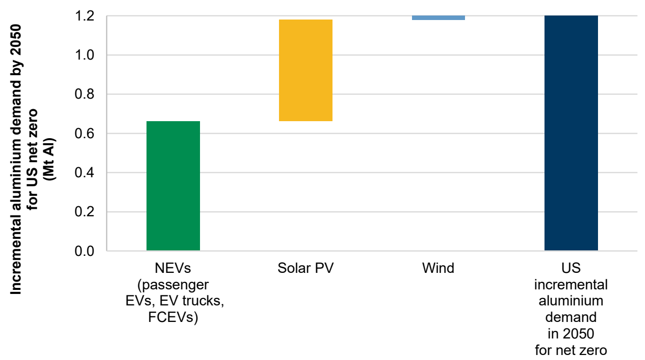
Electrification and clean energy is likely to have a major impact on total American demand for natural resources, and in particular metals such as aluminium, copper, lithium and nickel, demand for which is driven heavily on an acceleration in technologies such as renewables (solar panel, wind turbines manufacturing), power network infrastructure, charging infrastructure, electric vehicles and battery manufacturing. We attempt to quantify the potential impact of the path to net zero in the USA by 2050: we see scope for copper demand to rise by 0.8 Mtpa, **a c.35% increase from US copper demand in 2022**. Similarly, we expect the electrification trend to lead to a material increase in demand for metals such as aluminium, lithium, nickel and cobalt. Overall, we estimate c.1.2 Mt pa of average **incremental aluminium demand** to 2050, representing a c.20% increase on US annual aluminium consumption in 2022. The demand profiles for nickel, cobalt and lithium will to major extent depend on the mix of EV battery types adopted. We expect **lithium demand (LCE) in the US to increase by >700kt pa to 2050 on average (a 12-fold increase on the 2022 level), nickel demand to increase by 440kt pa (a 3-fold increase on 2022), and cobalt demand to increase by 70kt pa (a 5-fold increase on 2022)**. Conversely, the move towards renewable technologies should have a material impact on oil & gas demand, mostly from the end of the decade, when we expect both oil and gas demand to start contracting (with gas consumption the more resilient in the longer term, but still declining).

Exhibit 9: We estimate c.0.8 Mt of incremental average annual copper demand by 2050 for US net zero, representing a c.35% increase from US annual copper consumption in 2022...
Incremental copper demand in 2050E for US net zero



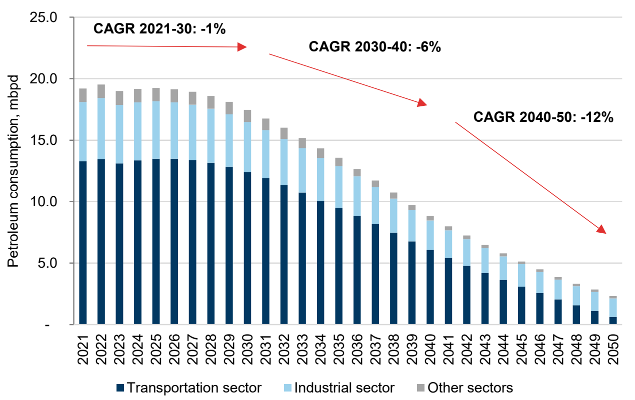
Source: Goldman Sachs Global Investment Research

Exhibit 10: We estimate c.1.2 Mt of incremental annual aluminium demand by 2050 for US net zero, representing a c.20% increase from US annual aluminium consumption in 2022
Incremental aluminium demand in 2050 for US net zero



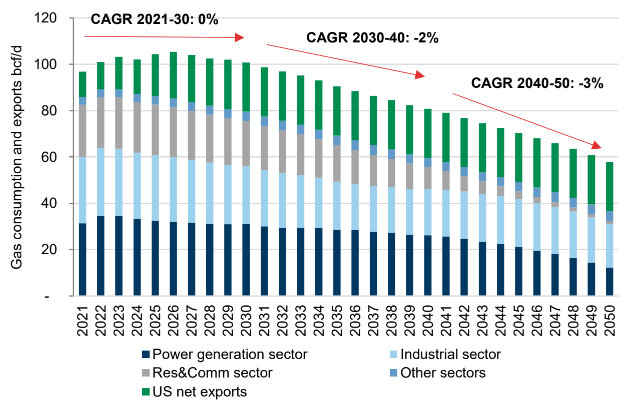
Source: Goldman Sachs Global Investment Research

Exhibit 11: We expect oil demand to materially fall from the end of the decade...
Total petroleum products consumption, mbpd, USA



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

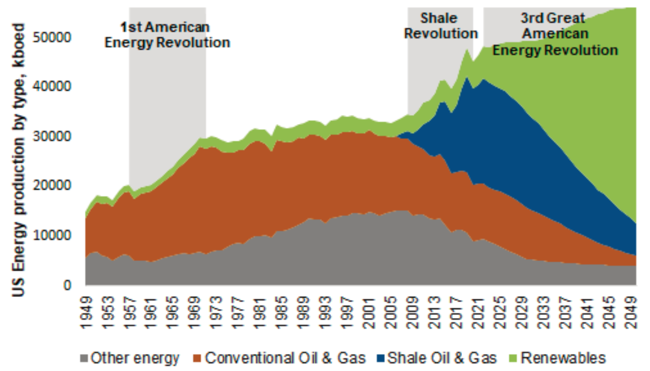
Exhibit 12: ...while gas demand should only grow because of increasing LNG exports
Total gas consumption and exports, bcm, USA



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

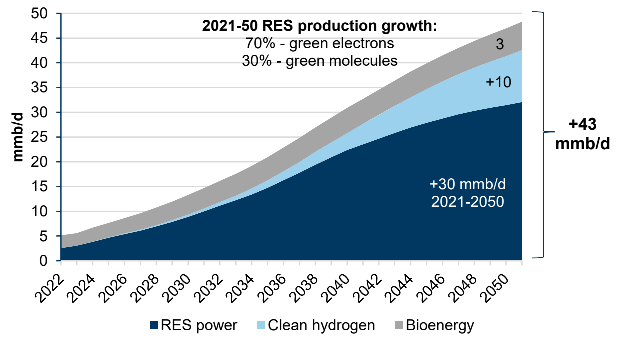
The US clean tech revolution — Our thesis in charts

Exhibit 13: We are entering the third American post-WW2 energy revolution...
US energy production by type, kboed



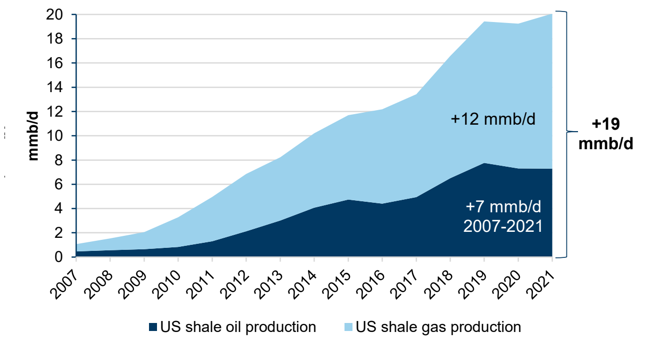
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 14: ...driven by renewable electrons and molecules...
US RES production, mmb/d



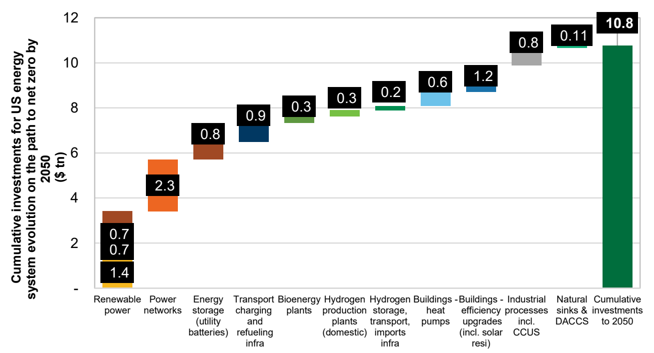
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 15: ...driving new energy supplies 2x the size of the shale revolution
US shale oil and gas production, mmb/d



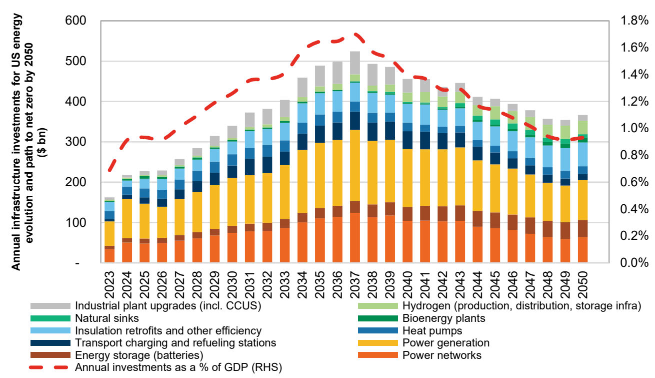
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 16: We see c.$11 trn being invested to reimagine the US energy system...
Cumulative investment opportunity by 2050 (US trn)



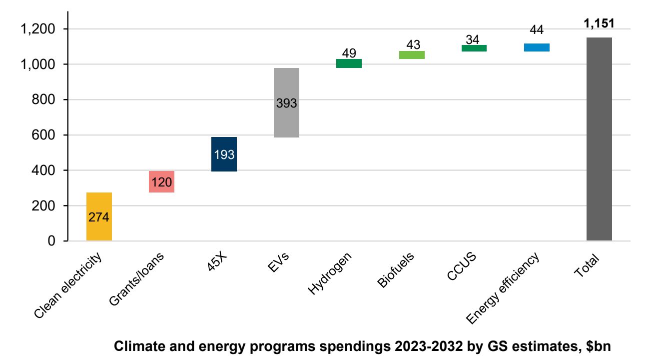
Source: Goldman Sachs Global Investment Research

Exhibit 17: ...equivalent to >1% of cumulative US GDP
Annual infrastructure investments for US energy evolution and path to net zero by 2050 ($ bn)



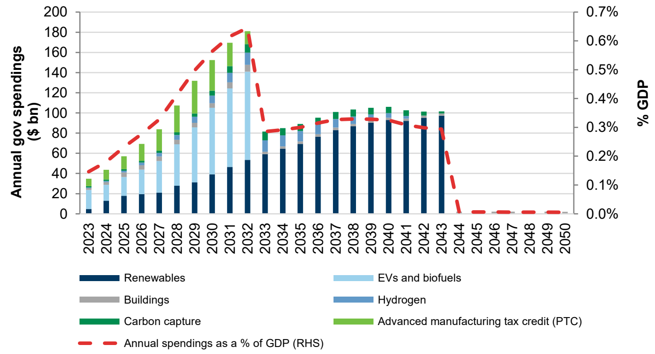
Source: Goldman Sachs Global Investment Research

Exhibit 18: We estimate that the IRA will cost the US gov. $1.2 trn by 2032...
Cumulative gov. spending for US 2023-2032 ($ bn)



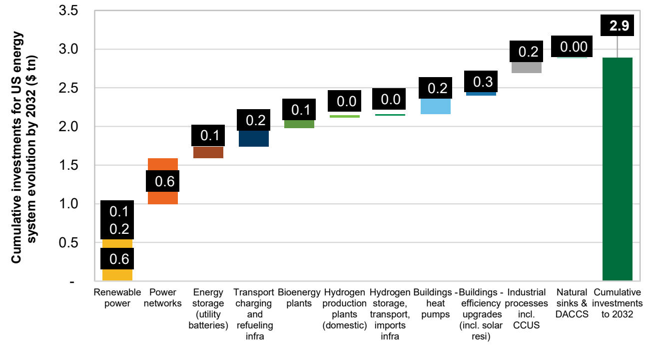
Source: Goldman Sachs Global Investment Research

Exhibit 19: ...with some incentives continuing thereafter...
Annual government IRA spending, $ bn



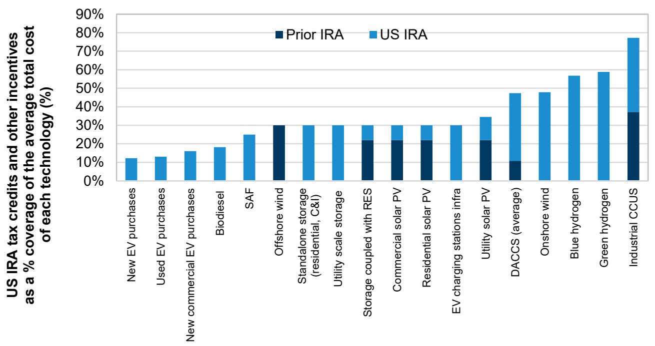
Source: Goldman Sachs Global Investment Research

Exhibit 20: ...unlocking $3 trn of investment by 2032E
Cumulative investment opportunity across sectors for the re-invention of US energy system by 2032E ($ trn)



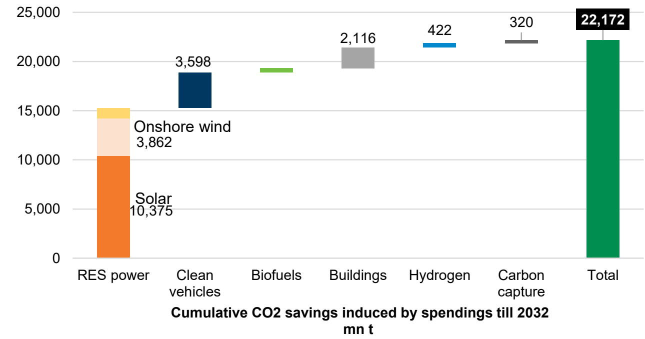
Source: Goldman Sachs Global Investment Research

Exhibit 21: The IRA is a breakthrough, especially for carbon capture and clean hydrogen
US IRA tax credits and other incentives as a % of coverage of the average total cost of each clean technology (%)



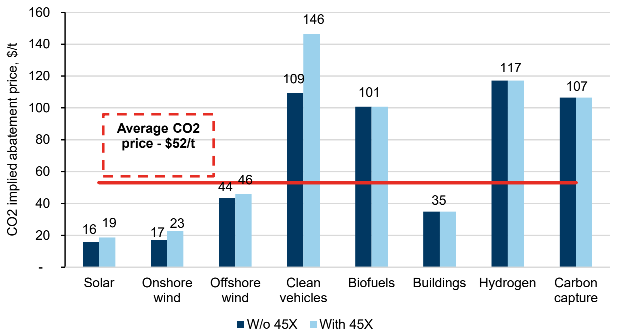
Source: US Treasury, Congressional Budget Office, Goldman Sachs Global Investment Research

Exhibit 22: This $3 trn investment by 2032E could save 22 Gt of CO2 emissions...
Cumulative CO2 savings to 2032; US, bridge by tech/sector



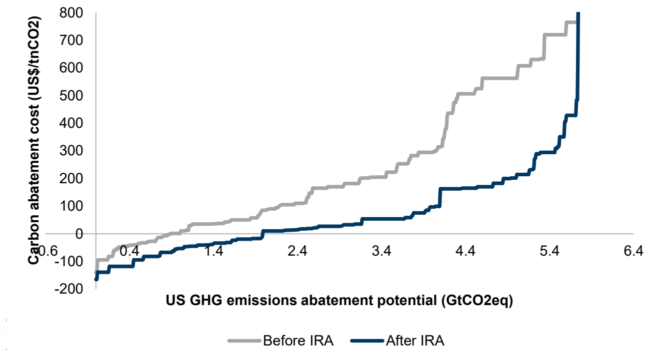
Source: Goldman Sachs Global Investment Research

Exhibit 23: ...implying a CO2 abatement price to the US government of $52/t
Implied CO2 abatement price, US/t



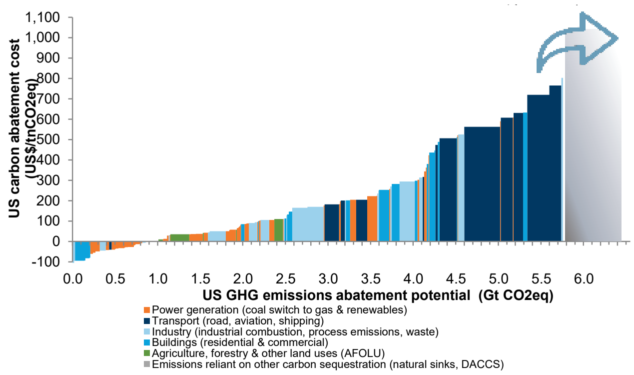
Source: Goldman Sachs Global Investment Research

Exhibit 24: The IRA has completely transformed the US cost curve of decarbonization...
US carbon abatement cost curve for anthropogenic GHG emissions



Source: Goldman Sachs Global Investment Research

Exhibit 25: ...from mostly out of the money...
US carbon abatement cost curve for anthropogenic GHG emissions before IRA



Source: Goldman Sachs Global Investment Research

Exhibit 26: ...to a very attractive investment proposition...
US carbon abatement cost curve for anthropogenic GHG emissions after IRA

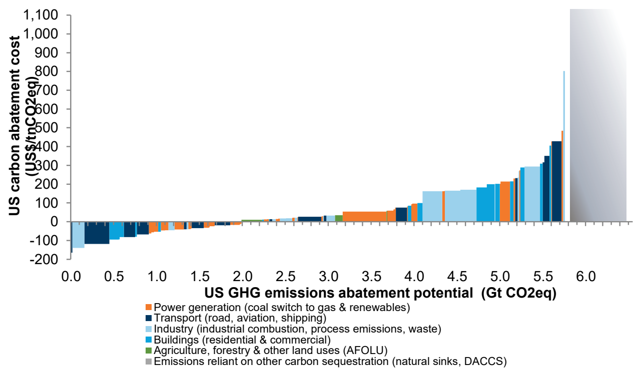
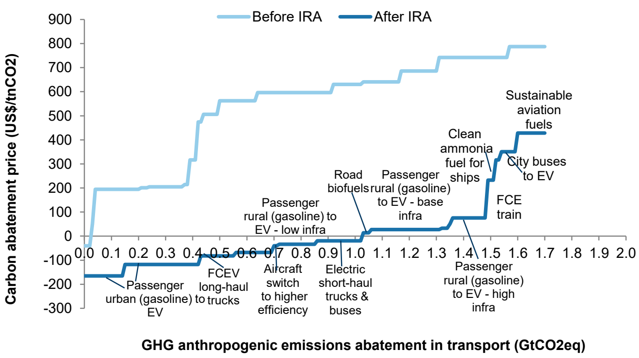
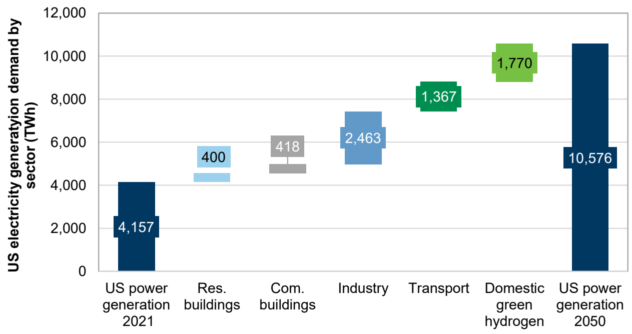


Exhibit 27: ...with the biggest impact on transport
USA transport sector cost curve of de-carbonization before and after IRA



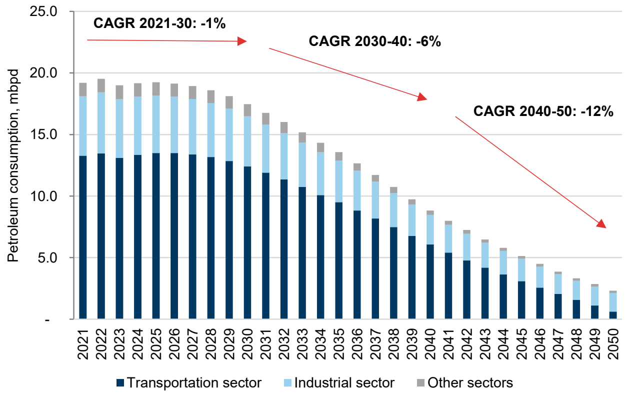
Source: Goldman Sachs Global Investment Research

Exhibit 28: We expect EVs, industry and green hydrogen to drive a >2x increase in power demand
US electricity bridge to 2050E (TWh)



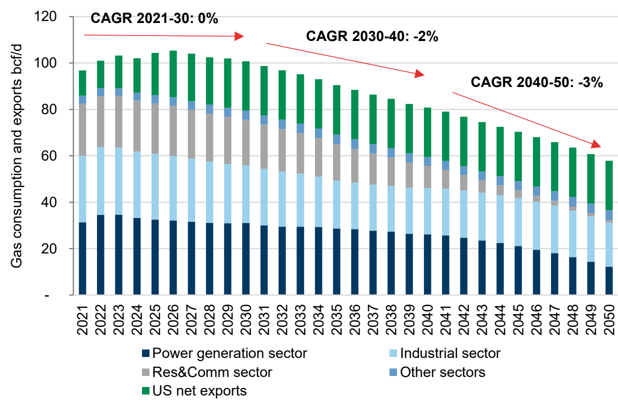
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 29: We expect oil demand to materially fall from the end of the decade...
US petroleum products consumption, mbpd



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

Exhibit 30: ...while gas demand should only grow because of increasing LNG exports
US gas consumption and exports, bcm

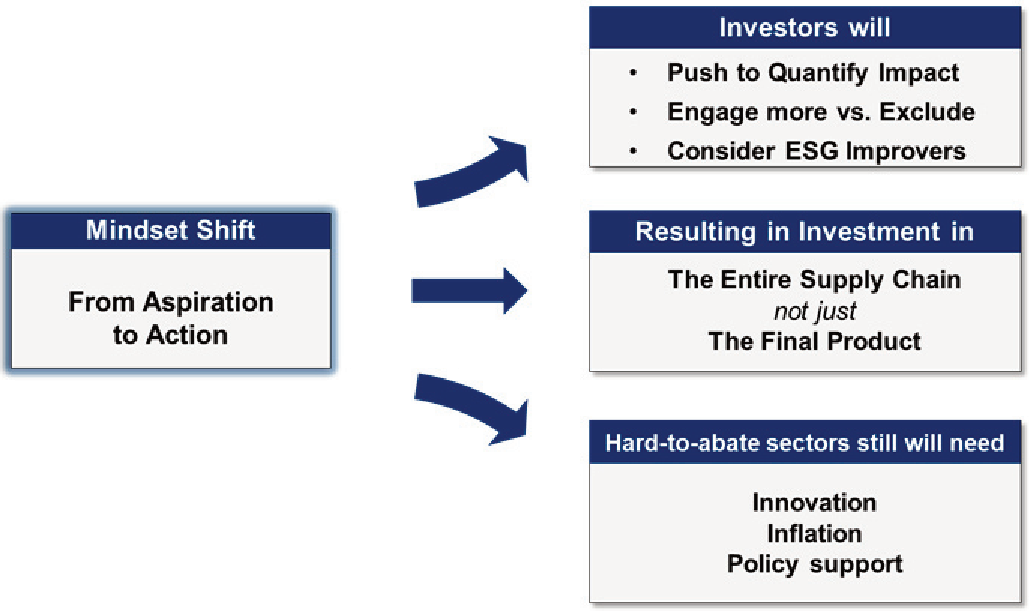


Source: EIA (historical), Goldman Sachs Global Investment Research

GS SUSTAIN: US Green Capex a key catalyst for multiple sustainable Investing themes

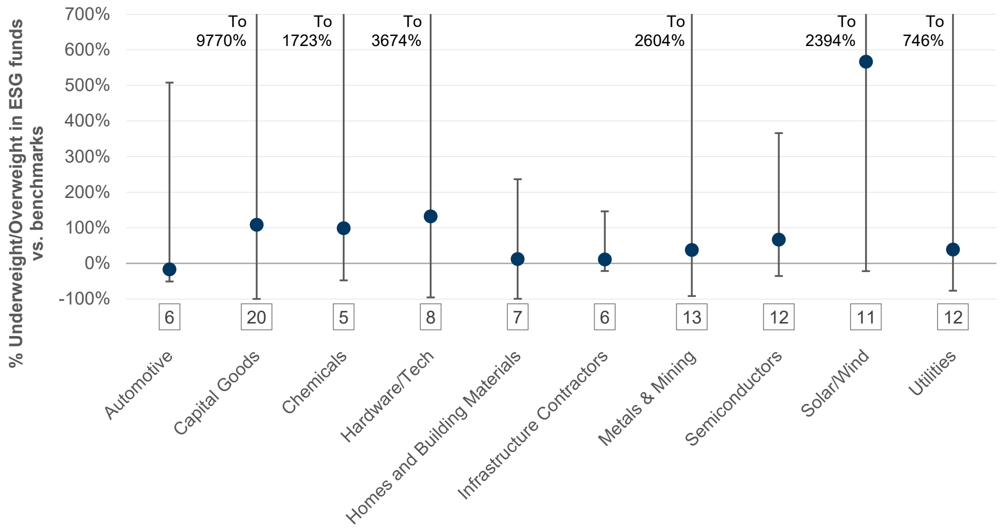
The potential for a third energy revolution in the US, catalyzed by the Inflation Reduction Act, can advance a shift from aspiration to action in sustainable investing, that we believe can drive a broadening of the sustainable investing universe. Currently, ESG fund assets are highly concentrated in market-weight positions in market bellwether stocks, and overweight positions in obvious thematic leaders (e.g., renewable energy, energy efficiency and water stocks). Many of the sectors essential or, at a minimum, needed on the path to Net Zero are still underweights, or are only modestly represented in ESG funds. We believe a combination of energy reliability issues in Europe, the United States and China in 2021, combined with the Russia-Ukraine war and inflationary pressures, are causing a shift From Aspiration to Action that will be a catalyst for a broadening of the investable universe among ESG funds, and a greater push to quantify impacts, increase engagement and a rising focus on 'Improvers'.

Exhibit 31: We expect continued momentum on the shift From Aspiration to Action, initially highlighted in our 2022 outlook, in 2023, with investment implications



Source: Goldman Sachs Global Investment Research

Exhibit 32: Even among Green Capex stocks we have highlighted in past research, ESG fund ownership is highly concentrated with overweights in Solar/Wind/Water and greater discovery value elsewhere
Range of ownership vs. benchmarks by ESG funds by vertical; dots represent median. Numbers at the bottom represent the number of companies considered in each vertical



Based on screens outlined in our Oct. 2022 Investing in Green Capex report

Source: Morningstar, Thomson Reuters, Goldman Sachs Global Investment Research

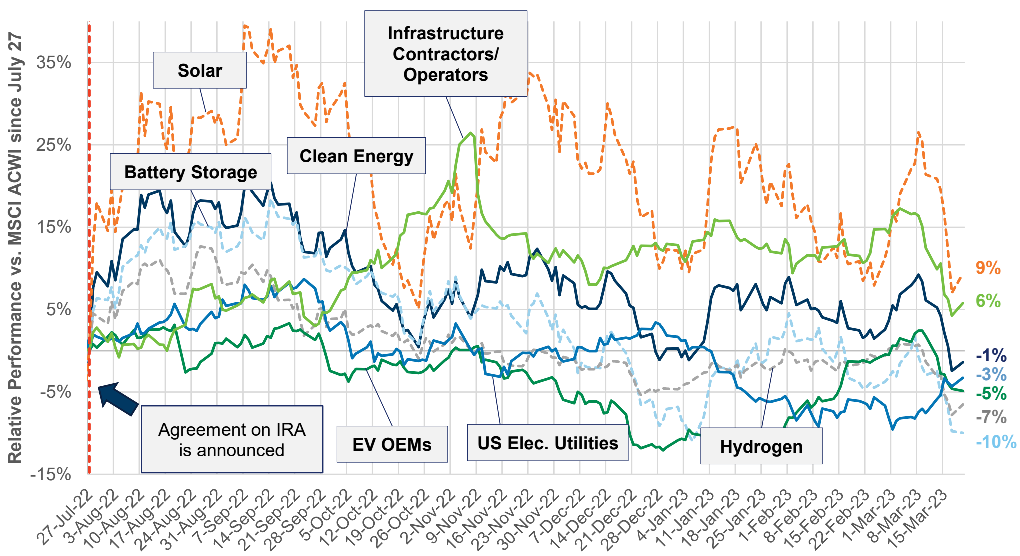
The breadth of incentives in the Inflation Reduction Act are positive for multiple Green Capex related themes we highlighted in our 2023 Sustainable Investing outlook report. In our view, the US IRA will be a catalyst for acceleration in Green Capex and will benefit stocks through the supply chain, with incentives and provisions touching almost all verticals in our Green Capex mosaic. This can favorably advance:

- **Clean Reliable Energy** — which we believe can continue to see rising differentiation even vs. Clean Energy.
- **Energy Efficiency** — underappreciated beneficiaries of policy- and technology-stimulated demand response.
- **Greenablers** — sectors early in the supply chain essential for decarbonization and other Sustainable Development Goals that warrant investment more urgently, owing to long lead time projects
- **ESG Improvers** — companies that can use the US energy revolution to either change business mix towards greater Green Revenue and/or lower greenhouse gas emissions intensity.

We still see opportunity for greater appreciation across sectors of the impact of US decarbonization investment growth — Solar and Infrastructure stocks are the only verticals that have broadly outperformed benchmarks since the Inflation Reduction Act agreement was announced (see Exhibit 33). Clean Energy stocks — comprising Solar, Battery Storage and Hydrogen — have lagged the MSCI ACWI by 1% since the agreement on the IRA was initially announced on July 27, 2022. Solar stocks have outperformed in this timeframe, but this has been more than offset by underperformance in Battery Storage and Hydrogen. Infrastructure stocks have outperformed the MSCI ACWI by 6% in the same period. Other areas exposed to the bill — Electric Vehicles and Electric Utilities levered to renewables — have underperformed vs. the MSCI ACWI since the agreement on the IRA was announced. We believe there exists potential for further appreciation of companies exposed to key themes of the IRA such as those highlighted later in the report, in particular for stocks levered to the Clean Reliable Energy theme via Battery Storage or Hydrogen — potential key areas of investor focus on the back of geopolitical events and accelerated deployments of renewables.

Exhibit 33: Since the announcement of the agreement on the IRA, Infrastructure and Clean Energy stocks (driven by Solar) have outperformed other themes with exposure to the IRA

Average relative stock performance vs. MSCI ACWI since the Inflation Reduction Act agreement was announced (July 27, 2022) for select stocks levered to critical areas of the IRA: Clean Energy (Solar, Hydrogen, Battery Storage), EV OEMs and Utilities. Relative performance for the entire group and broken out by category.



Data as of March 20. Companies may be included in more than one category.

Source: FactSet, Refinitiv Eikon, Goldman Sachs Global Investment Research

As recently detailed, we believe timing of investments or impact from the US IRA varies by sector, with Services companies potentially positioned to be the first revenue beneficiaries. As broadly discussed in their latest earnings calls, Infrastructure Contractors/Operators can potentially see initial greater impact from the US IRA in 2H 2023 and 2024. A similar timeline has been charted for Battery Storage Integrators, which are expected to likely see IRA tailwinds in the back end of 2023, with top line and bottom line to be impacted in 2024 and beyond. Opportunities for investments by Chemicals, Utilities and Cleantech (i.e., solar, battery storage and electrolyzers) companies extend beyond 2024, due to a combination of project complexity and capacity expansion.

However, there remain areas where corporates are waiting to see more clarity before committing capital — implementation/permitting above all. Based on most recent commentary from companies, we see four potential areas where corporates are waiting for more clarity when allocating capital on the back of the IRA:

Implementation/Permitting, Technology Development, Demand and Inflationary Pressure. We note implementation/permitting appear to be top of mind for managements as they outline capital allocation plans. Corporates across sectors broadly noted how more detailed implementation guidelines — particularly from the IRS — are still needed to make appropriate investment decisions, as well as support at the local level in addition to from the federal government. On Technology Development, we believe this could be particularly important for earlier-stage technologies such as green hydrogen, where managements also highlighted the need for more visibility on downstream Demand before executing on a project. On Inflationary Pressure, this would apply both to materials and labor and could potentially affect decision-making and related timeline when committing capital.

The investment path: $11 trn investment opportunity by 2050

Exhibit 34 shows the wide range of investment opportunities we see associated with the key infrastructure requirements to transform the US energy system. These include, among others, the increasing uptake of renewable power, battery energy storage, hydrogen and bioenergy, as well as an increasing focus on infrastructure investments, for power networks and charging stations (that will enable a new era of electrification), an upgrade of industrial plants, retrofitting of buildings and other existing heating infrastructure (enabling greater efficiency and uptake of electrification), and finally, a greater focus on carbon sequestration (natural sinks and carbon capture).

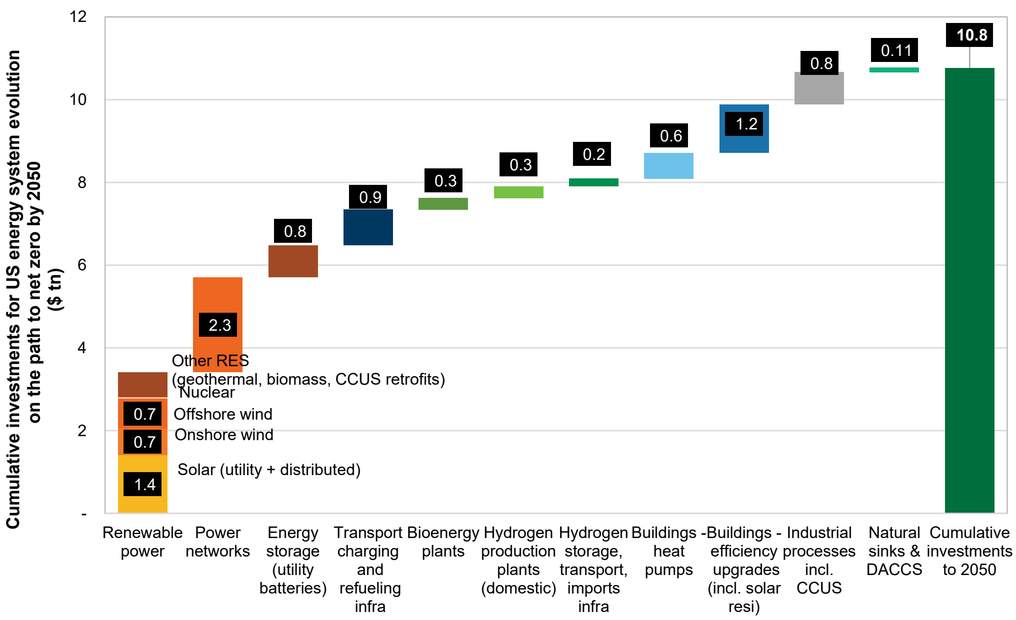
In aggregate, we estimate a total infrastructure investment opportunity of around $11.0 trn by 2050 for the transformation of US energy system on the path to net zero carbon, which implies an average annual green infrastructure investment opportunity of c.$400bn**. By 2032, we estimate $2.9 trn cumulative investment opportunity across sectors for the re-invention of US energy system, or on average $290bn annually.** We note that this figure focuses solely on infrastructure investments and does not include maintenance and other end-use capex.

To put this figure in context, over the coming decade this would represent >2x the total investment in the US shale revolution. The US oil & gas revolution (2008-17) led by US exploration & production companies unlocked 100+ bn bls of US shale oil resources with a short time to market, dramatically changing the industry's dynamics and resulting in total estimated investments of roughly $1.4 trn over 2008-2017. Nevertheless, investments in the US shale revolution were only c.50% of US clean tech revolution investment we expect to unfold by 2032.

Investments in power generation are at the heart of the energy transition, but renewable molecules should see the biggest percentage increase in spend. Clean power investments are at the core of the renewable revolution, owing to the fact that power generation is a key source of CO_2 emissions (c.30% in 2021 in the US), and also the key role of power infrastructure in electrification trends in transport, industry, buildings and in green hydrogen production. We estimate that total US power demand is set to increase 2.5x by 2050, vs. 2021. This calls for $6.6 trn of investment in renewable power by 2050 (57% of total), on our estimates. This includes the build-up of solar ($1.4 trn), wind ($1.4 trn), and other RES generation facilities ($0.7 trn), the expansion, upgrade and digitalization of power networks ($2.3 trn) and utility-scale energy storage facilities ($0.8 trn). Overall, we expect RES generation (ex.nuclear and hydro) to grow at a 9% CAGR through 2021-2050 in the US, and make up 44% of total generation capacity by 2030 (80% by 2050).

Exhibit 34: We estimate a c. $11.0 trn infrastructure investment opportunity for the renewable transformation of the US energy system

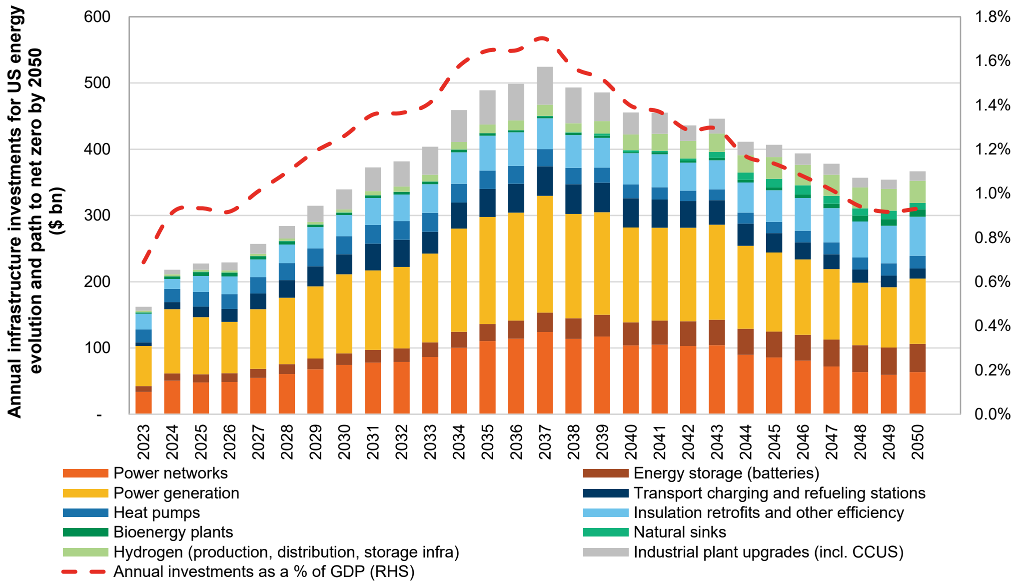
Cumulative investment opportunity across sectors for the re-invention of US energy system by 2050 ($ trn)



Source: Goldman Sachs Global Investment Research

We expect a clean tech investment profile rising to 2035, peaking at 1.7% of US GDP. The early years of our forecasts are almost entirely driven by electrification: renewable power, power networks, charging networks, buildings upgrades, followed by an acceleration in clean hydrogen spend and carbon capture. Overall, the average annual investment in de-carbonization that we estimate over 2023-50 is c.$400 bn, representing c.1.3% of US GDP on average over 2023-50, with the peak in the mid-2030s (c.$520 bn), representing c.1.7% of US GDP.

Exhibit 35: We expect clean tech investments to peak at 1.7% of US GDP by mid 2030s



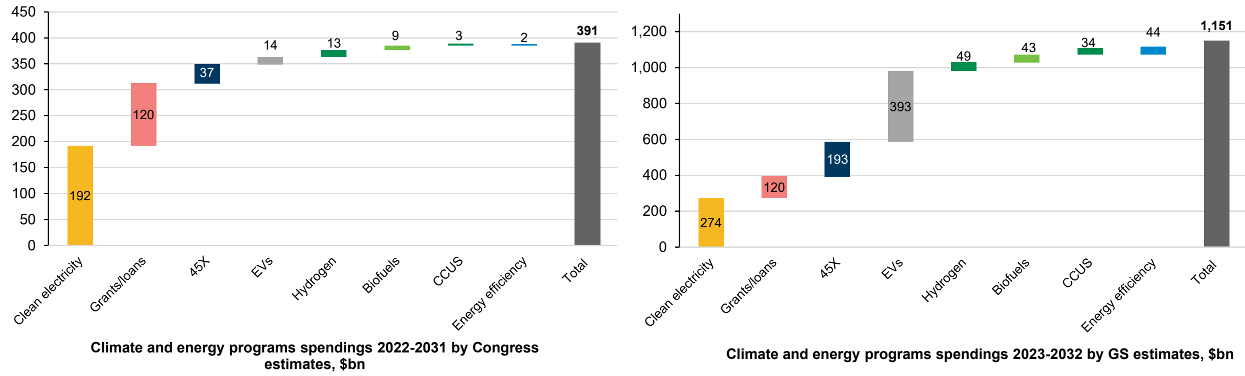
Source: Goldman Sachs Global Investment Research

We expect the IRA to cost the government $1.2 trn by 2032. On September 7, the Congressional Budget Office (CBO) released its final scoring of the Inflation Reduction Act. It estimated that the budgetary impact from the bill's Energy and Climate provisions would total $391 bn over 2022-31, of which c.$265 bn would come in the form of tax credits that incentivize businesses to invest in and produce renewable energy and low emission fuels, and individuals to make purchases that improve the energy efficiency of their homes and transportation choices. On our estimates, the **IRA is likely to cost the government around $1.2 trn to 2032, c.3x the CBO's estimate.** Compared with total investment opportunity of around $3 trn by 2032E this implies a 2.5x multiplier vs. the government incentives.

What is the incremental capex unlocked due to IRA? While $2.9 trn is our estimate of the total investment opportunity from low-carbon technologies by 2032, energy transition in the US has already started, and we estimate total US low-carbon investments in 2022 werec.$140 bn (including renewables, transportation, buildings, etc.). While potential incremental impact of the IRA alone on investment in the energy system might be challenging to isolate, for simplicity, we assume baseline annual investment in the US low-carbon energy system without the IRA at $140 bn going forward, or c.$1.4 trn for 2023-2032. This implies theoretical incremental capex incentivized by IRA of c.$1.5 trn — or $150 bn annually on average in 2023-2032.

Where do we differ from the CBO's estimates? We note that our IRA government spending estimates are three times higher than Congress's estimate of $391 bn over 2022-2031. **This is driven by higher estimates for all categories, especially our significantly higher estimates for advanced manufacturing tax credits (45X) and EV tax credits.** Key areas of uncertainty arising from IRA incentives remain the level of onshoring of battery and solar components, and the share of EVs eligible for tax incentives. According to our GS SUSTAIN colleagues, many companies are still in the very early stages of evaluating new US capacity following the passage of the IRA, with companies weighing these credits against the likelihood of higher manufacturing costs in the US relative to where the components are manufactured today. Depending on the level of onshoring of manufacturing facilities, IRA government spending may vary significantly.

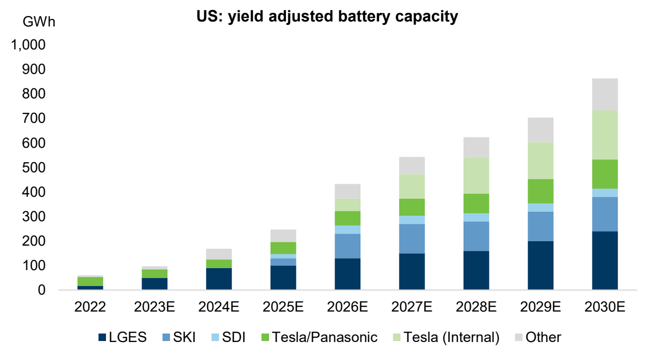
Exhibit 36: We note that our government spending estimates are 3x higher than Congress's estimate of $391 bn over 2022-2031
Cumulative government spending across sectors for the reinvention of the US energy system by 2032 ($ bn)



Source: US Treasury, Congressional Budget Office, Goldman Sachs Global Investment Research

45X: We estimate a more aggressive build-up of battery and solar manufacturing facilities than that assumed by the CBO, leading to higher advanced manufacturing tax credits. The 45X provides $35 per kWh of capacity for battery cells and $10 per kWh of capacity for battery modules, which according to our Asia Batteries analysts is roughly equal to c.35%-42% of the cost of production of automotive batteries in the US. US battery manufacturing capacities amounted to c.75 GWh in 2022, and based on announced projects (see Exhibit 37), the current pipeline of battery plants amounts to c.**900 GWh by 2030, with the vast majority of this announced capacity for manufacturing battery cells together with battery modules.** We believe, Congress's estimates assume a more conservative manufacturing facilities build-up. Similar to batteries, domestic solar manufacturing capacities are at early stage of development, with production of PV cell and wafers being virtually non-existent, we believe IRA incentives are likely to boost development of the industry, and we currently expect c.50GW of module capacity, c.30GW of cell capacity and c.15GW of polysylicon/wafer capacity by 2032. **Overall, we assume 45X spending to 2032 at around $190 bn, significantly higher than the CBO's estimate of $37 bn.**

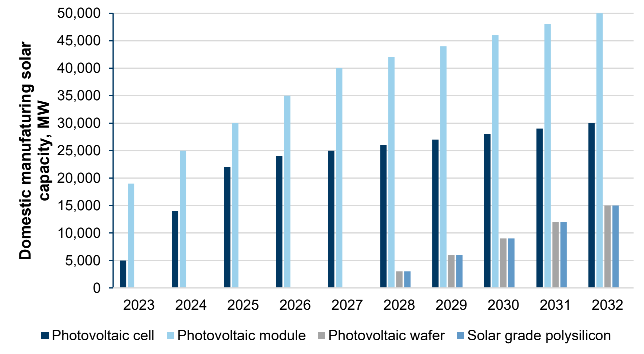
Exhibit 37: Battery capacity addition is set to accelerate in the US driven partially by the self-sufficiency incentives



Market shares for LGES and SKI not adjusted for JV stake

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 38: We currently expect c.50GW of module capacity, c.30GW of cell capacity and c.15GW of poly/wafer capacity by 2032
Domestic solar manufaturing capacities, MW



Source: Goldman Sachs Global Investment Research

Clean vehicle tax credits: the magnitude of the incentive program will depend on the speed of EV adoption, and critical materials and battery components requirements to be published in March 2023. For 2023, the IRS published 21 EV car models eligible for tax credits, which make up c.75% of EV sales in the US (with the rest being either outside the incentive price range or assembled outside the USA), on our estimates. In December 2022, the US Department of Treasury issued a press release commenting that it expects to issue a notice of proposed rule making on the critical materials and battery components requirements for the clean vehicles-related credits in March 2023. As a result, the restrictions in the IRA related to battery components and materials will only go into effect once the guidance is issued, per the press release. We believe more vehicles would therefore be eligible for full IRA credits in early 2023, albeit for a limited time.

To estimate potential IRA incentives for EVs, we look at US self-sufficiency in key critical materials, at anodes and cathodes as key battery components, and battery assembly. Widespread EV battery chemistries (NCA, NCM, LFP) primarily depend on five critical minerals: lithium, cobalt, manganese, nickel, and graphite. We look at US self-sufficiency including free-trade countries across nickel and lithium given they constitute >50% of total mineral cost. For lithium, the US has multiple sourcing options for lithium, despite limited local production, given the country's free trade agreements with Australia, Chile and Canada (these countries account for >80% of global lithium supply), and our EV battery team estimates US lithium self-sufficiency (incl. free-trade countries) to well exceed 100% in 2023-2032. For nickel, we note that mine nickel supply from Canada, Australia and the US amounted to c.300kt in 2022, and US recycling volumes are c.100kt (link), implying >100% self-sufficiency to 2030E, based on the EV battery nickel demand we estimate (see section *"The potential implications for metals demand"*). Regarding battery manufacturing, c.50% of batteries sold in EVs are produced locally, and we expect this share to increase to c.90% by 2032, based on announced battery plants capacities and US battery demand. For cathodes/anodes, the US has limited domestic production capacity, given the dominance of Chinese producers, and our Battery team expect US self-sufficiency in cathode/anodes to increase moderately to c.15-25% by 2030. To model potential IRA incentives, we assume 25% of cars are ineligible for tax credits based on price range/assembly outside the US, and that the share of cars eligible for the full $7.5k tax credit increases with the US's increase in self-sufficiency in cathode/anode components (from c.7% in 2024E to 15% by 2032E). We assume the remainder (c.60%) will be eligible for a $3.75k tax credit, based on critical component criteria which we assume will apply to the rest of the cars. Overall, we arrive at average subsidy per vehicle of c.$3k for 2024-2032E, which coupled with our EV sales forecasts, results in c.$300 bn of cumulative tax incentives to 2032E on light-duty vehicle EVs and c.$90 bn on medium and heavy trucks, significantly higher than the $14 bn CBO estimate. We also note that share of eligible EVs and total clean vehicle tax credits might be subject to change post the release of guidance from the Department of Treasury in March'23, and we provide sensitivity analysis (Exhibit 39) to show the range of fiscal impacts of the IRA program from clean vehicle tax credits.

Exhibit 39: IRA spending on EV tax credits will vary significantly, depending on the pace of EV adoption and the number of cars eligible for credits

Cumulative IRA spending on new light vehicle EV, $ bn

		Average credit per vehicle, $/car							
		500	1,500	2,500	3,500	4,500	5,500	6,500	7,500
EV sales by 2030 mn	4	15	44	73	103	132	161	190	220
	6	21	63	105	148	190	232	274	316
	8	28	83	138	193	248	303	358	413
	10	34	102	170	238	305	373	441	509
	12	40	121	202	283	363	444	525	605
	14	47	140	234	328	421	515	608	702

Source: Goldman Sachs Global Investment Research

Exhibit 40: Headway has been made in battery self-sufficiency ex-China, though more needs to be done

Self-sufficiency across the battery value chain (supply/demand)	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Upstream: Lithium										
China domestic	36%	48%	58%	79%	117%	120%	127%	120%	114%	100%
China (+ global equity shares)	60%	74%	89%	113%	157%	165%	177%	168%	158%	139%
US domestic	2%	3%	3%	3%	3%	2%	2%	2%	1%	1%
US (+ free trade countries)	388%	413%	319%	301%	272%	235%	207%	185%	162%	143%
Midstream: Cathode										
China	157%	180%	206%	244%	272%	273%	261%	248%	236%	221%
Europe	0%	8%	12%	42%	36%	38%	34%	28%	26%	26%
US	4%	2%	2%	4%	19%	26%	23%	21%	19%	24%
Midstream: Anode										
China	198%	212%	299%	341%	355%	352%	336%	307%	295%	271%
Europe	2%	2%	2%	2%	3%	4%	5%	4%	6%	9%
US	6%	4%	5%	5%	6%	10%	12%	14%	13%	16%
Downstream: Battery manufacturing										
China	122%	149%	184%	213%	246%	275%	284%	287%	293%	298%
Europe	70%	74%	76%	78%	80%	90%	98%	102%	102%	102%
US	66%	53%	66%	73%	103%	134%	128%	128%	127%	126%

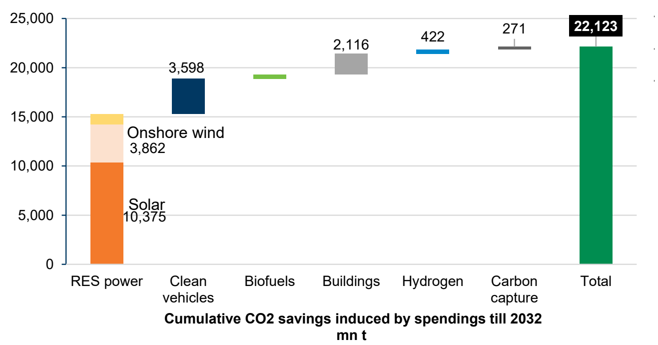
Source: Wood Mackenzie, SNE Research, Company data, Goldman Sachs Global Investment Research

Are there upper limits on IRA tax incentives? We note in line with our GS SUSTAIN team's report that the CBO numbers are estimates of the potential budgetary impact as a result of the IRA tax credits. These impacts can come in the form of direct spending (in the case of credits with the direct pay option) or loss of Federal tax revenue. The tax incentive in the IRA that has a funding cap is the Advanced energy project credit, which was allocated $10bn. We also note that absolute amounts of grants programs for agriculture/clean air/etc. are stated in the IRA (c.$120bn). For all other credits, mainly tax credits, there is no cap, and the actual budgetary impact over 10 years could be substantially different from the current CBO estimates.

How likely are IRA changes post-2024 if there is a shift to a Republican-led executive and legislative branch? Both investors and corporates have asked about the risk of potential changes to IRA incentives if the Republican party were to control the executive branch and both houses of Congress post the 2024 election. Our GS Sustain team along with our Washington economic research team believe that an effective tax increase via eliminating incentives is less likely. They note that many of the incentives highlighted as potentially transformative — such as Carbon Capture and Hydrogen — are likely, in their view, to be deployed meaningfully in states such as Texas and Louisiana, reflecting the location of industrial infrastructure, states in which the majority of elected leaders to the House and Senate are typically Republicans.

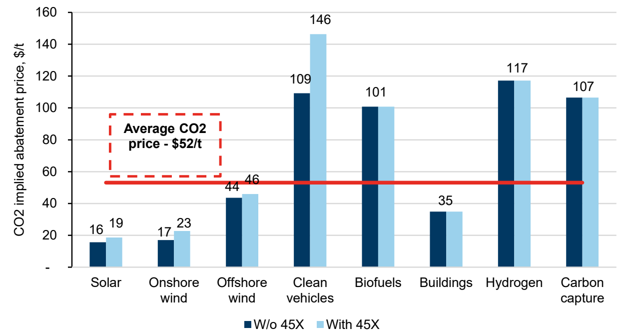
We estimate that CO2 savings resulting from IRA incentives and induced investments to 2032 will amount to 22 gigatonnes, implying a $52/t cost of CO2 abated. We estimate how many tonnes of CO2 will be abated by IRA incentives and the implied CO2 abatement price. We expect CO2 savings from IRA incentives and induced investments to 2032 to amount to 22 gigatonnes (including the CO2 savings beyond 2032 from the investments taken by 2032), with half coming from additional solar and wind capacity. The theoretical unit cost of CO2 abated for the government, on our estimates, will amount to $52/t, assuming $1.2 trn of government incentives to 2032. This CO2 abatement price varies by technology: while for solar and onshore wind the implied CO2 price is less than $25/t, for hydrogen, EVs and biofuels this number exceeds $100/t (reflecting the harder- to-abate nature of these emissions and relative technological immaturity).

Exhibit 41: We expect the IRA to inctivize 22 Gt of CO2 emission abatement...
Cumulative CO2 savings to 2032E; US, bridge by tech/sector



Source: Goldman Sachs Global Investment Research

Exhibit 42: CO2 implied abatement price is $52/t, with RES generation at the lower end and hydrogen and EVs/biofuels at the higher end
Implied CO2 abatement price, US/t



Source: Goldman Sachs Global Investment Research

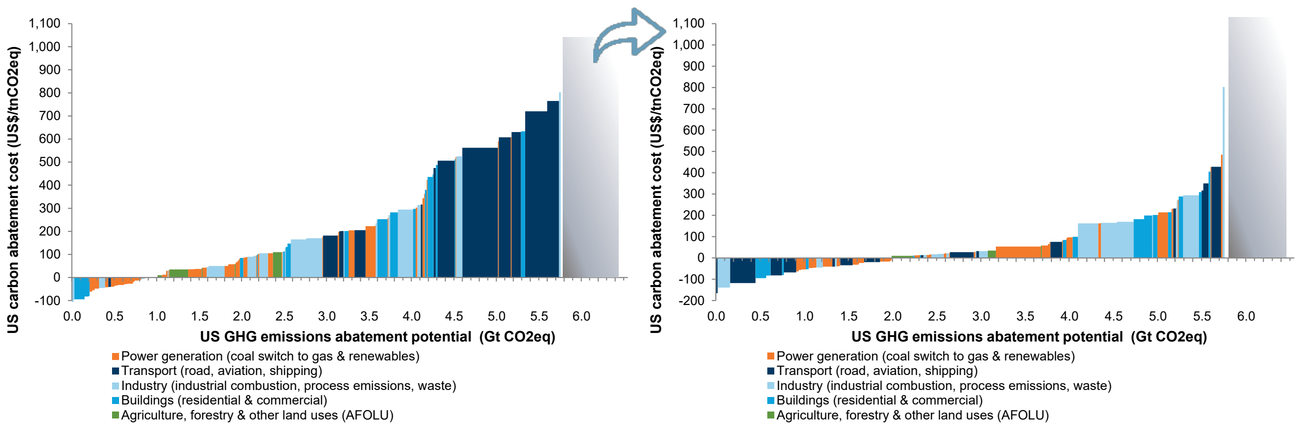
IRA has transformed the Carbonomics cost curve, lowering it by 75%

In our deep-dive de-carbonization report, we had introduced in detail our Carbonomics carbon abatement cost curves. The Carbonomics cost curves show the reduction potential and carbon abatement cost for anthropogenic GHG emissions through >100 different applications of GHG conservation and sequestration technologies across all key emitting sectors in the region the cost curve is addressing. In this report, **we introduce the first Carbonomics de-carbonization cost curve for the USA** and also **show the transformation of the cost curve, incorporating US IRA tax credits and other incentives,** presented in Exhibit 43 below.

Overall, we expect all the key technologies addressed in our de-carbonization cost curve to play a role in facilitating the path to net zero, each in their respective sector. The speed of de-carbonization in each sector is largely dependent on the current carbon abatement cost and state of readiness of the available clean technologies presented in our Carbonomics cost curve. As such, in our models for US energy and emissions evolution on the path to net zero, different sectors de-carbonize at different speeds and have a different carbon budget allocation, depending on their relative cost positioning and readiness on our de-carbonization cost curve. We note that our Carbonomics cost curve of de-carbonization **is not static, and is expected to evolve over time as the costs of existing technologies continue to change, and as technological innovation leads to the addition of further de-carbonization technologies across sectors.** As such, **our energy evolution and net zero models are also dynamic, and are expected to evolve over time** as technological innovation and focus on de-carbonization continues.

Exhibit 43: The IRA has transformed the cost curve of the US bringing most technologies in the money, especially in the transportation and buildings sectors

US 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 prior and after IRA



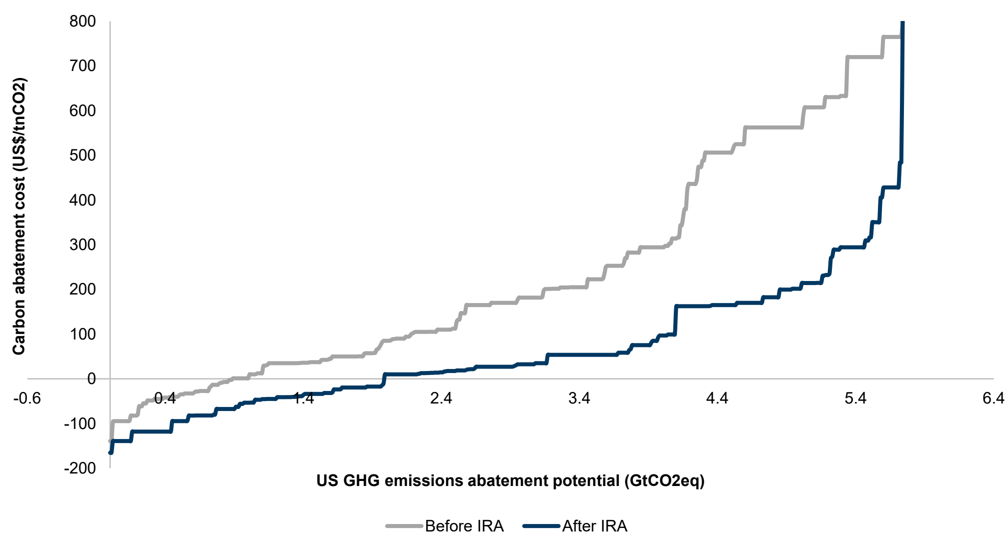
Source: Goldman Sachs Global Investment Research

The IRA has transformed the cost curve of the US, bringing most technologies in the money, especially in the transportation and buildings sectors.

As shown in the exhibit below, our USA 2023 Carbonomics cost curve shows a significant shift down after the incorporation of tax credits and other incentives provided by the IRA, primarily attributed to the lower abatement carbon cost for transport and buildings. The transport sector has notably moved to the lower end of the cost curve, with more technologies moving into the money (such as Hydrogen FCEV long-haul trucks, EV trucks short-haul and passenger urban/rural EVs). Exhibit 27 shows the decrease in carbon abatement price of various technologies used to decarbonize the transportation sector, associated with the implementation of IRA. The decreases are primarily driven by the modified tax credit for new EV purchases (a maximum credit of $7,500 per vehicle), tax credit for commercial clean vehicles, with battery capacity of not less than 15 kWh (the credit is capped at $40,000 or $7,500 for vehicles weighing less than 14,000 pounds) and the extension of tax credit for biofuels, and the creation of a new sustainable aviation fuel credit. Additionally, the 45V PTC for clean hydrogen of up to $3/kg of hydrogen introduced in the IRA should also have a positive impact on the US transport carbon cost curve, benefiting FCEVs and hydrogen trains adoption.

Buildings is another sector sees a significant shift on the cost curve after the introduction of the IRA. Exhibit 47 shows the decrease in the carbon abatement price of various technologies used to decarbonize the buildings sector, associated with the implementation of the IRA. This is primarily driven by residential clean energy tax credits, energy-efficient home improvement credits and energy-efficient commercial building credits, mainly benefiting the purchase price of heat pumps and hydrogen boilers.

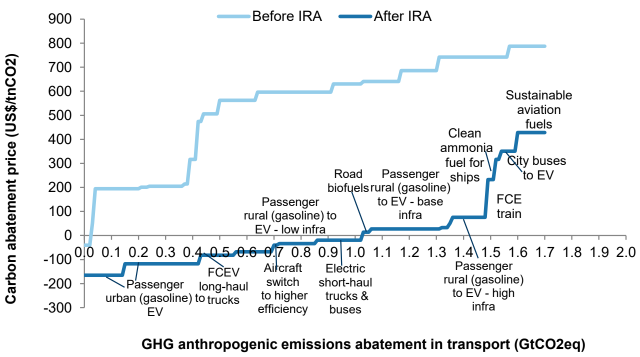
Exhibit 44: The IRA has transformed the cost curve of de-carbonization for the USA, pushing it down 75%
US carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and current costs, assuming economies of scale for technologies in the pilot phase prior to, and after, the IRA



Source: Goldman Sachs Global Investment Research

Exhibit 45: USA transport sector cost curve has faced the most significant shift downwards thanks to IRA...

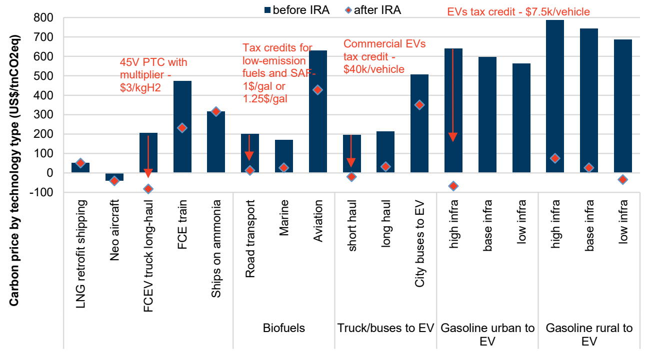
USA transport sector cost curve of de-carbonization before and after IRA



Source: Goldman Sachs Global Investment Research

Exhibit 46: ...with many technologies moving into the money (such as Hydrogen FCEV long-haul trucks, EV trucks short-haul and passenger urban/rural EVs)

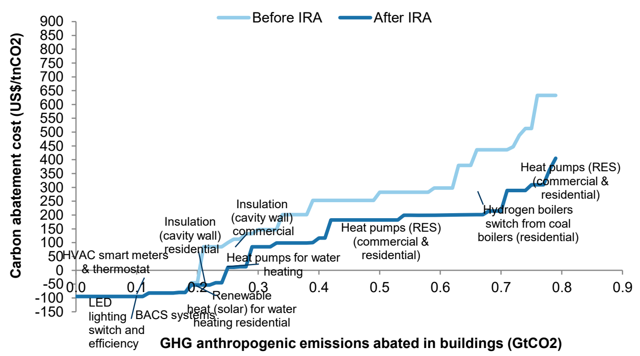
Carbon price by technology type in transportation sector (US$/trnCO2eq)



Source: Goldman Sachs Global Investment Research

Exhibit 47: Buildings is another sector that sees a significant shift on the cost curve after the introduction of IRA...

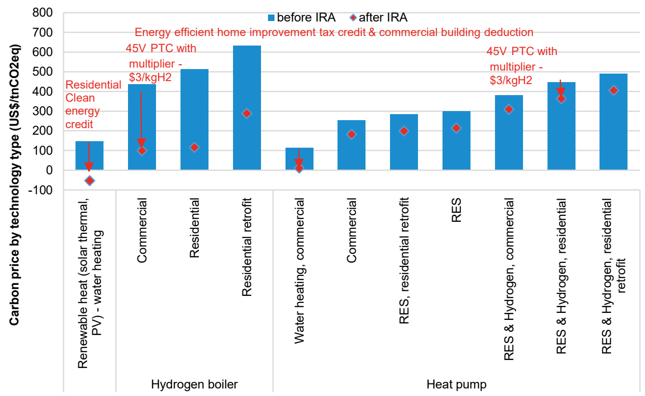
USA buildings sector cost curve of de-carbonization before and after IRA



Source: Goldman Sachs Global Investment Research

Exhibit 48: ...with the most significant changes coming from water heating with RES, heat pumps and hydrogen boilers

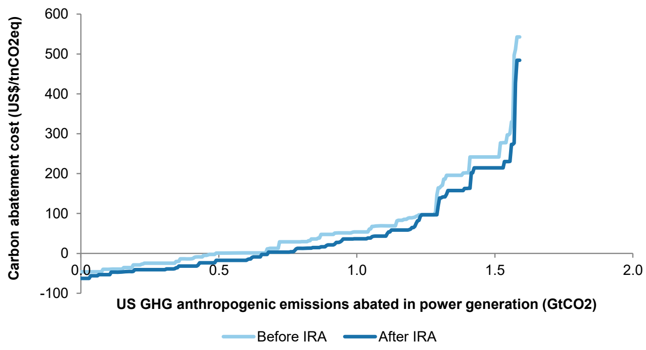
Carbon price by technology type in buildings sector (US$/trnCO2eq)



Source: Goldman Sachs Global Investment Research

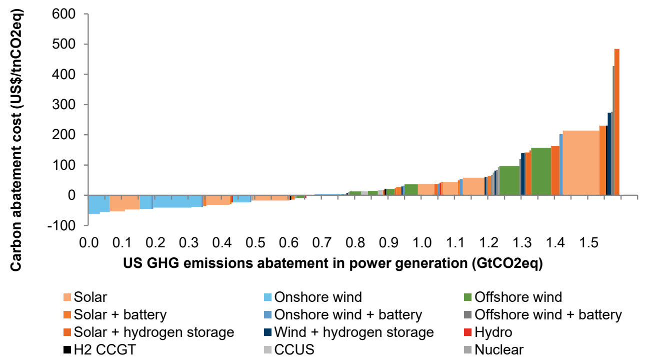
The IRA also supports decarbonization of power generation through the carbon capture tax credit (an extension of the 45Q tax credit for CCUS which also increases its scope to include direct air capture), the introduction of the 30% ITC for utility-scale battery storage technologies, the extension and modification of the investment tax credit (ITC) for renewable electricity, and the reintroduction of the solar PTC and 45V PTC for clean hydrogen. The increased rate of investment tax credit for both solar/wind energy, greater clarity on the longevity of credits, and new options for solar power to apply a PTC instead of an ITC, should contribute to a visible decrease in the carbon price of solar and on/offshore wind technologies in our view.

Exhibit 49: The IRA supports decarbonization of power generation
USA power generation cost curve of de-carbonization before and after IRA



Source: Goldman Sachs Global Investment Research

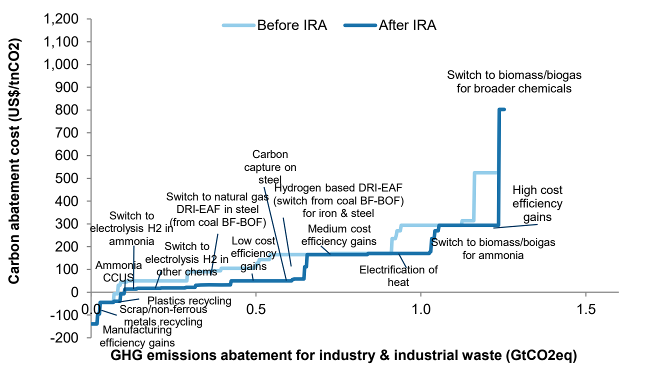
Exhibit 50: Increased rate of ITC for both solar/wind energy and new option for solar power to apply a PTC instead of ITC should contribute to a visible decrease in the carbon price of solar and on/offshore wind technologies
USA power generation cost curve of de-carbonization



Source: Goldman Sachs Global Investment Research

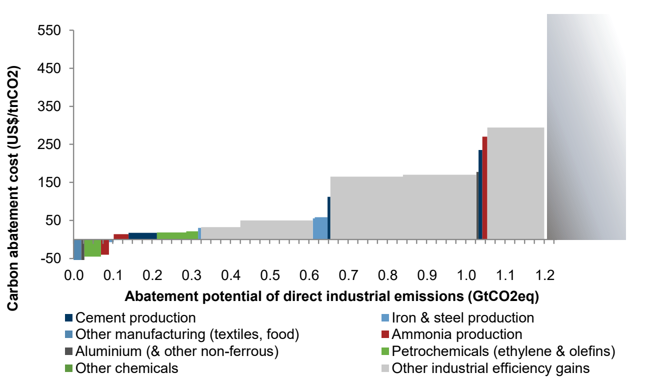
The industrial sector has been also positively impacted by IRA incentives, which is primarily driven by an increase and extension of the carbon capture (45Q) tax credit, benefiting ammonia CCUS (it has moved into money after the increase in 45Q credit), cement, chemicals, steel and non-ferrous metals CCUS. While significantly improved, we do not expect the new 45Q to make CCUS fully economic in all applications. However, it should accelerate investment in projects that are lower on the cost curve. Moreover, the 45V PTC for clean hydrogen of up to $3/kg of hydrogen has decreased the carbon price of switching to green hydrogen in ammonia by c.95%, in other chemicals by c.75% and switching to hydrogen based DRI-EAF from coal BF-BOF for iron and steel by c.60%, we estimate.

Exhibit 51: The IRA supports decarbonization of the industrial sector mainly through the carbon capture tax credit and green hydrgen PTC...
USA industrial sector cost curve of de-carbonization before and after IRA



Source: Goldman Sachs Global Investment Research

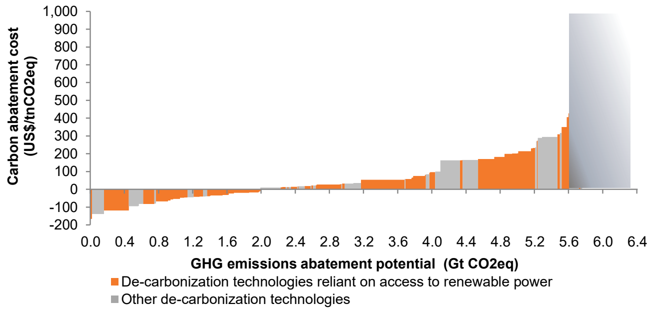
Exhibit 52: ...bringing CCUS and hydrogen-based technologies to the lower end of the cost curve
USA industrial sector cost curve of de-carbonization



Source: Goldman Sachs Global Investment Research

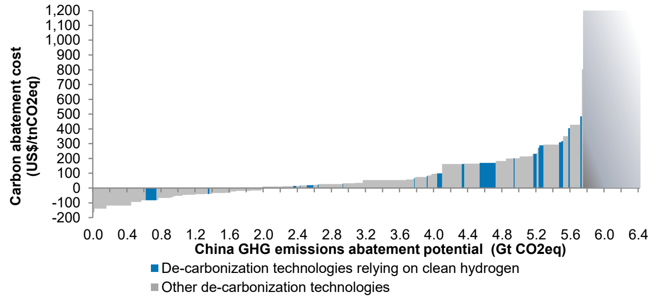
Renewable power and clean hydrogen are two dominant technologies leading decarbonization of the US energy system. Examining the emerging technologies that could meaningfully transform the de-carbonization cost curve, it becomes evident to us that access to renewable power is a critical de-carbonization component, driving the de-carbonization of c.67% of current US emissions. Clean hydrogen (we assume 50/50 blue/green hydrogen for the US split) is also currently at the forefront of this technological challenge: based on our analysis, it has the potential to transform c.15% of the total global GHG emissions in our cost curve, and can be attractively positioned in a number of transportation, industrial, power generation and heating applications.

Exhibit 53: Access to renewable power is critical, driving the de-carbonization of c.67% of current US emissions
GHG emissions de-carbonization cost curve with orange indicating technologies reliant on access to renewable power (clean electricity)



Source: Goldman Sachs Global Investment Research

Exhibit 54: Clean hydrogen is also important, aiding the de-carbonization of c.15% of US GHG emissions on our estimates
Carbonomics cost curve with emissions abatement potential attributed to clean hydrogen indicated



Source: Goldman Sachs Global Investment Research

Reduction of emissions and path to net zero

A more sustainable energy system: A path consistent with the emission reduction ambitions of net zero by 2050

Our model for the USA's energy evolution is consistent with the long-term strategy of the USA, targeting net zero by 2050. Our USA model addresses all key emitting sectors in the region: power generation, buildings (residential, commercial), transport (light, medium and heavy-duty road transport, transit vehicles, aviation, rail and marine), industry (including industrial combustion, industrial processes, fuel extraction and other fugitive and waste emissions) and agriculture. This enables us not only to model energy and process technological evolution by industry, but also to track and estimate the resulting overall emissions (both energy and process) stemming from each of these industries, and the broader USA region considered in our analysis.

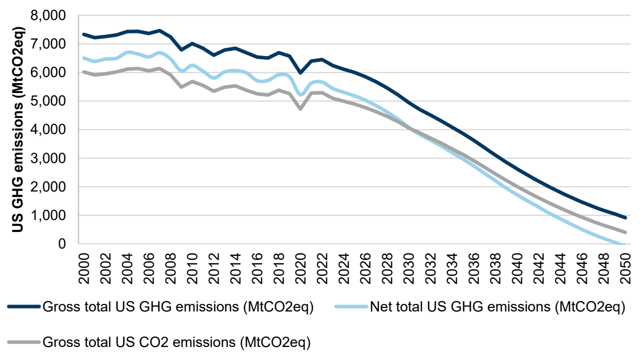
The emissions profile resulting from our model of the USA's energy evolution is shown in Exhibit 55. It shows a c.40% GHG emissions reduction vs. the 2005 level for the region by 2030, and net zero by 2050.

With regard to emissions accounting, we include in our emissions profile the contribution of the land-use change and forestry (LULUCF) sector, and direct air capture with carbon storage (DACCS), consistent with the long-term strategy of the USA to remove 1,000-1,8000 MtCO2eq per year in 2050.

We estimate this investment to deliver a 27% reduction of emissions by 2030 (vs. 2021) and a c.40% reduction (vs. 2005) and will lead the USA to net zero carbon by

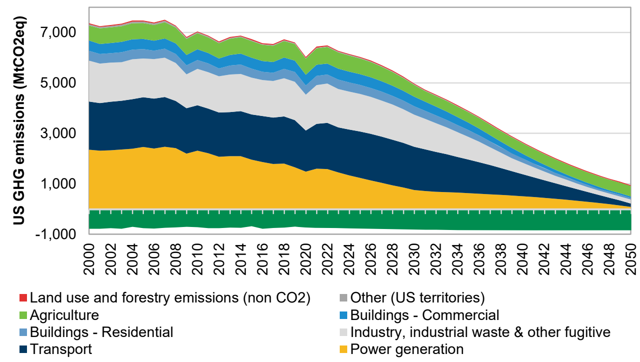
2050. In the US, the greatest volumes of GHG emissions come from transport (30%), power generation (25%) and industry (25%), accounting for c.80% overall.

Exhibit 55: Our model of the USA's energy evolution is consistent with the US climate target of becoming net zero by 2050...
USA GHG emissions (MtCO2eq)



Source: Goldman Sachs Global Investment Research, US EPA, IEA, IRENA

Exhibit 56: ...and adopts a sectoral approach, modelling the emissions across all key emitting sectors
USA GHG emissions (MtCO2eq) by key emitting sectors, including LULUCF



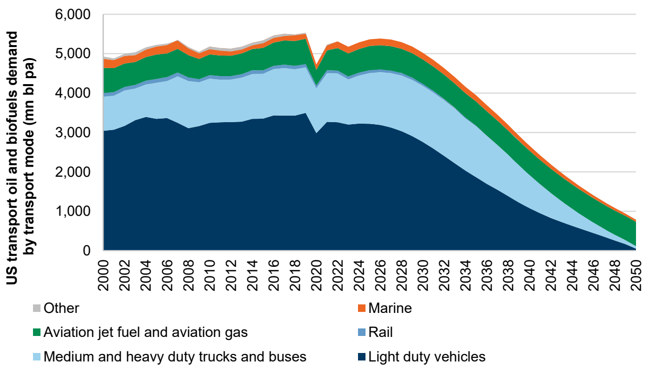
Source: Goldman Sachs Global Investment Research, US EPA, IEA, IRENA

Transportation: a deep dive into the path to net zero carbon

Transportation sits at the lower end of the cost curve after the implementation of IRA, with the sector responsible for c.28% of the US's final energy consumption and c.28% of net US GHG emissions. As part of our analysis, we lay out the evolution of oil and biofuels demand and the de-carbonization path for US transportation, as shown in Exhibit 57, addressing all key transportation modes: light-duty vehicles, medium and heavy-duty trucks and buses, rail, transit, aviation and marine transport. We highlight that the speed of energy transformation and de-carbonization varies depending on the transport mode, 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 largely de-carbonized through electrification) are the two transport modes with a faster relative de-carbonization, given the readiness and rising scale of the clean technologies for both (electrification). Conversely, aviation decarbonizes at a slower pace, given the still largely undeveloped or early stage development de-carbonization alternatives (sustainable aviation fuels, synthetic fuels, clean hydrogen and ammonia/methanol), which we expect to enjoy large uptake in adoption, owing to IRA tax credits and incentives. We further address how the fuel mix of the energy consumption of transport evolves over time in our US energy evolution model and present the results in Exhibit 58.

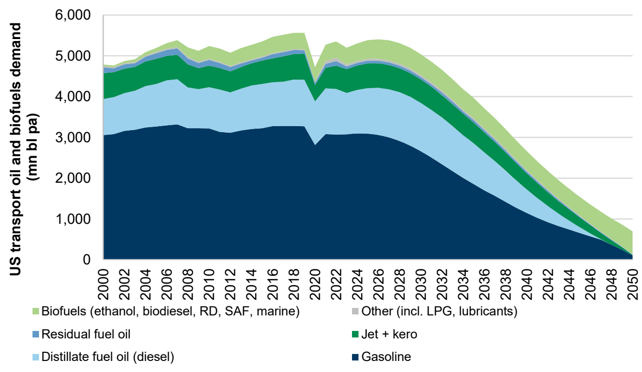
Overall, electricity increases its share in total transport energy consumption to c.50% by 2050E. Bioenergy, clean hydrogen & hydrogen-derived fuels (synthetic fuels, ammonia/methanol) all emerge as important energy sources for transportation, particularly for shipping, aviation and heavy long-haul heavy transport (lorries).

Exhibit 57: In our US energy evolution model, we address oil and biofuel demand evolution for each transport mode...
US transport oil and biofuel demand by transport mode (mn bl pa)



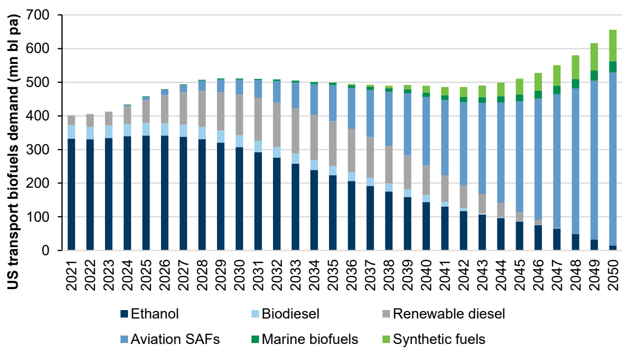
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 58: ...and of each oil, including biofuels
US transport oil and biofuel demand by fuel (mn bl pa)



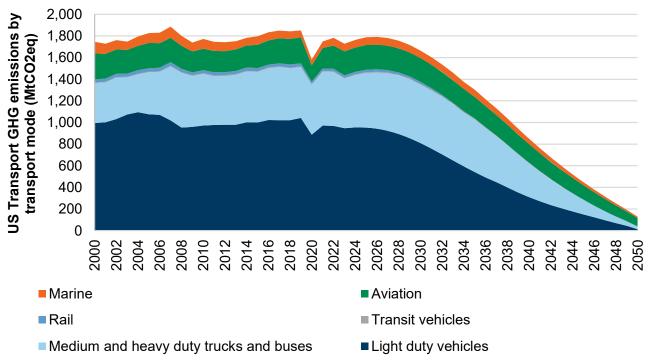
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 59: Bioenergy demand is accelerating with SAF dominating biofuel consumption in the US by 2025E...
US transport biofuel demand (mn bl pa)



Source: EIA, Goldman Sachs Global Investment Research

Exhibit 60: ...driving the required emisions reduction mostly from 2030E
US transport GHG emissions (MtCO2)



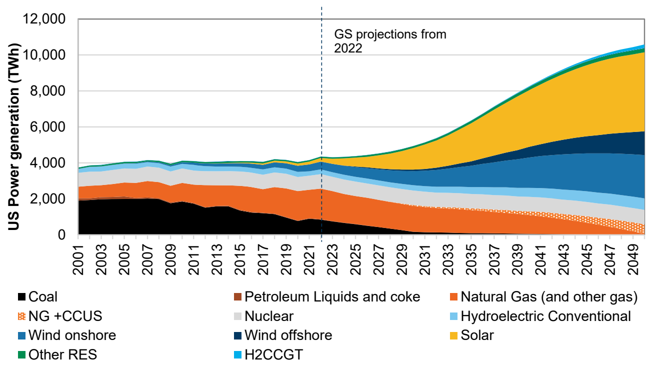
Source: EIA, Goldman Sachs Global Investment Research

Power generation: a deep dive into the path to net zero carbon

Power generation is the most vital component of the USA's energy evolution and net zero path, with the sector contributing a quarter of total anthropogenic GHG emissions in the region. The role of power generation is, in our view, only likely to increase in the coming decades, as the penetration and pace of electrification is rapidly increasing across sectors as these progressively follow their own energy evolution and de-carbonization path, including, amongst others, the electrification of road transport, buildings, industrial manufacturing processes and low-temperature industrial heat. Overall, we expect **total US demand for electricity generation to more than double** (vs. 2021) **and surpass 10,500 TWh,** as the de-carbonization process unfolds and **electricity forms c.35% of the overall US final energy consumption mix**.

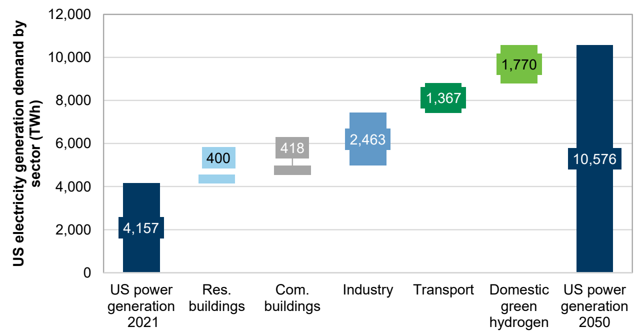
Based on our US Carbonomics cost curve analysis, power generation currently dominates the low end of the carbon abatement cost spectrum, with plenty of technologies already being in money, with renewable power technologies already developed at scale and having costs that have fallen rapidly over the past decade, making them competitive with fossil fuel power generation technologies in the US. As shown in Exhibit 64, the transformation of power in the US has already started, and has accelerated over the past decade with renewable power the most critical component of the mix moving forward. Based on our US energy evolution model, we estimate that **the share of renewables in the US power mix will rise from c.20% currently** (2021, including solar and wind, hydro, bioenergy and renewable waste) **to c.50% by 2030, and >85% by 2050**.

Exhibit 61: We estimate that total demand for power in the US will increase 2.5 times to 2050...
US electricity generation (TWh)



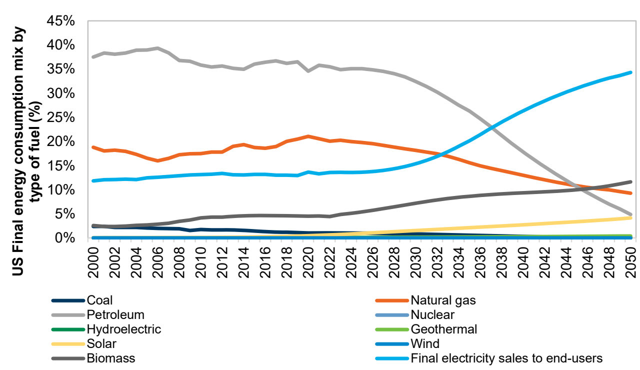
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 62: ...as it forms a critical part of the energy evolution and de-carbonization route for other sectors such as the electrification of transport, buildings, industry, production of green hydrogen...
US electricity bridge to 2050E (TWh)



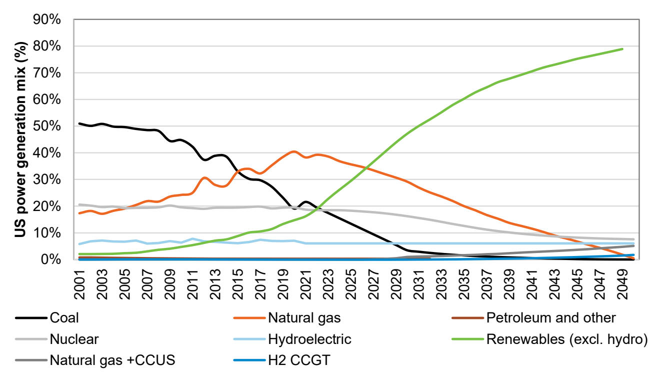
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 63: ...and its share in the US final energy mix rising, reaching c.34% of the US final energy consumption, from c.13% currently
US final energy consumption mix per our US energy evolution model (%)



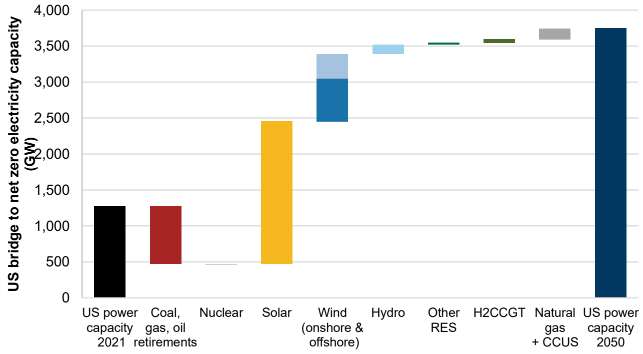
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 64: The transformation of the power generation mix has already started and we expect it to accelerate from here with renewable energy having the most critical role to play...
US electricity generation mix (%)



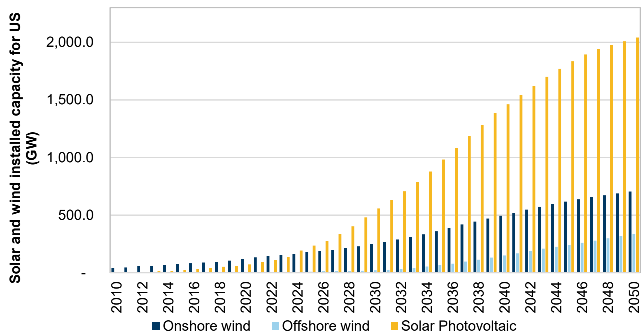
Source: IEA, Goldman Sachs Global Investment Research

Exhibit 65: ...and dominating capacity additions from here, with total installed renewable capacity reaching 3,700 GW by 2050...
US generation capacity additions bridge (GW)



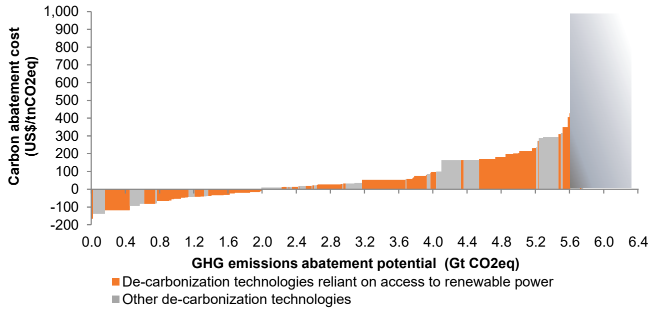
Source: EIA, Goldman Sachs Global Investment Research

Exhibit 66: ...driven predominantly by solar and wind (onshore and offshore)
Solar PV and wind installed capacity for US (GW)



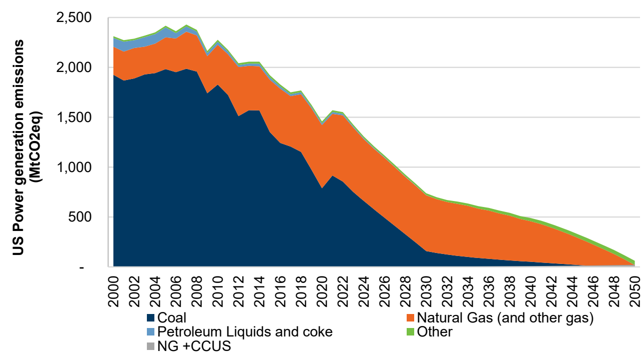
Source: IEA, Goldman Sachs Global Investment Research

Exhibit 67: Access to renewable power is the most critical de-carbonization component, being broadly vital for the de-carbonization of c.67% of the current US emissions
US GHG emissions de-carbonization cost curve with orange indicating technologies reliant on access to renewable power (clean electricity)



Source: Goldman Sachs Global Investment Research

Exhibit 68: Power generation emissions have been on a downward trajectory in the US for most of the last two decades, and we expect that to continue to 2050, despite the slowdown in 2021-22
Power generation CO2 emissions



Source: IEA, Goldman Sachs Global Investment Research

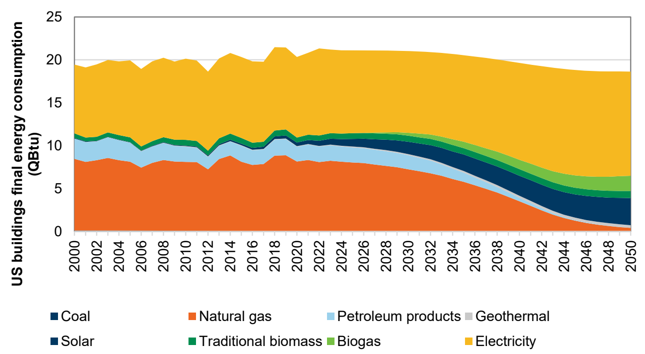
Buildings: a deep dive into the path to net zero carbon

Buildings, both residential and commercial, account for c.40% of final energy consumption in the US, with the energy mix currently dominated by electricity and natural gas (primarily for heating). Whilst the key technologies that govern energy evolution and 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 the need for comparatively costly retrofits essential to achieve net zero emissions by 2050, particularly for residential buildings where the switch is largely reliant on consumer preference. As such, any aspiration for gross zero emissions in buildings has to come with the need for an accelerated pace of retrofits.

Our energy evolution model for US incorporates a step change in the **pace of acceleration of energy efficiency, as well as the flexibility of the stock and a shift away from fossil fuels**. The former can be achieved by a combination of measures, including the switch to best-available technology (BAT) across appliances such as heat pumps, hydrogen boilers, insulation (cavity wall, floor), automation and smart meters, and will largely be governed by underlying building codes and standards. The latter is largely dependent on the cost and availability of clean alternative technologies.

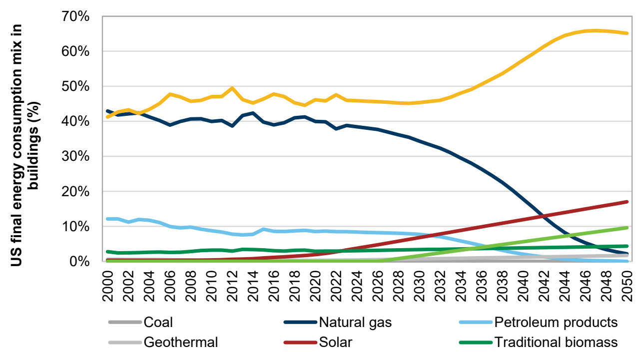
Overall, as shown in Exhibit 69, **electricity accounts for around a half of the total final energy consumption of buildings, and we expect its share to reach c.65% by 2050,** whilst the share of direct renewable energy, such as residential solar, geothermal and bioenergy, is also increasing over time, reaching >32% by 2050E. Solar power/bioenergy consumption is expected to increase strongly from 2%/3% to 17%/14%. This implies, on our estimates, **more than 50 million heat pumps being installed across the US by 2030**. Increasing heat pump installations and solar modules, coupled with increased spending on efficiency and insulation, contribute to **c.$1.8 trn of cumulative infrastructure investments for buildings in the USA by 2050** (mostly retrofits) in our analysis.

Exhibit 69: The current final energy consumption of buildings is dominated by electricity and natural gas consumption, each accounting for c.46%/40% of the final energy consumption across total buildings (residential and commercial)..
USA Buildings final energy consumption (PJ)



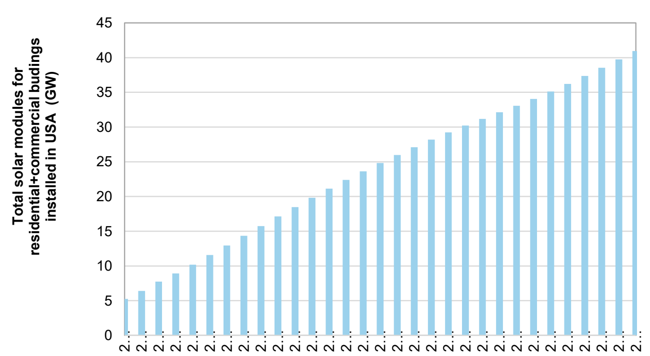
Source: EIA (historicals), Goldman Sachs Global Investment Research

Exhibit 70: ...with electrification and solar power dominating the energy mix longer term, each representing c.65%/17% of the mix respectively...
USA Buildings final energy consumption mix in buildings (%)



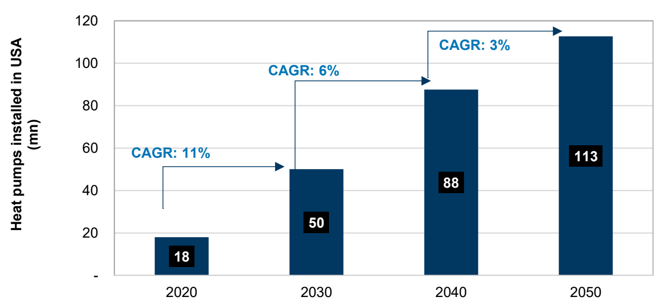
Source: EIA (historicals), Goldman Sachs Global Investment Research

Exhibit 71: ...solar modules demand increasing 3-fold by 2030E and 6-fold by 2050E...
Cumulative solar PV installed in US (GW)



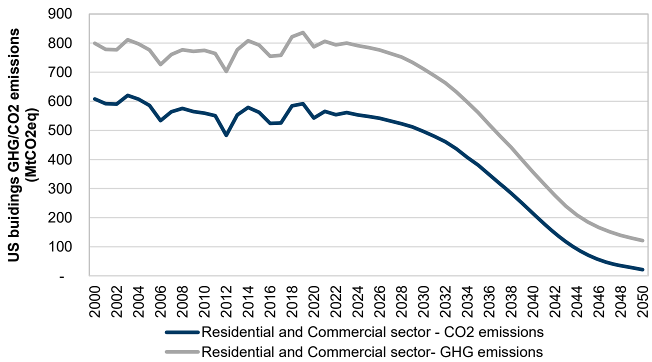
Source: Goldman Sachs Global Investment Research

Exhibit 72: ..and heat pump installations surpassing 50 mn by 2030E
Heat pumps installed in the US (mn)



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 73: The switch to electrification and accelerated efficiency improvements drive US buildings' carbon emissions lower
US buildings otal GHG/CO2 emissions (MtCO2eq)



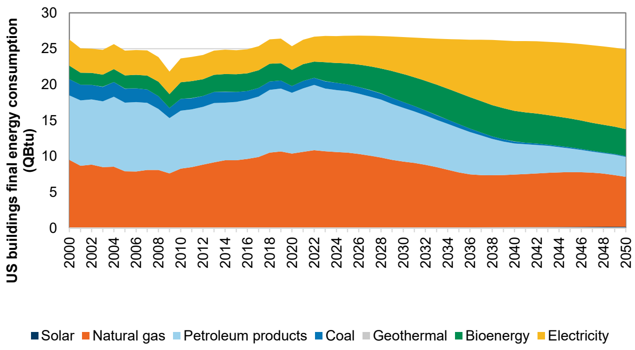
Source: IEA, Goldman Sachs Global Investment Research

Industry: a deep dive into the path to net zero carbon

The industrial sector accounts for c.28% of the US's final energy consumption, making it the third-largest energy consuming industry in the US after power generation and transport. The sector contributed almost a quarter of gross GHG emissions in 2021. The industrial sector for the purpose of this analysis incorporates all of industrial combustion, industrial processes, waste and other fugitive emissions (including those associated with the extraction and refining of fossil fuels).

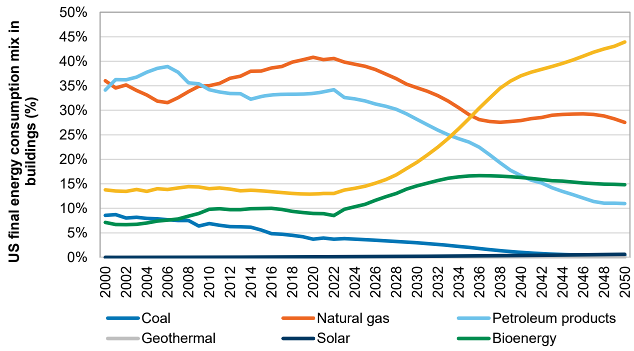
We believe US industry, similar to the transport and buildings sectors, will have to undergo a technological revolution on its path to net zero, with the key levers of this transformation being energy efficiency, electrification, hydrogen, circular economy and CCUS (for sectors where an alternative energy source does not drive the complete abatement of emissions, such as in processes such as cement production). Overall, our model for US industry points to a long-term share of electricity of c.45% and bioenergy, both in the form of biogas and biomass (c.15%) as shown in Exhibit 75, with bioenergy being vital for heavy industries where direct electrification is not possible given the high temperatures involved in these industrial processes.

Exhibit 74: We see energy efficiency, electrification, hydrogen, circular economy, bioenergy as key drivers of the energy transformation of US industry...
US industry final energy consumption (QBtu)



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

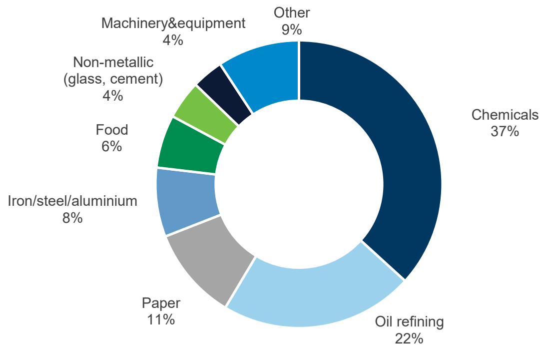
Exhibit 75: ...required to de-carbonize and diversify the energy of low-temperature conventional manufacturing processes and heavy industry
US industry final energy consumption fuel mix (%)

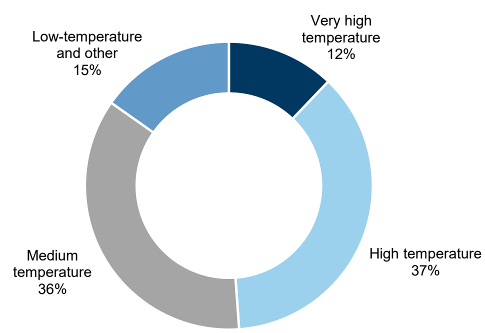


Source: EIA (historical), Goldman Sachs Global Investment Research

The energy evolution of US industry will differ both in both pace and technological and fuel mix, depending on the specific process and its characteristics. More broadly, US industrial energy consumption is split fairly evenly between low- and medium-temperature heat processes such as oil refining, paper and broader manufacturing, and high-temperature heat processes, primarily heavy industry such as iron and steel, non-metallic minerals and non-ferrous metals manufacturing, as well as petrochemicals. Whilst energy and material efficiency (including circular economy and waste management) will likely be relevant for all industrial sub-segments, we note that the dominant technologies and ultimate energy mix will differ for each type of industrial process. Overall, we view electrification as likely to be the dominant source of energy for low temperature heat processes (such as broader equipment manufacturing), whilst molecular sources of energy including bioenergy, hydrogen and hydrocarbons retrofitted with carbon capture are likely to dominate high temperature processes for which full electrification is not possible with existing technologies at scale.

Exhibit 76: US industry is split between low and high temperature processes...
US industry final energy consumption split by sub-industry and type of process, 2021





Source: Goldman Sachs Global Investment Research

Exhibit 77: ...making the need for both electrification but also molecular energy sources for its de-carbonization and energy evolution

Example of industrial processes by heat temperature and ways of decarbonization

	Heat temperature	Examples of processes	Available clean technologies
c.12%	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.37%	High-temperature heat 400-1,000 degrees	Steam reforming and cracking in petrochemicals (ammonia, methanol)	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c.36%	Medium-temperature heat 100-400 degrees	Oil refining Broader manufacturing	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity
c.15%	Low-temperature heat < 100 degrees and other unclassified	Washing, rinsing, food preparation Broader manufacturing	Fossil fuels + CCUS Bioenergy Clean hydrogen Electricity

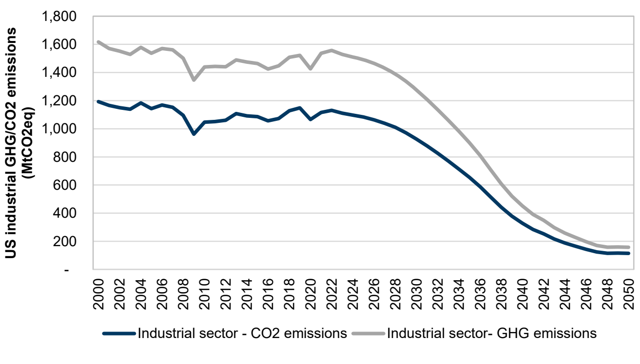
Applicable and currently available at large scale
Applicable but not yet at large scale
Not applicable

Source: Goldman Sachs Global Investment Research

Overall, our US industry energy model is consistent with a notable acceleration of industrial GHG emissions reduction (including industrial combustion, processes, fugitive and waste emissions). We note nonetheless that gross industrial GHG emissions never reach absolute zero, given the harder-to-abate process emissions across key sectors, making the need for LULUCF (defined earlier in this report and including natural sinks) important for net zero for the region. The overall profile of US industrial emissions is presented in Exhibit 79, including fugitive and other waste emissions.

Exhibit 78: Clean hydrogen, CCUS, electrification, and the circular economy drive buildings' carbon emissions lower

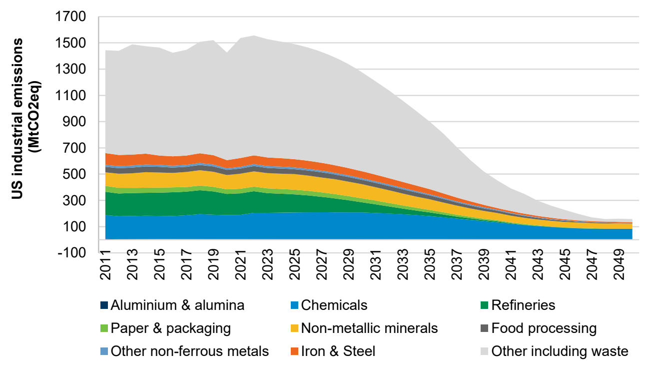
US industrial total GHG/CO2 emissions (MtCO2eq)



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

Exhibit 79: Industrial emissions stem from a very diverse range of sources and industries, requiring an ecosystem of de-carbonization technologies, including carbon offsets, to achieve net zero GHG emissions by 2050E

US industrial GHG emissions (MtCO2eq)



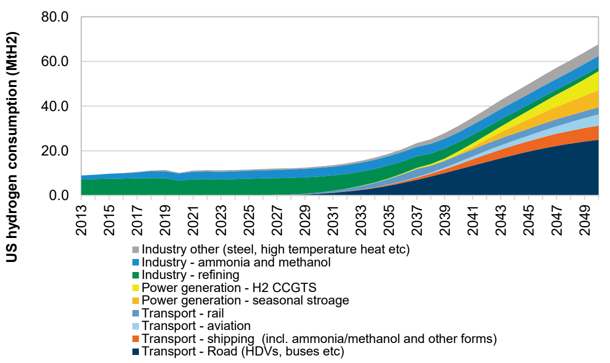
Source: EIA (historical), Goldman Sachs Global Investment Research

A run through by technology (renewables, EVs, Hydrogen, CCUS, biofuels)

As we have highlighted numerous times in our Carbonomics research series and our global net zero models, we believe that the energy evolution and path to net zero calls for an evolution of the de-carbonization process **from one dimensional (renewable power) to a multi-dimensional ecosystem**. Four more technologies are emerging as transformational in our view, in addition to renewable power: **hydrogen, bioenergy** (including the role of biogas)**, battery energy storage, and carbon sequestration** (both natural sinks and carbon capture). All of these will, in our view, be required to help the stability and resilience of the energy path we envisage for the US.

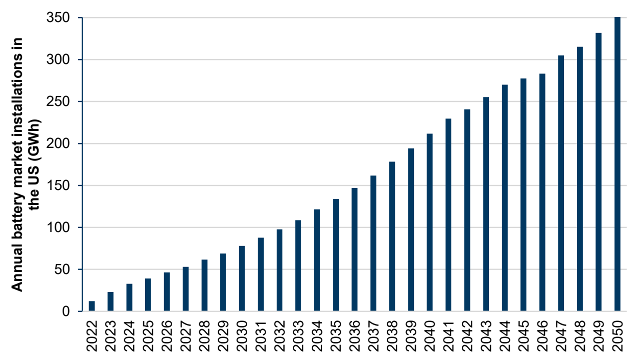
Renewable power generation is a key driver of the path to net zero carbon. However, it suffers from two key problems that need to be addressed: intermittency and seasonality. As the growth in renewable power accelerates, intraday and seasonal variability has to be addressed through energy storage solutions. **To reach full replacement of coal and natural gas and 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**, with batteries addressing intermittency and hydrogen addressing seasonality. We incorporate both of these technologies in our energy evolution path for the US. This low carbon infrastructure however will require time to be built. **Until the relevant energy storage infrastructure** (networks and smart grids) and technologies (utility scale batteries and hydrogen) are ready to support an increasingly electrified energy economy, we argue that **both natural gas and nuclear power have a role to play in the near term, to enable a smooth energy transition and help avoid a power crunch.**

Exhibit 80: We expect US hydrogen consumption to rise multi-fold on the path to net zero...
Hydrogen consumption (MtH2)



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

Exhibit 81: ...complementing the rising need for utility-scale batteries to support an increasingly intermittent renewable power-dominated grid
Annual battery market installations in the US (GWh)



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

Renewables: the key pillar on the decarbonization path

Renewables is the most vital component for any net zero path

Power generation is an important component of the US's energy evolution and net zero path, with the sector contributing to c.25% of total GHG 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 is rapidly increasing across sectors as these progressively follow their own energy evolution and de-carbonization path, including, amongst others, the electrification of road transport, buildings, industrial manufacturing processes and low-temperature industrial heat. Overall, we expect total US demand for electricity generation to more than double (vs. that of 2021) and surpass 10,000 TWh as the de-carbonization process unfolds and electricity forms c.75% of the overall US final energy consumption mix.

Based on our US Carbonomics cost curve analysis, power generation currently dominates the lower 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. **Currently, solar and wind are the cheapest electricity sources in the US, and the IRA is marginal to further cost reduction, as it mostly extends existing credits.** Based on our model, we estimate that the share of renewables in the US power mix will rise from c.15% currently (2021, including solar and wind, bioenergy and renewable waste, excl. nuclear and hydro) to >40% by 2030 and >80% by 2050.

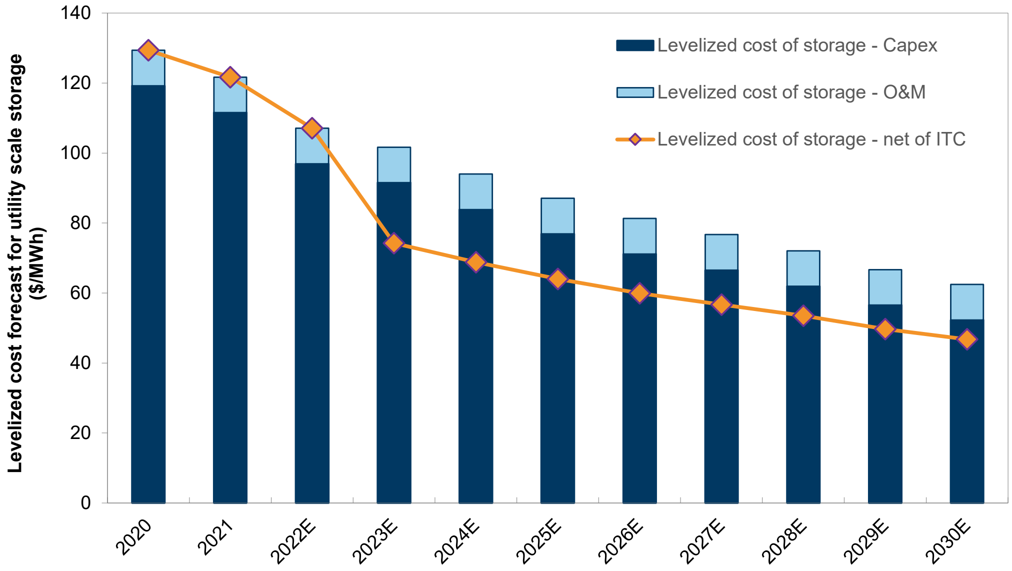
As the growth in renewable power accelerates, intraday and seasonal variability has to be addressed through energy storage solutions, as highlighted in an earlier section of this report. To reach full de-carbonization of power markets, we believe two key technologies will likely contribute to solving the energy storage challenge: utility-scale batteries and hydrogen, each having a complementary role. We incorporate both of these technologies in our model for US energy evolution. Energy storage and the need for extensive network infrastructure is a particularly important consideration as demand for power generation growth accelerates, to ensure a resilient global energy ecosystem.

Battery storage: IRA is transformational for utility-scale battery storage

The IRA added standalone energy storage to the list of technologies that qualify for the energy investment tax credit and raised the credit rate to 30% versus 26% previously. The issue of intermittency has always been a critical weakness to renewables such as wind and solar, as they cannot reliably supply energy throughout the 24 hours of a day. However, there was not a prior investment tax credit for utility-scale energy storage. The IRA now adds energy storage to its ITC and has raised the overall rate of the credit to 30% (previously 26% in 2022, 22% in 2023). According to estimates from our Clean Energy team, the levelized cost of utility-scale storage incorporating on a net basis the new ability to apply the ITC is expected to be $74 per MWh in 2023. This represents a 43% reduction relative to 2020 costs, when there was no ITC for storage.

Exhibit 82: The levelized cost of utility-scale stationary storage net of ITC in 2023 is expected to be 43% less than 2020, when there was no ITC for storage

Innovation/cost deflation have also been contributing factors



Source: BNEF, Goldman Sachs Global Investment Research

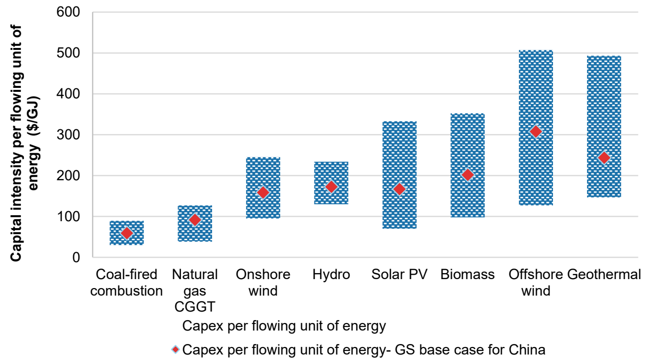
The power generation investment opportunity: Higher capital intensity of renewable power and the rising importance of energy storage and networks infrastructure pave the way for a c.$6.7 trn investment opportunity

Earlier in this report, we highlighted the substantial potential investment creation opportunity associated with the US energy evolution path. Renewable power generation acts as a major contributor to this infrastructure investment opportunity. This is mainly attributed 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, lower opex and IRA incentives, compared with traditional hydrocarbon developments.** In fact, in the current commodity price landscape, **renewable power on aggregate improves the affordability of power.**

As the growth in renewable power accelerates, intraday and seasonal variability has to be addressed through energy storage solutions, as highlighted in an earlier section of this report. 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 model for Europe's energy evolution. **Energy storage and the need for extensive network infrastructure** is a particularly **important consideration**

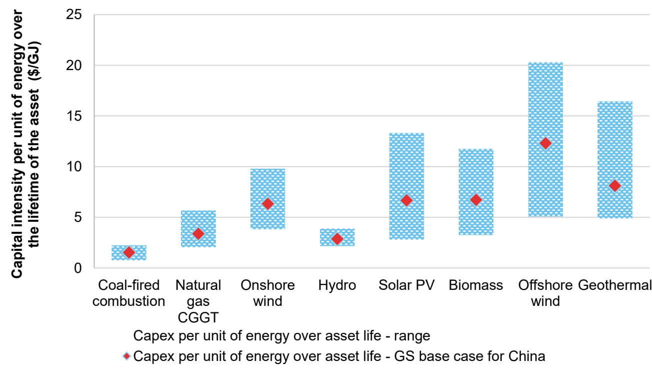
as demand for power generation growth accelerates, to ensure a resilient global energy ecosystem.

Exhibit 83: 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), latest available data



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 84: ...and over the lifetime of the asset
Capex per unit of energy over the life of the asset (US$/GJ) for each technology, latest available data



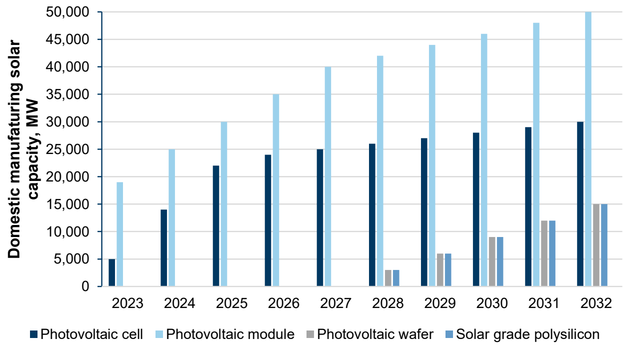
Source: Company data, Goldman Sachs Global Investment Research

45X credit to boost US solar manufacturing capacities

45X credit provides incentives for US solar and wind components manufacturers. Components that qualify for the new credit include solar panels, inverters, trackers, wind turbines, and batteries. According to our Clean Energy team, these credits represent roughly >40% of the current cost for solar panels, 20%-50% for inverters (depending on the inverter), and 15%-20% for trackers. These credit would begin to phase down in 2031 and end by 2033.

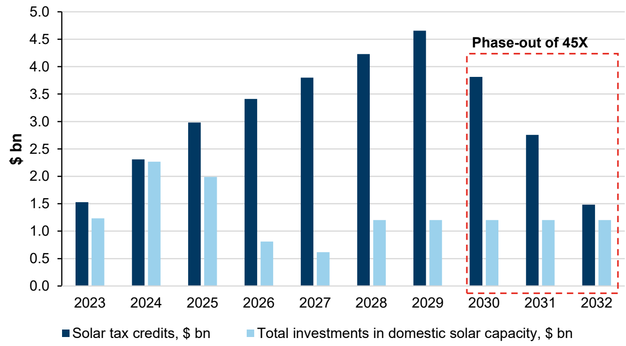
Solar: Over 20GW of additional module and cell manufacturing capacity has been announced since the passage of the IRA. According to our Clean Technology Team, following the passage of the IRA, there have been a multitude of announcements from solar and storage suppliers to build new US capacity. Some of the most notable announcements have come from module suppliers which are building new GW-scale factories to take advantage of lucrative manufacturing credits. **Overall, over 20GW of additional module and cell manufacturing capacity has been announced since the passage of the IRA, according to PVTech.** While currently, domestic solar manufacturing capacities are at early stage of development, with production of PV cell and wafers being virtually non-existent, we believe IRA incentives are likely to boost development of the industry, and we currently expect c.50GW of module capacity, c.30GW of cell capacity and c.15GW of poly/wafer capacity by 2032. **Overall, we estimate investment in domestic solar manufacturing at $13bn, and c.$30bn of government incentives by 2032.**

Exhibit 85: We currently expect c.50GW of module capacity, c.30GW of cell capacity and c.15GW of poly/wafer capacity by 2032
Domestic solar manufaturing capacities, MW



Source: Goldman Sachs Global Investment Research

Exhibit 86: We estimate overall investment in domestic solar manufacturing at $13bn and c.$30bn of government incentives by 2032
Solar tax credits and investments in domestic solar manufacturing capacity, $ bn



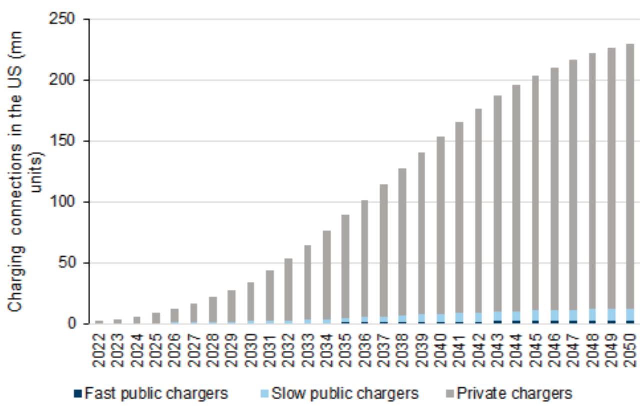
Source: Goldman Sachs Global Investment Research

Electric vehicles

Charging and refueling infrastructure critical for the transformation of transport: we estimate a c.$0.8 trn infrastructure investment opportunity in US

The ability to facilitate the energy evolution of transport envisaged, with a rapid uptick of electrification and alternative fuels, calls for substantial infrastructure investments. We estimate this at $0.7 trn cumulatively to 2050, of which $0.6 trn accounts for EV/PHEV charging and $0.1 trn for refueling stations. This is imperative for the increasing number of public and private chargers, as well as alternative fuels refueling stations.

Exhibit 87: The energy evolution of transport requires, on our estimates, c.$0.7 trn in charging and refueling infrastructure investments
Charging connections in the US (mn units)



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

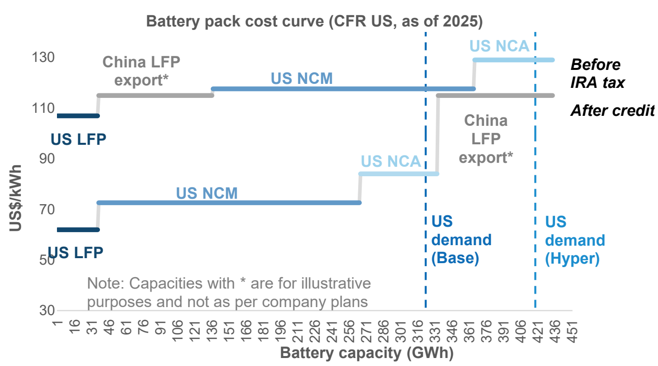
US EV battery plants: potential onshoring on the back of 45X credit

The IRA effectively lowers the US domestic battery cost curve by US$45/kWh. The US IRA may reshape the battery cost curve by supporting local battery suppliers — in the case of the US market, the IRA offers a US$45/kWh credit for locally manufactured battery cells and modules, effectively lowering the domestic cost curve by US$45/kWh (Exhibit 88). The nickel-manganese-cobalt (NCM), and nickel-cobalt-aluminium (NCA) batteries manufactured in the US were previously less cost-competitive than lithium-iron-phosphate (LFP) battery exports from China, but are now at large cost advantage vs. Chinese exports, according to our Battery team.

We currently estimate c.900 GWh by 2032, from c.75 GWh currently of EV battery plants capacity, which implies c.90% self-sufficiency by 2032. Currently, there are c.9,00 GWh of EV battery cells projects announced in the US, and we note that >50% of these are post FID. Additionally, we see companies starting to accelerate investment decisions to build EV battery plants in the US. We estimate a c.$70 bn initial capital investment in EV battery plant manufacturing capacity by 2032, and c.$130 bn of government incentives by 2032, in the form production tax credits.

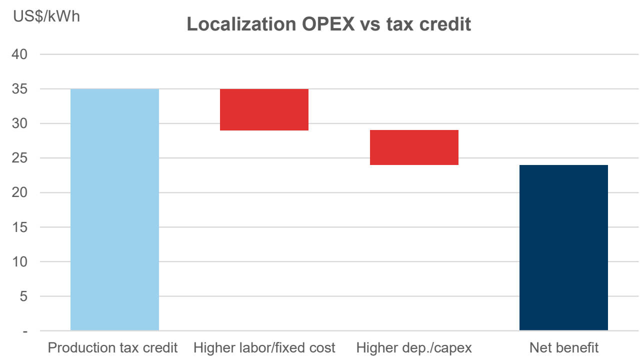
Exhibit 88: The IRA effectively lowers the US domestic automotive battery cost curve by $45/kWh

In a global battery capcity surplus, policies like the US IRA support local manufacturing against Chinese exports



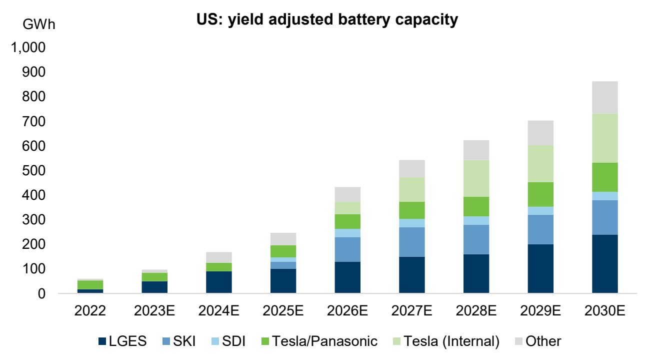
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 89: Even accounting for risk of higher labour and capex inflation, the advanced manufacturing tax credits can be a significant potential tailwind to profitability for battery companies



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 90: Capacity additions set to accelerate in the US, driven partially by self-sufficiency incentives

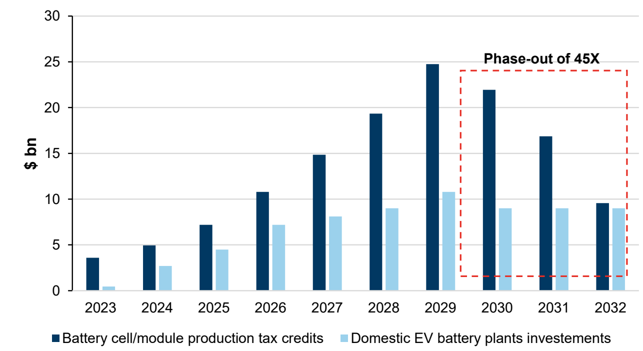


Market shares for LGES and SKI not adjusted for JV stake

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 91: We estimate c.$70 bn of initial capital investment in EV battery plant manufacturing capacity by 2032 and c.$130 bn of government incentives by 2032

EV battery plant capex and 45X credits, $ bn



Source: Company data, Goldman Sachs Global Investment Research

Korean battery companies are key enabler for US battery onshoring

We see the IRA of 2022 as a significant positive for Korean battery makers which are rapidly expanding capacities in the US (we forecast their market share to grow in the US from 11% in 2021 to 55% in 2025E) after years of building know-how and also fast enabling localization of the supply chain.

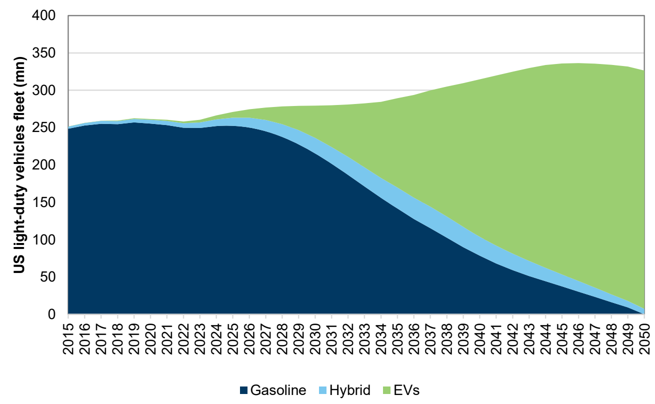
Based on already announced projects, we forecast the Korean battery makers' market share will grow in the US from 11% in 2021 to 55% in 2025 (including the stakes of JV partners). We see limited competition risks for Korean battery makers in the US, as the local ecosystem is still evolving, while Chinese battery makers' expansion plans within the US have been more limited.

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

We believe road transport is at the start of its most significant technological change in a century, with electrification, autonomous driving and clean hydrogen at the core of the de-carbonization challenge. For light-duty vehicles (LDVs) transport (primarily constituting passenger vehicles, special purpose vehicles, motorcycles, commercial vehicles and short/medium-haul trucks), we consider electrification the key de-carbonization technology. Overall, we estimate that the total LDV US road fleet (including passenger vehicles, short and medium-haul trucks) will increase c.25% by 2050 (from a 2021 base), with new energy vehicles (NEVs, including all of BEVs, PHEVs and FCEVs) reaching 100% penetration in the road transport fleet by 2050, as shown inUS passenger LDVs fleet (mn vehicles)Exhibit 92 for a path consistent with net zero emissions by 2050.

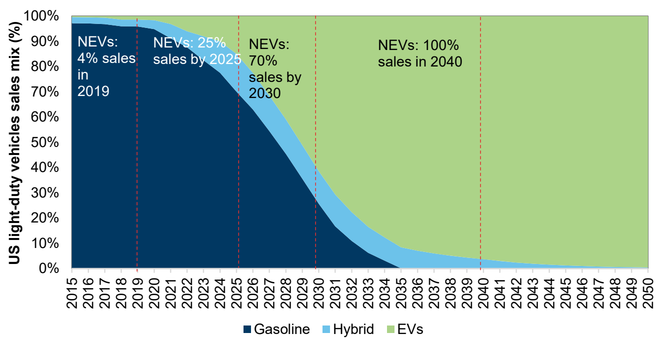
While we project considerable growth in pure battery vehicles in the ultimate de-carbonization solution for light road transport (essential for a net zero path), we expect multi-energy powertrain to also play a role in the facilitation of this transition, accounting for a considerable portion of sales and the fleet over the next 20 years. Multi-energy vehicles include plug-in hybrid EV (PHEVs), range-extended EVs, and light emission hybrid cars (HEVs). Overall, considering all NEV types, our net zero path requires NEV penetration in the light-duty road transport fleet reaching 20% by 2030, close to 70% by 2040, and 100% by 2050. NEV sales make up 25%/70%/98% of total LDV sales by 2025/30/35E respectively, effectively reaching zero carbon intensity in LDV sales by 2035, as shown in Exhibit 93. We primarily focus on the evolution of the fleet for the purpose of emission accounting in this analysis, with the fleet evolution reliant on both vehicles sales and retirements, as it is ultimately the penetration in the fleet that directly translates into transport emissions.

Exhibit 92: US energy evolution model calls for a transformational shift in the mix of the LDVs fleet to 2050...
US passenger LDVs fleet (mn vehicles)



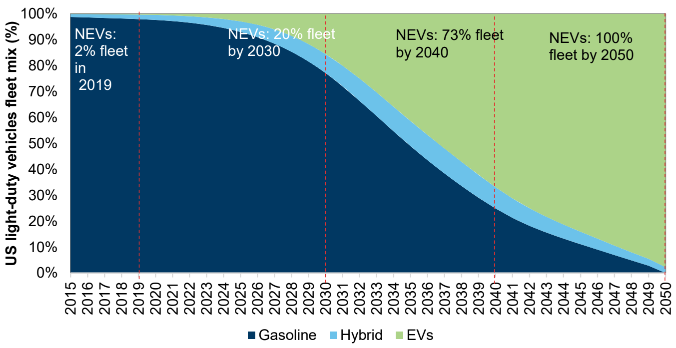
Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 93: ...with the share of NEVs in the sales mix reaching 98% by 2035E and 70% by 2030E...
US passenger LDVs sales mix (%)



Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 94: ...and driving the transformation of the fleet with a c. 12-15 year delay given the replacement cycle of average vehicles
US passenger LDV fleet mix evolution (%)

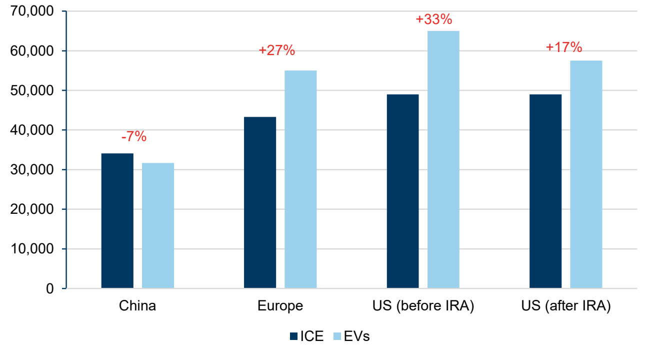


Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

IRA: clean vehicle tax credit to meaningfully decrease price difference between ICE and EV cars

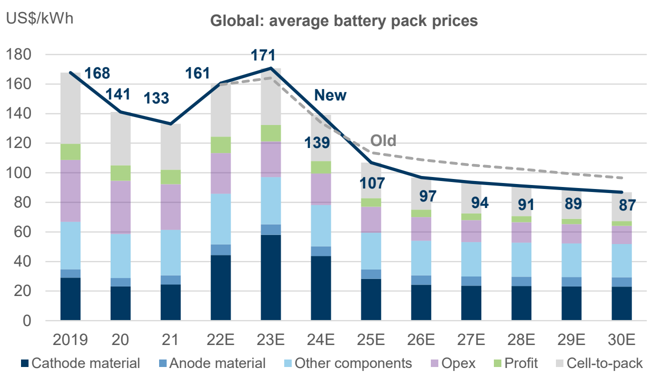
The IRA has introduced considerable tax credits for clean vehicles, significantly decreasing the price difference between EV and ICE cars. According to reports, the current average retail price of an EV car is c.$65k (link), while the average price of an ICE car is $c.49k (link), according to Kelley Blue Book estimates. The IRA introduces clean vehicle tax credits for consumers of up to $7.5k, which address up to c.50% of the average price difference between ICE and EV cars. To qualify for any light vehicle consumer credits under the IRA, the vehicle must meet several new provisions, including final assembly in North America, meet a certain price threshold depending on the vehicle type (all SUVs/pickup trucks/vans must have an MSRP below $80k, all other vehicles (e.g., sedans) must have an MSRP below $55k), and buyers must qualify based on modified gross income limitations. In addition, the vehicle must have a certain percentage of its battery materials from the US, or countries with which the US has a free trade agreement (worth $3,750 of the credit). Additionally, a certain percentage of battery components need to be from North America (also $3,750 of the credit), and those percentages increase over time.

Exhibit 95: The IRA (assuming full $7.5k credit) could meaningfully decrease the price difference between ICE and BEV cars...
Average retail price ICE vs. BEV ($), 2022



Source: Kelley Blue Book, Goldman Sachs Global Investment Research

Exhibit 96: ...and we forecast a gradual improvement in battery cell costs will materialize post 2023



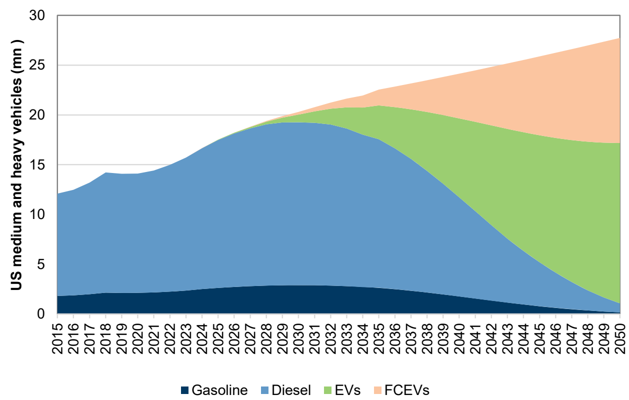
Source: Wood Mackenzie, SNE Research, Goldman Sachs Global Investment Research

Heavy-duty road transport: competitive landscape encompassing electrification, bioenergy and potential clean hydrogen

While we believe that electric vehicles screen as the most attractive de-carbonization solution for LDV applications, including short and medium-haul transport, we believe that the space becomes more competitive once we look to address heavier segments of the transportation market, primarily buses and lorries. We note that both bioenergy and clean hydrogen could be key competing technologies when long-haul heavy transport is considered (primarily lorries), given its high energy content per unit mass and shorter refueling time. Although the FCEVs (fuel cell electric vehicles) global stock was estimated (by IEA) to be around 51,600 at the end of 2021, owing to a limited product offering, non-competitive price points and little infrastructure, we see the recent policy drive towards de-carbonization as a reason to reconsider the potential for FCEVs. Despite small absolute volumes, the growth of FCEVs could accelerate notably, particularly in heavy long-haul transport applications, buses and forklifts.

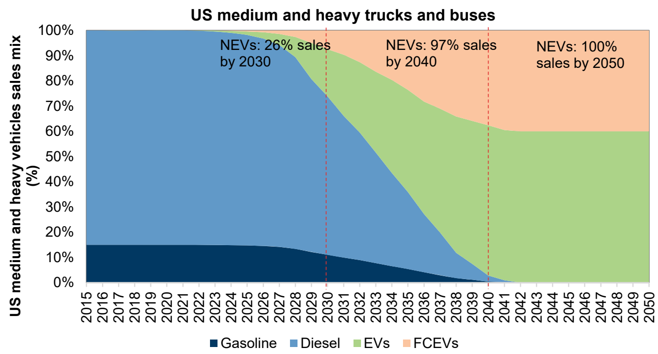
Overall we model considerable growth in both electric vehicles and FCEVs as the penetration of both overtakes internal combustion engine vehicles in the coming decades for buses and heavy-duty lorries, as presented in Exhibit 98. However, the shift in the fleet mix for heavy-duty vehicles starts later than the transition in LDVs, given the lower product offering and the need for further technological innovation (in the case of long-haul large capacity batteries) and cost deflation (in the case of fuel cells). Overall, considering all NEV types, our net zero path requires NEV penetration in the medium and heavy vehicles transport fleet reaching 5% by 2030, 50% by 2040, and 100% by 2050. NEVs sales make up 26%/64%/97% of total LDV sales by 2030/35/40E respectively, broadly in line with the US government target to convert 30% of medium- and heavy-duty vehicle sales to zero emissions by 2030 and convert all new medium- and heavy-duty vehicle sales to zero-emission vehicles by 2040.

Exhibit 97: We expect the evolution of the medium and heavy fleet in US to be dominated by electrification and clean hydrogen...
US medium and heavy vehicles (mn units)



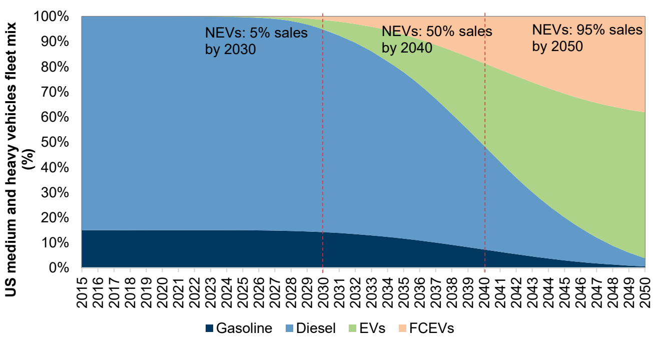
Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 98: ...with the share of NEVs in the sales mix reaching 26% by 2030E and close to 100% by 2040E
US medium and heavy vehicles sales mix (%)



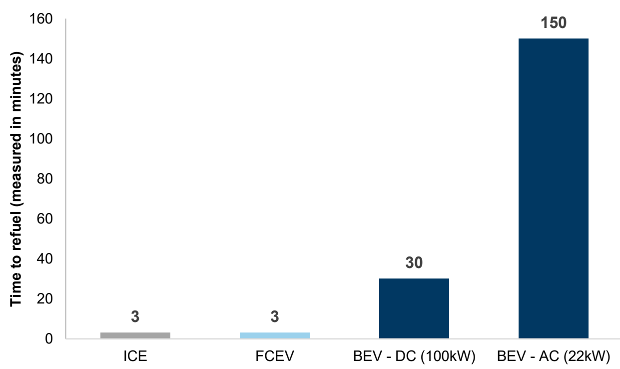
Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 99: Shift in fleet mix for medium- and heavy-duty vehicles starts later than the transition in LDVs, given the lower product offering and the need for further technological innovation
US medium and heavy vehicles fleet mix (%)



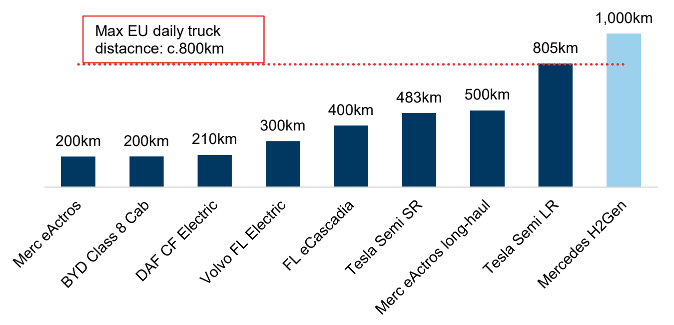
Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 100: Hydrogen outperforms significantly when we compare the refueling times of FCEVs and BEVs at different kW charging ratings...
mins to refuel/recharge



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 101: ...and also provides a range advantage, particularly useful for long-haul truck applications
ZEV Class 8 trucks and range (km)

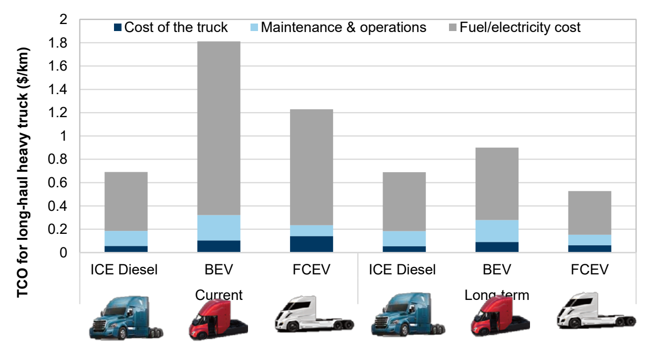


EU max daily driving time at 9 hours (assuming average speed of 90km/h)

Source: Transport & Environment, EU, compiled by Goldman Sachs Global Investment Research

In the exhibits below, we compare the total cost of ownership for ICE, BEV and FCEV, for heavy-duty long-haul trucks. As we look into heavy-road long-haul transport, we find the hydrogen proposition potentially competitive, with a TCO that is similar to that of BEV but benefiting from lower weight and faster refueling times. While both options remain more costly than conventional diesel ICE trucks, we expect technological innovation and cost deflation that generally comes on the back of economies of scale to reduce the costs of both technologies over time.

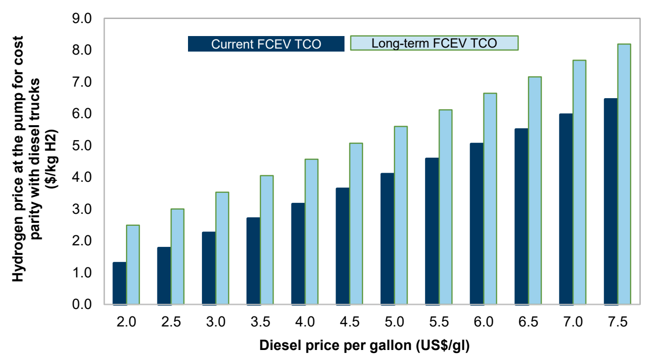
Exhibit 102: Long-haul heavy transport could be a new potential end market for hydrogen, with FCEV trucks becoming cost competitive, yet we note the share of long haul HDVs in European transport is relatively small
Total cost of ownership of a Class 8 truck (15 years assumed useful life)



* Diesel price assumption of US$6.5/gl, retail power price assumption of $0.6/kWh ($0.4/kWh long-term), hydrogen price at the pump of $12/kg ($5/kg long-term)

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 103: Longer term, we estimate a hydrogen price around US$4-4.5/kgH2 would be sufficient for cost parity with diesel (normalized diesel prices)
Hydrogen price at the pump required for cost parity with diesel



Source: Goldman Sachs Global Investment Research

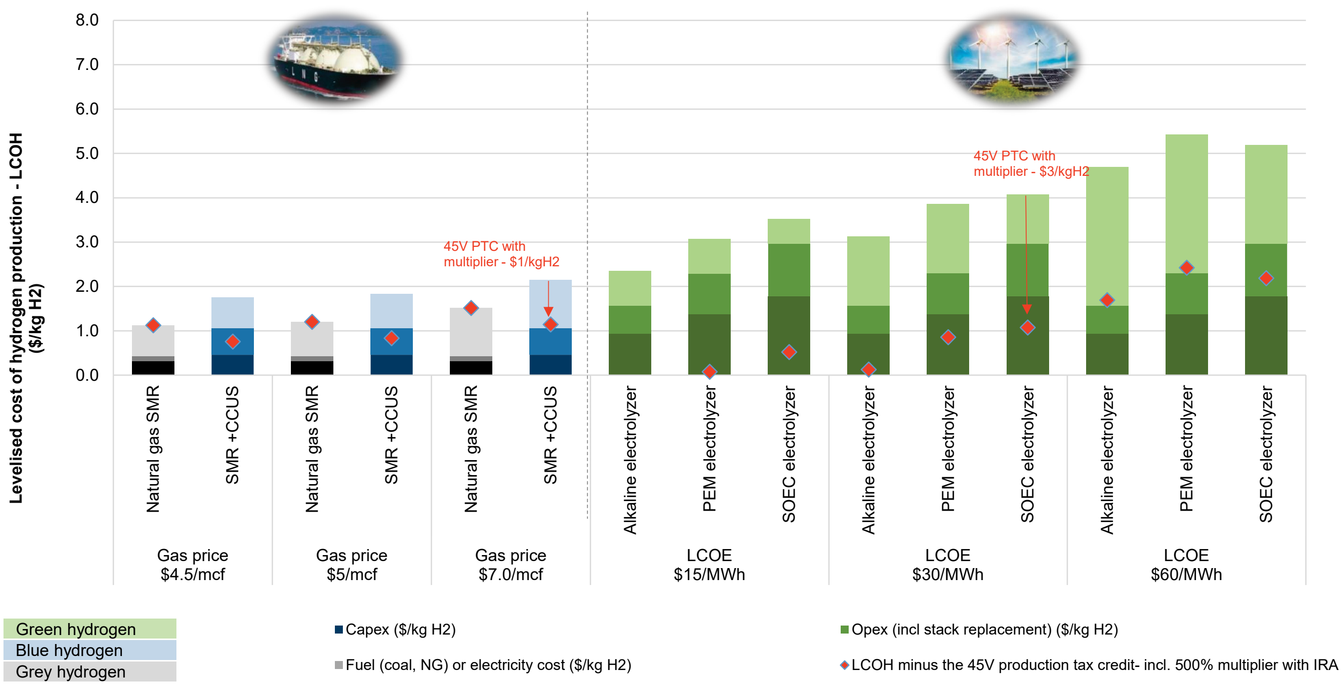
Hydrogen

US Inflation Reduction Act is transformational for the economics of clean hydrogen

Clean hydrogen PTC significantly improve the economics of Green Hydrogen and, more modestly, Blue Hydrogen. The IRA introduces a production tax credit (PTC) for clean hydrogen of up to $3/kg of hydrogen, provided lifecycle CO2-equivalent emissions are not greater than 4 kgCO2-eq/kg of hydrogen produced. The PTC applies to clean hydrogen produced after 2022 at a qualifying facility on which construction starts before 2033. Hydrogen must be produced in the US, in the ordinary course of the taxpayer's trade or business, and in compliance with other requirements as determined by the Secretary of the Treasury. The PTC appears to apply to all hydrogen produced in the US, even if such hydrogen is exported.

In the exhibit which follows, we illustrate the critical importance of PTC for clean hydrogen production economics. We present bars showing the levelised cost of producing brown, grey, blue and green hydrogen at various coal, natural gas and renewable power prices respectively without the use of any credits. We use a required cost of capital (IRR) of 8% for the purpose of this analysis and current costs of electrolysis equipment for green hydrogen. A $3/kgH2 production tax credit for green hydrogen (including the 500% multiplier) would make green hydrogen produced with a levelised cost of renewable power of <US$45/MWh (including their relevant PTC/ITC for renewables) already at cost parity with grey and blue hydrogen produced from natural gas at natural gas prices of c. US$7.5/mcf. **This effectively fully bridges the cost gap between grey (fossil based) hydrogen and green hydrogen from renewable power**.

Exhibit 104: The 45V production tax credit could prove to be a game-changer for clean hydrogen economics (both green and blue), bridging entirely the cost differential vs. grey hydrogen
Levelised cost of hydrogen production - LCOH ($/kgH2)



* LCOH figures based on current technology costs (ie. electrolysers) and with a required return of 8% (IRR). **45V PTC includes the multiplier impact. ***For blue hydrogen we assume up to 95% of the CO2 is captured.

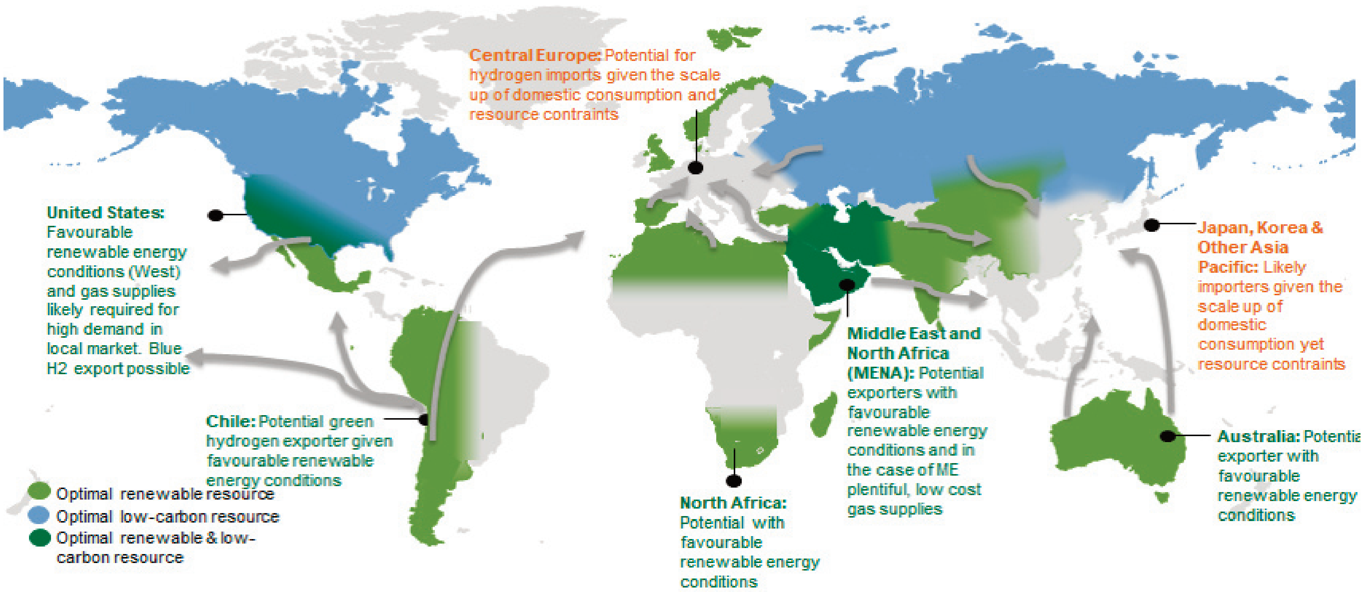
Source: Goldman Sachs Global Investment Research

The US is one of the few regions globally, where both 'blue', 'green' (and potentially also 'pink') hydrogen production appears attractive with respect to

economics and resource availability. For blue hydrogen, the availability of comparatively low-cost gas, in combination with carbon capture and onshore storage capabilities (lower cost than offshore), places the US in a key competitive position for the production and potential export of blue hydrogen. Similarly, low-cost renewable power availability in key parts of the US (solar and wind), combined with the tax credits available for the renewable power production (which can be used in addition to the 45V tax credit for hydrogen production), make green hydrogen competitive in key parts of the region (such as California), as shown in Exhibit 105. Overall, we estimate that c.30% of the global hydrogen market could end up being involved in international trade (cross-border transportation), with the US potentially also having a role in that market, depending on the level of domestic consumption. The 45V tax credits are available for all domestic production, including hydrogen volumes that are exported.

Exhibit 105: The US is one of the few regions globally where both 'blue' and 'green' hydrogen can be key competitive low carbon solutions, given the region's comparatively low cost gas and onshore CO2 storage capabilities, as well as low-cost renewable power sources in key parts of the country, for blue and green hydrogen respectively

Potential evolution of an international clean hydrogen market

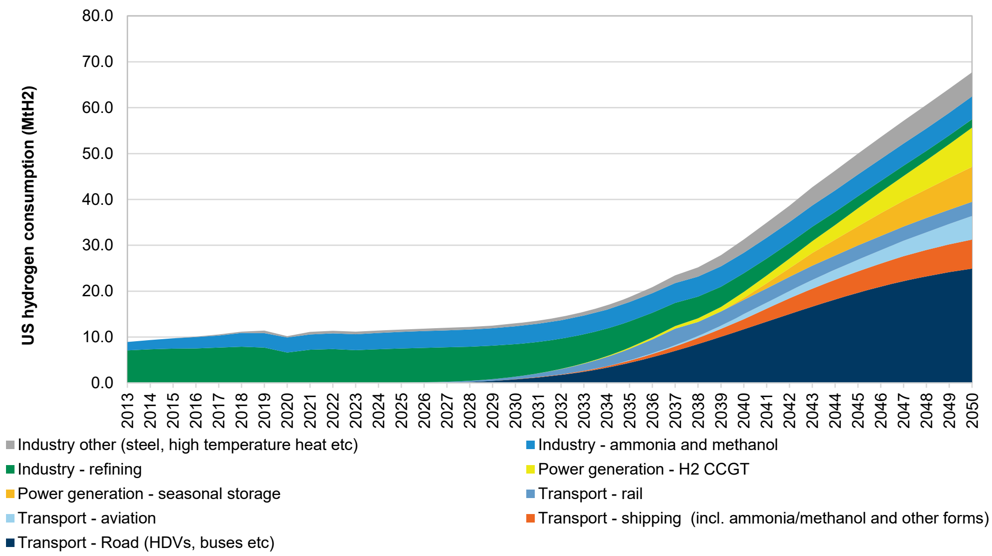


Source: Compiled by Goldman Sachs Global Investment Research

The rise of the US green hydrogen economy: Bridging the gap between energy sustainability and energy resilience

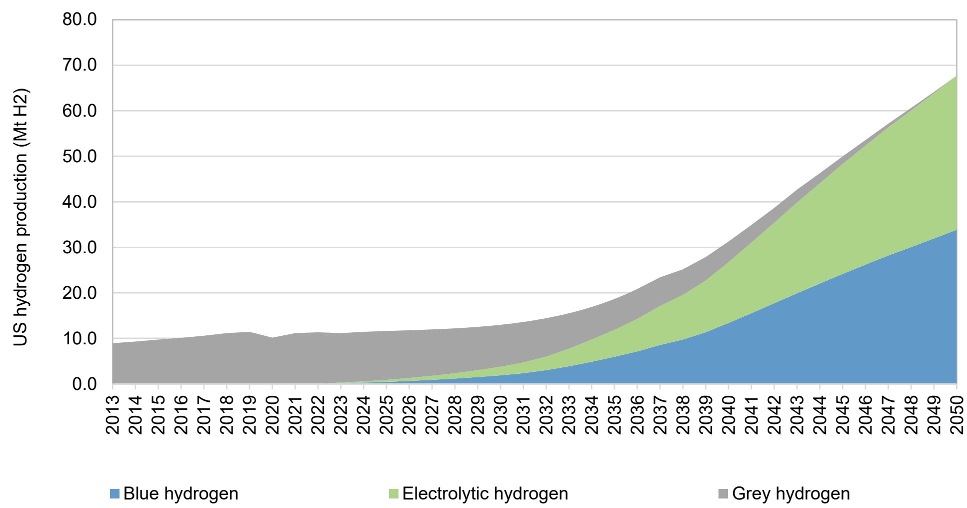
Hydrogen has a critical role to play in any aspiring energy evolution path which largely relies on the resilience of an increasingly electrified energy system dependent on renewable sources. Hydrogen has a wide range of applications across sectors including, but not limited to, its potential use as an energy vector and storage (seasonal) solution that can extend electricity's reach, industrial energy source and industrial process feedstock including 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. We estimate that clean hydrogen can constitute c.6% of US total final energy consumption, with its addressable market growing to c.70 Mtpa by 2050.

Exhibit 106: Our US energy evolution model sees total hydrogen demand increasing to c.70 Mtpa by 2050
Hydrogen consumption for US (Mtpa)



Source: EIA, Goldman Sachs Global Investment Research

Exhibit 107: We expect green hydrogen's share to increase from 0% in 2021 to 50% in 2050
Hydrogen consumption for US (Mtpa)



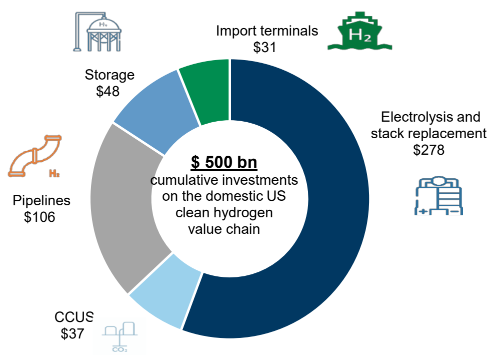
Source: Goldman Sachs Global Investment Research

Clean hydrogen creates a c $0.5 trn cumulative investment opportunity for US clean hydrogen supply chain

Our US energy path consistent with ambitions to reach net zero by 2050 laid out for hydrogen calls for $0.5 trn of cumulative investments in the US hydrogen value chain to 2050. This figure captures investments in the direct supply chain of clean hydrogen, including investments required for its production (electrolyzers and CCUS for green and blue hydrogen, respectively), storage, distribution, transmission and global trade (import terminals). We note this is solely domestic US capex investments in the direct supply chain of clean hydrogen and does not include capex associated with end markets (industry, transport, buildings) or upstream capex associated with the power generation plants required for electricity generation for green hydrogen.

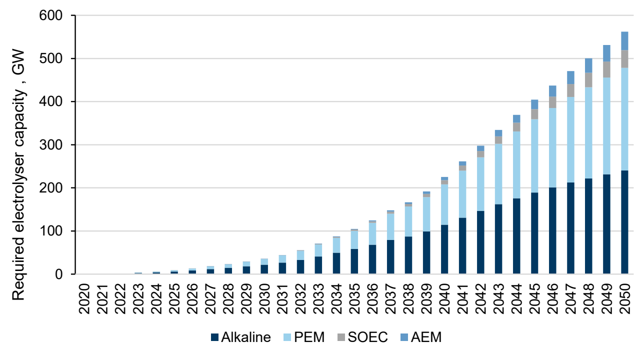
We estimate IRA clean hydrogen incentives at $50bn to 2032 and $120bn to 2041 based on our expectations that clean hydrogen demand will increase from <1 mn t in 2022 to 6 mn t by 2032 and 27 mn t by 2040. We assume 50/50 blue and green hydrogen, with blue hydrogen qualifying for $1/kg production credit and green hydrogen — for $3/kg. Given hydrogen production facilities built before 2033 are eligible for PTC for 10 years of operation, we assume tax incentives last until 2041 (facilities put into operation in 2032 receive last subsidies in 2041).

Exhibit 108: We estimate c.$0.5 trn of cumulative US investments will be required in the clean hydrogen supply chain to 2050...
Cumulative investments in the domestic US clean hydrogen value chain to 2050E (US bn)



Source: Goldman Sachs Global Investment Research

Exhibit 109: ...with electrolysis capacity making up the largest share of these investments
Installed electrolysis capacity required for US hydrogen consumption, GW



Source: US Department of Energy, Goldman Sachs Global Investment Research

Carbon capture

The cost of capture is highly process-specific with the US IRA tax credit amounts making carbon capture economically viable across a wider range of industries

The IRA substantially increases tax credits for direct carbon capture and more modestly for industrial carbon capture. The IRA increased the 45Q credit to $85 per tonne for carbon sequestration, $60 per tonne for carbon sequestration with utilization such as enhanced oil recovery (EOR), and $180 per tonne for direct air capture (DAC). Under prior law, the credits would max out at $50 per metric ton for sequestered carbon and $35 per ton for sequestered carbon with EOR in 2026. The US IRA extends the Carbon Capture Credit to carbon capture-qualified projects that begin construction prior to January 1, 2033. It also reduces the minimum capture thresholds required to qualify for the credit, and notably increases the credit value per metric ton of CO2, particularly for DACCS projects and projects that do not use the captured CO2 for enhanced oil recovery (EOR) as shown in the following exhibit.

Exhibit 110: The US IRA substantially increases the support for both industrial CCUS and direct air carbon capture (DACCS), with a higher credit rate, longer duration, greater payment type optionality, and captured volume thresholds

45Q Carbon capture Tax Credit							
Carbon capture source	**CO2 utilisation and storage**	**Tax credit previously** *(start construction by 2026)*	**Tax credit US IRA** *(start construction by 2033)*	**Payment type previously**	**Payment type US IRA**	**Min CO2 volume captured previously**	**Min CO2 volume captured US IRA**
		US$/kg CO2	*US$/kg CO2*			*ktpa*	*ktpa*
Industrial source	Utilized, EOR	up to $35	up to $60	Tax credit for all 12 years of incentive	Direct payment for first 5 years and then tax credit for remaining 7 OR Tax credit for all 12 years	Industrial: 100 ktpa Power: 500 ktpa DACCS: 100 ktpa	Industrial: 12.5 ktpa Power: 18.8 ktpa DACCS: 1 ktpa
Industrial source	Direct sequestration	up to $50	up to $85				
Direct Air Capture	Utilized, EOR	up to $35	up to $130				
Direct Air Capture	Direct sequestration	up to $50	up to $180				

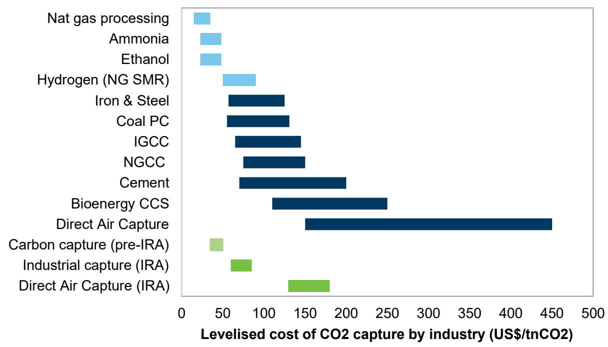
* The credit rates presented in this table are subject to the condition that certain prevailing wage/apprenticeship and other requirements are satisfied. These requirements are laid out in the official Act document.

Source: The Senate of the United States, Goldman Sachs Global Investment Research

Cost curve suggests most impactful for fertilizer/petchem capture, select direct air capture opportunities. In Exhibit 111, we show our estimated per metric ton cost ranges of CCS for different industries, according to data from the Global CCS Institute. On a global basis, the median cost of CCS for the majority of these industries is much higher than the $85/ton 45Q credit. In the US, many of the carbon capture opportunities being pursued are with industrial plants (ethanol, petrochemicals, steel), which could lead to an acceleration in investment. Additionally, the new higher threshold for direct air capture is likely to be supportive, but cost reductions/scale will be key. **We estimate that additional IRA incentives compared to pre-IRA can account for 30%-60% of the cost of direct air capture (maximum impact is achieved at minimum $150/t levelized cost of DACCS and extra $95/t IRA incentive), 20%-40% for cement, iron & steel and power generation (NGCC, IGCC) and 70%-10% for ethanol/ammonia production, implying most impact for fertilizer/petchem capture.**

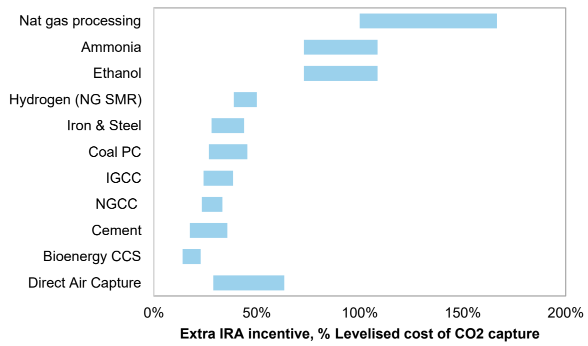
One key factor in determining the cost of capturing is the concentration of carbon in the flue gas that is produced in the industrial combustion process. Other factors include the distances between capturing sites and storage sites (pipeline cost and carbon compression cost) and types of storage site used (onshore vs. offshore).

Exhibit 111: Global carbon capture cost curve and old/new US incentives for carbon capture with sequestration



Source: Global CCS Institute, Goldman Sachs Global Investment Research

Exhibit 112: Cost curve suggests most impactful for fertilizer/petchem capture, select direct air capture opportunities
Extra IRA incentive, % Levelised cost of CO2 capture

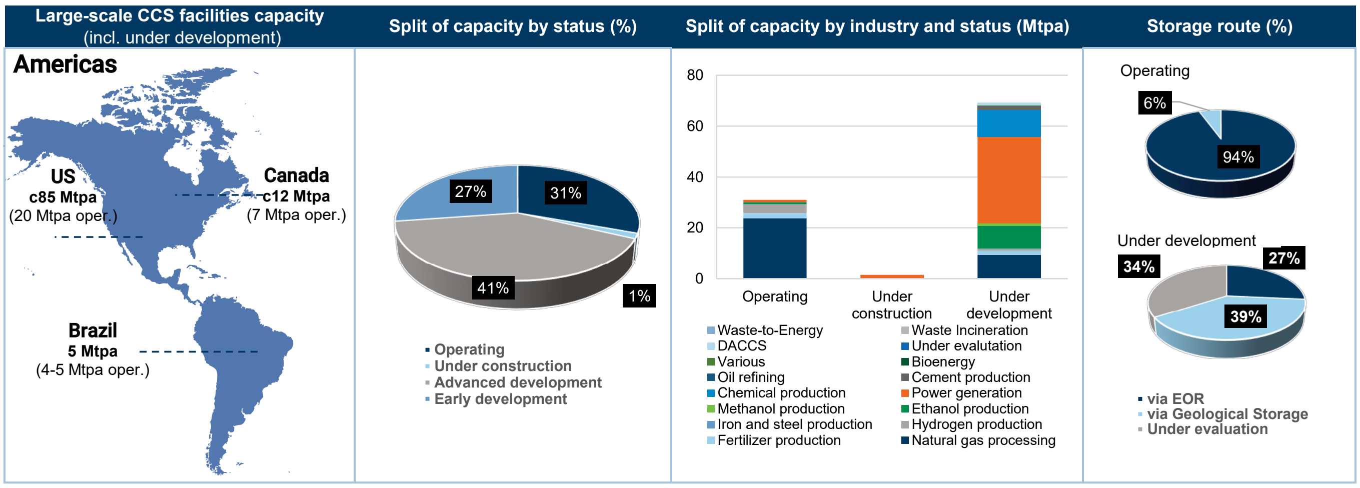


Source: Global CCS Institute, Goldman Sachs Global Investment Research

The revival of the carbon capture industry: We identify more than 100Mtpa of large-scale projects in the pipeline in the US

Despite their critical role to any aspirational path aiming to reach net zero by 2050, carbon capture technologies have been to date largely under-invested. We nonetheless believe in the return of interest in the technology, following a lost decade, with more projects under development. Currently, we identify more than 25 commercial scale CCS facilities operating globally (mostly in the US, Canada, the UK and Norway), with total capacity around 40Mtpa. We believe the US could be a region of key competitive cost advantage in carbon capture, owing to its onshore carbon storage and utilisation capabilities. Moreover, we are already starting to see a large portion of the current CCS projects pipeline focusing on new processes capture, such as power generation, industrial processes including chemicals, cement, oil refining and hydrogen production, as opposed to the traditional natural gas processing industrial separation. Overall, **we identify >60Mtpa of large-scale projects in the pipeline in the US, with another 40 mtpa pipeline for projects of smaller-scale and pilot plants.**

Exhibit 113: The United States could become one of the lagrest carbon capture and storage hubs globally, with a pipeline of large-scale industrial projects already in the pipeline and under development.



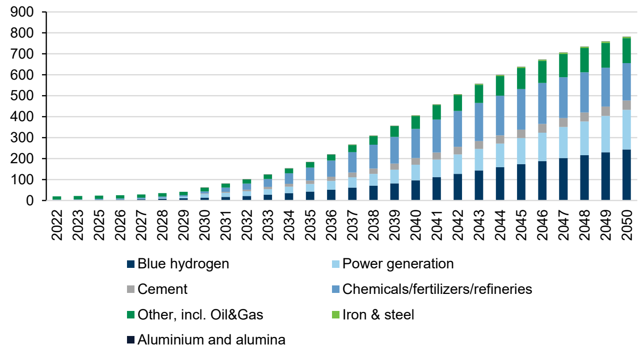
Source: Global CCS Institute CO2RE, data compiled by Goldman Sachs Global Investment Research

We model >100 mt of carbon captured by 2032 and >700 mn t by 2050 driven by power generation, blue hydrogen and industrial applications

We expect carbon capture to pick up sharply, primarily driven by power generation and blue hydrogen production. Currently, there are c.20 mn t of carbon capture facilities operating in the US, majority of which (85%) capture CO2 from Oil & Gas operations, which are then either sold to industrial facilities or injected into the subsurface to boost oil recovery (enhanced oil recovery (EOR) technique). We expect carbon-captured volumes to increase dramatically to c.100 mn t by 2032 and 780 mn t by 2050, primarily driven by carbon-capture technology adoption in power generation, blue hydrogen production and industry. We see most carbon-capture facilities under development **in the power generation sector,** where coal/gas-fired power plants are adding carbon-capture facilities to reduce the CO2 footprint. We currently model c.5% of 2050 power generation mix being from natural gas power plants combined with CCUS facilities (540 TWh). Assuming c.0.4 t CO2/MWh of natural gas power generation, and a 90% capture rate, this implies c.190 mn t of carbon captured during natural gas generation by 2050. **For clean hydrogen,** we expect c.70 mtpa of production by 2050, with 50% being green hydrogen and 50% blue hydrogen. Hydrogen produced from natural gas via steam reforming emits c.10 kg of CO2 per 1 kg of hydrogen, so a 90% capture rate would imply >200 mn t of carbon captured from blue hydrogen production. **In the industrial sector, chemicals drive the biggest increase of carbon capture facilities** — we assume natural gas coupled with CCUS accounts for c.30% of energy & non-energy chemicals consumption, resulting in c.170 mn t of CCUS facilities by 2050. **Overall, our US energy path is consistent with ambitions to reach net zero by 2050, and as laid out for carbon capture calls for $250 bn of cumulative investments to 2050.**

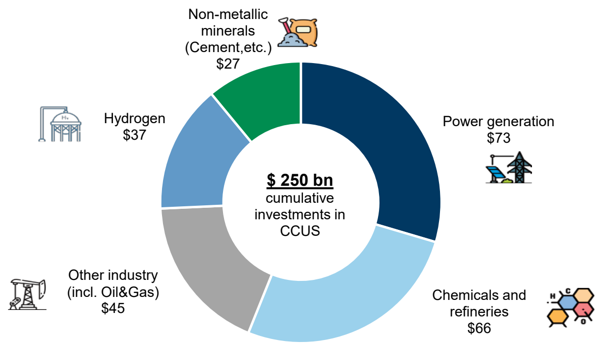
We estimate IRA incentives for carbon capture at >$30bn to 2032, based on our expectations that US carbon capture facilities will increase from c.20 mn t in 2022 to 100 mn t by 2032 and 400 mn t by 2040. We assume a growing share of early stage direct air capture and sequestered CO2 driving an increase in average carbon capture credits from c.$60/t (given a majority of current CCUS facilties sequester CO2 with EOR) to $75/t by 2032 and $80/t by 2040. Given carbon capture facilities built before 2033 are eligible for PTC for 12 years of operation, we assume tax incentives last to 2043 (facilities put into operation in 2032 receive the last subsidies in 2043). According to the Congressional Budget Office, 45Q credits for CCUS are estimated to cost $3.2 bn to 2032. We note, however, that the CBO assumptions on tax credit usage are largely based on historical trends, and with an acceleration in technology development, federal spending on CCUS tax credits would be expected to rise substantially.

Exhibit 114: We expect carbon capture to pick up sharply, to >100 mtpa by 2035 and >700 mn t by 2050
US carbon captured, mn t by industry



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

Exhibit 115: We estimate c.$250 bn of cumulative US investments will be required in CCUS to 2050...
Cumulative investments in the domestic US CCUS to 2050 ($ bn)



Source: Goldman Sachs Global Investment Research

Bioenergy

Biogas, advanced biofuels, renewable waste and biomass all have their key roles in the energy transition of specific industries

Bioenergy is already an important part of US energy consumption, mostly in the form of solid biofuels (primarily used in buildings and industry) as well as road biofuels blended in road transport. We see biogas, advanced biofuels (including both road biofuels and sustainable aviation fuel -SAF) as well as solid biofuels and RES waste as continuing to have an important role in the US energy system. While currently ethanol makes up c.80% of liquid biofuels consumption, we expect its share to decline as consumption of advanced biofuels and SAF picks up. We expect the SAF share in aviation fuels to expand from 0% in 2021 to almost 100% in 2050, reaching c.515 mn bbl pa of consumption by 2050 (compared to close to zero in 2021 and 571 mm bbl pa jet & kerosene consumption).

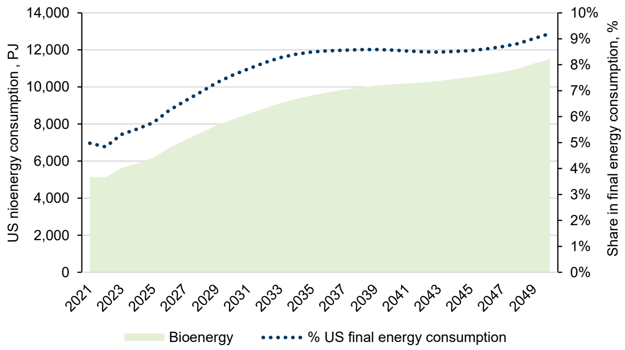
IRA: switching from BTC to fuel production credit in 2025

IRA extends BTC to the end of 2024 and switches incentives to production credit from 2025. The IRA extends the $1/gal Biodiesel Blender's Tax Credit (BTC) for two additional years (2023-24), providing near-term policy certainty for producers of renewable diesel and biodiesel. In 2025 under the IRA, the BTC switches to become a clean fuel production credit (45z credit), providing domestic biofuels producers a tax credit based on the emission factor of their renewable fuels. The 45z credit under the IRA is in place for 2025-27. Further, the IRA introduces specific, higher credit values, under both the BTC and 45z, for aviation fuel, providing incremental policy support for the still-nascent sustainable aviation fuel (SAF) market.

We estimate IRA incentives for biofuels at $15 bn by 2027. Currently, consumption of biodiesel and renewable diesel is at 75 mn bbl pa (c.2% of road fuel consumption), which we estimate to almost double to 130 mn bbl pa by 2027. Production of biodiesel/RD is estimated at c.60 mn bbl pa in 2022. Currently, there are >100 mn bbl of biofuels capacity additions announced to 2030, and we believe the majority of biofuels consumption will be met with domestic production. We estimate IRA incentives for biofuels at $15 bn by 2027, with majority of spending (c.$13 bn) being directed to renewable/biodiesel and the rest directed to SAF given current consumption and production of SAF are close to zero, which we model increasing to 20 mn bbl pa by 2027.

SAF: still-nascent technology with significant long-term opportunity. Jet fuel demand is one of the single hardest areas of liquid fuel demand to decarbonize and presents significant long-term opportunity (571 mm bbl pa jet & kerosene consumption in the US in 2022). Still, we note uncertainties remain around feedstock availability, and technology being in very early stages, to make project economics attractive. IRA incentives (up to $1.75/gallon depending on SAF emissions intensity) reduce price difference between conventional fuel and SAF (which is currently 2x-4x more expensive than conventional jet fuel), still not eliminating it entirely. Therefore, we believe IRA is supportive for the technology, but it still requires technological advancements to lower overall cost before wider adoption. We currently estimate SAF consumption at 30 mn bbl by 2030 (c.5% of total jet demand), with major demand uplift coming after 2035.

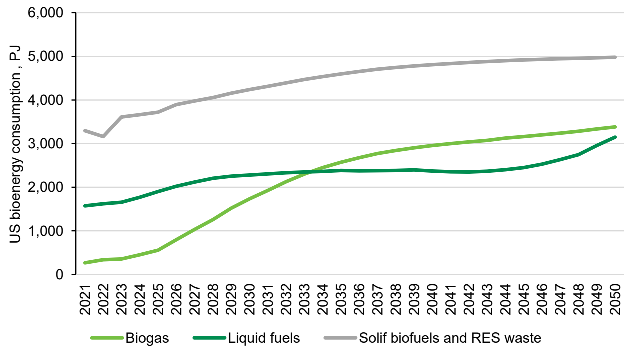
Exhibit 116: We expect US final bioenergy consumption to continue to increase from here on the path to net zero..
US bioenergy final energy consumption (PJ)



*Including international aviation and international maritime bunkers

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

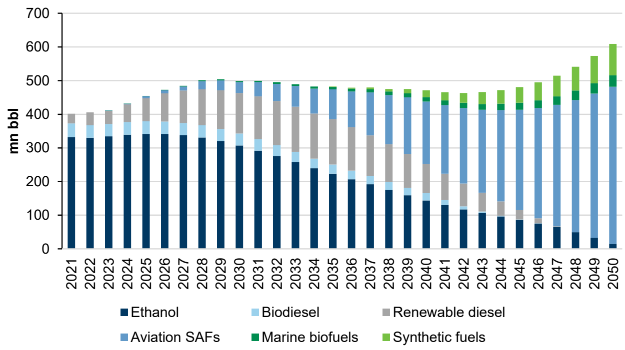
Exhibit 117: ...primarily driven by growth in biogas and advanced biofuels (in particular SAF)
US final energy consumption split by bioenergy product (PJ)



*Including international aviation and international maritime bunkers

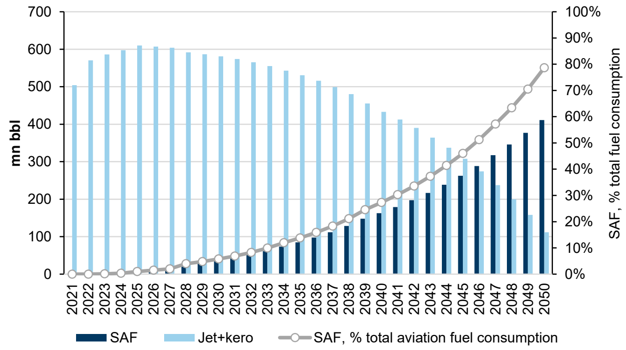
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 118: We expect production of renewable diesel to expand with sequential decline after 2040 as electrification picks up, while SAF is set for long-term production expansion
US liquid biofuels consumption, mn bbl



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

Exhibit 119: We expect SAF's share in aviation fuels to expand from 0% in 2021 to c.80% in 2050
Aviation fuels consumption, mb bbl and SAF share, %



Source: Goldman Sachs Global Investment Research

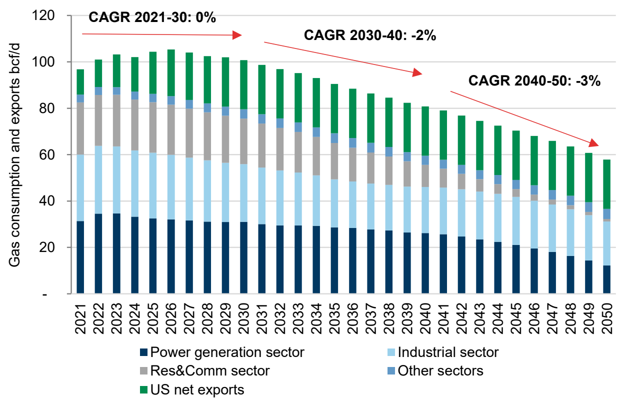
The role of hydrocarbons: Oil and gas demand to decline by 2030

Whilst the US's energy transformation should undoubtedly lead to a reduction in the consumption of hydrocarbon energy sources over time, we note that the outlook across hydrocarbons differs depending on the end consuming sectors (markets) they serve, and their respective pace of energy transformation, as well as their respective carbon contents. In this section, we address the outlook and implications resulting from the energy consumption profiles for natural gas, oil and oil products and coal for the region, in light of the current geopolitical landscape and disruptions.

Natural gas: Demand decline acceleration post 2030E, but much more resilient than oil

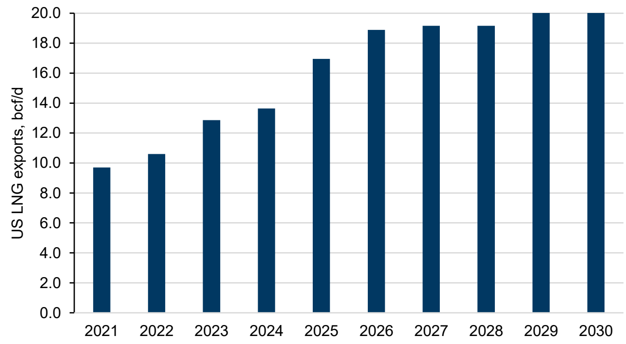
Gas consumption flat until 2030E, decline acceleration post 2030E, but quite resilient. Power generation (37%), the industrial sector (33%) and the residential & commercial sector (26%) are the largest consumers of gas in the US. In power generation, we estimate gas demand is set to decline from 30 bcf/d to 12 bcf/d in 2050, given replacement with RES generation, although the fall will likely be somewhat compensated with natural gas+CCUS plants, which we estimate will account for 5% of the 2050 power generation mix. The Industrial sector is one of the hard-to-abate areas, as its gas uses include non-energy consumption applications, such as feedstock for chemicals manufacturing. Moreover, we believe there could be upside to our US industrial gas demand forecast if the US increased its global market share of heavy industries, due to its energy cost advantage, and new IRA incentives moving industrial capital to the US from other parts of the world. In the residential & commercial sector, we estimate that gas will be almost fully replaced by the use of electricity, given the expected widespread installation of heat pumps, development of residential solar, etc. Overall, we expect domestic gas demand to decline at a c.3% CAGR in 2030-2040 and at a 4% CAGR to 2050, reducing from 89 bcf/d in 2022 to 37bcf/d in 2050E. Gas net exports from the US, primarily driven by LNG capacity additions, are set to grow from 11 bcf/d in 2022 to >20 bcf/d by 2030E, cushioning the overall impact from US gas consumption; exports are set to decline at a c.2% CAGR through 2030-40E and at a 3% CAGR to 2050E.

Exhibit 120: Gas consumption flat until 2030E, decline acceleration post 2030E, but quite resilient vs. oil
Total gas consumption and exports, bcm, US



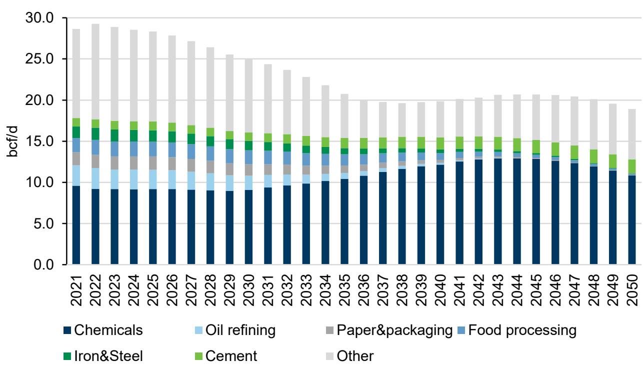
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 121: US LNG exports are set to double to 20 bcf/d
US LNG export capacity, bcf/d



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

Exhibit 122: Industrial gas demand expected to be resilient, primarily driven by limited replacement in chemicals industry
Industrial gas demand 2021-2050, bcf/d, US

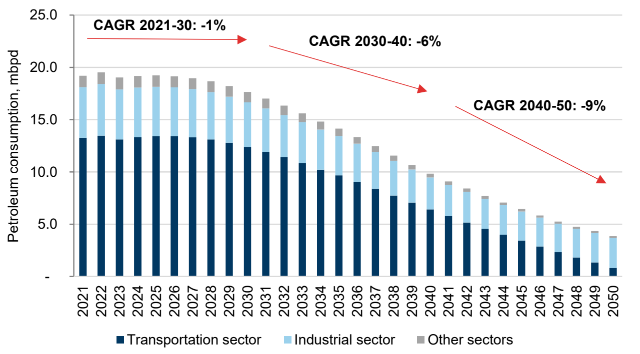


Source: EIA (historical), Goldman Sachs Global Investment Research

Oil and petroleum products: Demand decline acceleration post 2030

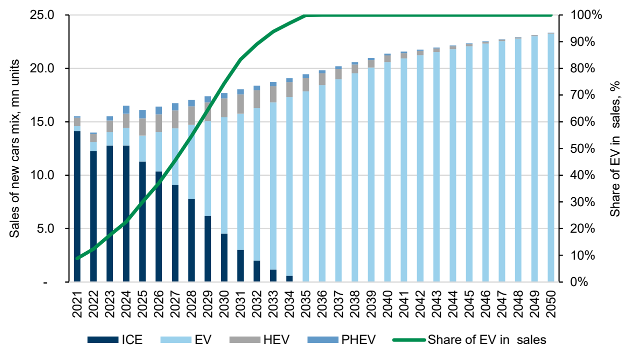
Oil demand flat to 2030E, demand decline acceleration post 2030E. Transport accounts for 70% of oil consumption in the US, and the adoption of EVs is crucial for oil demand development. We estimate oil consumption to 2030 will remain resilient, with 2030 oil consumption at 17.7 mbpd, compared to c.20 mbpd in 2022. Post 2030, we see oil demand declining on higher share of EVs in the fleet and better charging infrastructure: we estimate oil demand declining to 10 mbpd by 2040 and to 4 mbpd by 2050. We estimate the EV share of the total fleet by 2030 to be at 20%, having a limited impact on oil demand. Post 2030, however, the share of EVs in the total fleet is set to increase significantly: we expect to 75% by 2040E and 100% by 2050E. We estimate that 1 EV car replacing one ICE car in the total fleet leads, on average, to an 11 barrels pa oil demand reduction. As such, 1 mn extra usint sales of EV cars should lead to an 11 mn barrels pa (30 kbpd) reduction in oil consumption. It is worth noting, however, that oil demand does not reach absolute zero by 2050E, given oil's use in non-energy consumption applications, such as a feedstock for chemicals manufacturing.

Exhibit 123: Oil demand flat to 2030E, demand decline acceleration post 2030E
Total petroleum products consumption, mbpd, US



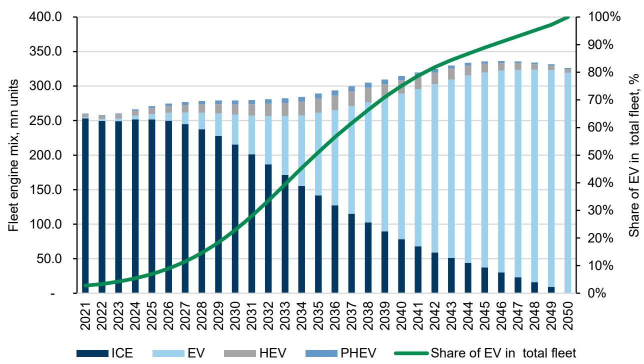
Source: EIA (historical), Goldman Sachs Global Investment Research

Exhibit 124: While we expect the share of EVs in car sales to grow significantly to 2030E (from 10% in 2021 to 75% by 2030E)...
Car sales mix, US



Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

Exhibit 125: We estimate EV share in total fleet by 2030E to be at 20%, having a limited impact on oil demand; post 2030E, however, the share of EVs in the total fleet in set to increase significantly: we expect 75% by 2040 and 100% by 2050
Car fleet mix



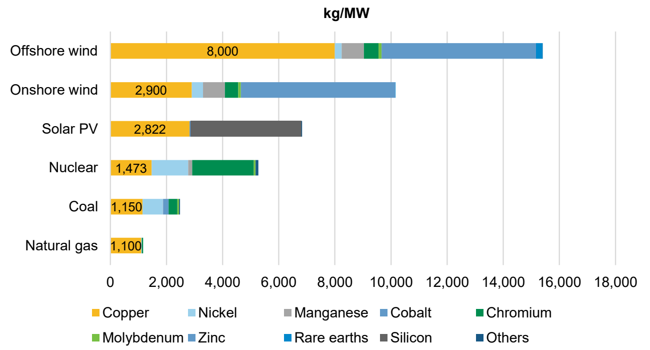
Source: US Bureau of transportation statistics, Goldman Sachs Global Investment Research

The potential implications for metals demand

At the heart of the path to net zero USA by 2050 lies the need for access to clean energy and an accelerated pace of electrification for transport and several segments of industry, as we outline in the previous sections of this report. Electrification and clean energy is likely to have an impact on total US 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 USA by 2050, 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 gasoline vehicles).

For base metals, we expect a 35%/20% incremental uplift from green capex to copper/aluminium demand in the coming decades. According to the IEA, solar/wind generation capacities require 2.5x-7x more copper than gas/coal, with offshore wind being the highest in copper intensity, requiring 8t of Cu per MW of capacity compared to 1t for gas/coal. EV cars require >2x copper than conventional cars, according to the IEA. **We find that incremental copper demand from low-carbon technologies amounts to 0.8 Mtpa in 2023-2050 on average, a c.35% increase from US copper demand in 2022** (2.2 mn t), with half of increase coming from EVs and the rest from renewables. Similarly, as shown in the exhibits that follow, we expect the electrification trend to lead to a material increase in demand for aluminium as well. According to CRU (link), plug-in hybrids and EVs require 25%-27% more aluminium than ICE cars (160 kg/vehicle). In solar/wind, our commodities team estimates c.7.5t/MW of aluminium required for solar panel and c.1t/MW for wind turbine. **We find that incremental aluminium demand from low-carbon technologies amounts to 1.2 Mtpa in 2023-2050 on average, a c.20% increase from US aluminium demand in 2022** (5.5 mn t), with 55% of increase coming from EVs and the rest from renewables.

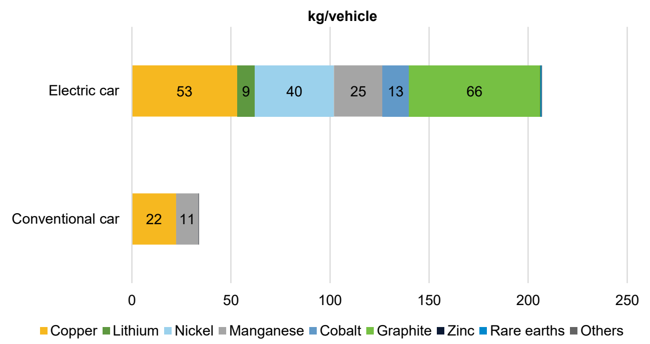
Exhibit 126: Solar/wind generation capacities require 2.5x-7x more copper than gas/coal
Minerals used in clean energy technologies compared to other power generation sources



Does not include steel/aluminium analysis.

Source: IEA

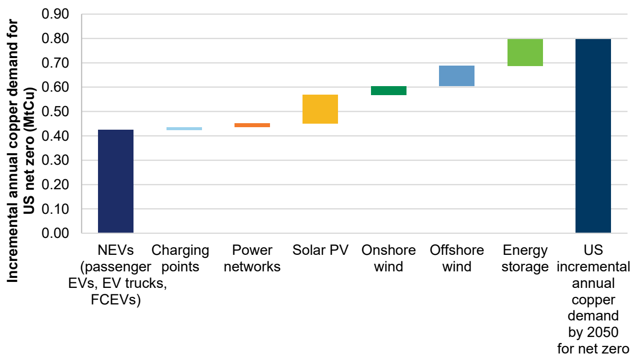
Exhibit 127: EVs require >2x copper than conventional cars
Minerals used in electric cars compared to conventional cars



Steel and aluminium not included. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode

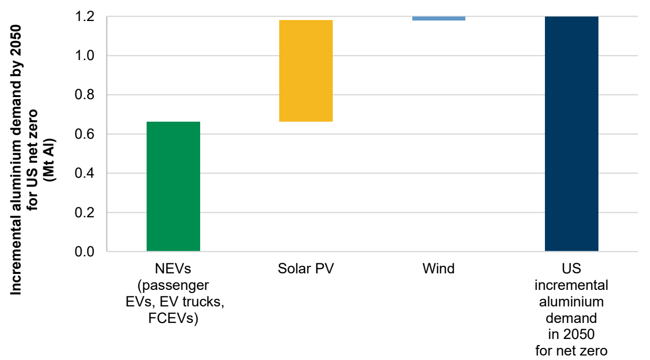
Source: IEA

Exhibit 128: We estimate c.0.8 Mt incremental average annual copper demand by 2050 for US net zero, representing a c.35% increase from US annual copper consumption in 2022...
Incremental copper demand in 2050 for US net zero



Source: IRENA, International Copper Association, Goldman Sachs Global Investment Research

Exhibit 129: We estimate c.1.2 Mt incremental aluminium demand by 2050 for US net zero, representing a c.20% increase from US annual aluminium consumption in 2022
Incremental aluminium demand by 2050 for US net zero (Mt Al)

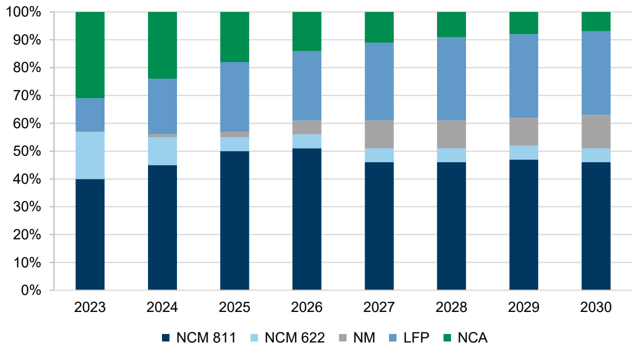


Source: IRENA, World Bank, Goldman Sachs Global Investment Research

For battery metals such as lithium, nickel and cobalt we expect demand growth by several folds. Demand profile for nickel, cobalt and lithium will to major extent depend on the mix of EV battery types adoption. We currently model a gradual increase in the share of LFP batteries which do not contain nickel or cobalt, in line with automakers' comments that they intend to increase the share of LFP batteries in their EVs (link). We find that incremental nickel demand from EVs amounts to 440kt in 2023-2050 on average, 3x increase from US nickel demand in 2022. For cobalt and lithium (LCE), we find incremental demand at 70kt (c.5x increase) and 700kt (c.12x increase), respectively.

Exhibit 130: We currently model a gradual increase in the share of LFP batteries in line with automakers' comments that they intend to increase share of LFP batteries in their EVs

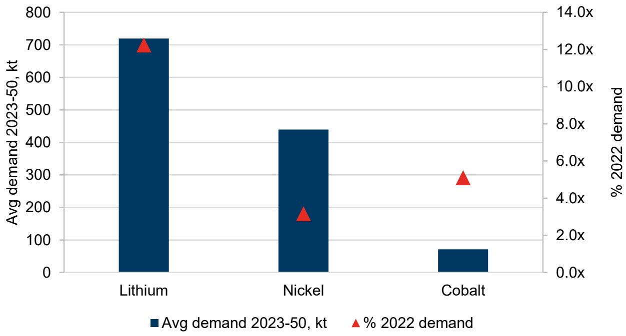
EV battery by type mix in US, %



Source: Goldman Sachs Global Investment Research

Exhibit 131: Lithium to be the biggest beneficiary given content of lithium of similar across battery types

Lithium, cobalt, nickel demand increase



Source: Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Michele Della Vigna, CFA, Yulia Bocharnikova, Brian Lee, CFA, Neil Mehta, Brian Singer, CFA, Enrico Chinello, Ph.D., Nikhil Bhandari, Jerry Revich, CFA, Mark Delaney, CFA, Joe Ritchie, Adam Samuelson, Emily Chieng, CFA, Ati Modak, Adam Bubes, CFA and Vivek Srivastava, 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	47%	37%	16%	64%	58%	48%

As of January 1, 2023, Goldman Sachs Global Investment Research had investment ratings on 3,201 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. **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) 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, 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.