Goldman Sachs Research

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Carbonomics

Tariffs, deglobalization and the cost of decarbonization

Our updated Carbonomics cost curve considers >100 different applications for decarbonization tech across key emitting sectors, reflecting technological innovation and a growing push for local supply chains and tariffs. Our four key conclusions:

Innovation delivers, but is two-speed this year: Technological innovation continues to lower the decarbonization cost curve as the lower half of the cost curve moves down on average by 7% yoy. However, more-expensive technologies in hard-to-abate sectors are becoming more expensive. This is our fifth Carbonomics cost curve, and technological innovation has delivered a cumulative 45% decline for the lower 50% of the cost curve since 2019.

Batteries, solar and biofuels drive decarbonization costs down; decarbonizing industry remains most challenging: Batteries see the most cost improvement, lowering the cost of decarbonizing passenger transport and the cost of solar paired with battery storage by 30%+. Standalone **solar power generation** costs have fallen 12% yoy, while biofuels have become 40% cheaper. Conversely, **we see little progress** in industry, mostly on a lack of progress with hydrogen-dependent technologies.

Deglobalization could add 30% to decarbonization costs: Some clean technologies are manufactured locally (bio-energy, grids, electrolysers), but others have a dominant, global, low-cost supplier (solar, batteries) that continues to gain cost competitiveness, raising questions over the benefits of local manufacturing vs. imports. We flex our Carbonomics cost curve, measuring the cost of decarbonization based on the lowest-cost global supplier, vs. local production in the US/Europe. This shows that a 115%/55% average import tariff is needed for Western clean tech production to be competitive in solar panels/batteries, and would result in a 30% rise in the Carbonomics cost curve.

Lower gas prices would foster de-carbonization and lower the power Carbonomics cost curve by 20%: In view of growing LNG supply from 2026 and a potential restart of Russian gas flows lowering gas prices, we find that the benefit of accelerated coal-to-gas switching more than offsets the negative impact on renewable economics

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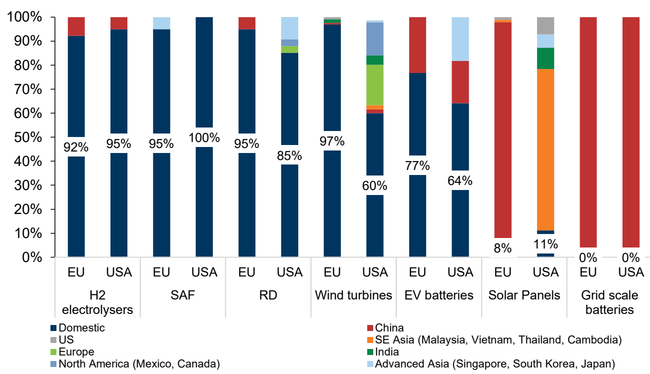
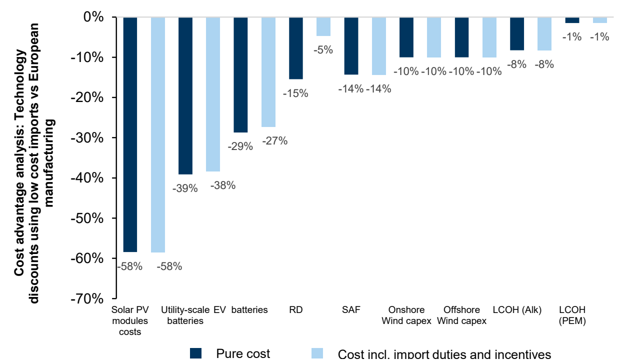
Carbonomics in 12 charts

Exhibit 1: Some clean technologies are largely manufactured locally (bio-energy, grids, electrolysers), but others have a dominant global low-cost supplier (solar, batteries)...
Technology deployment in EU and US (domestic vs. imported)



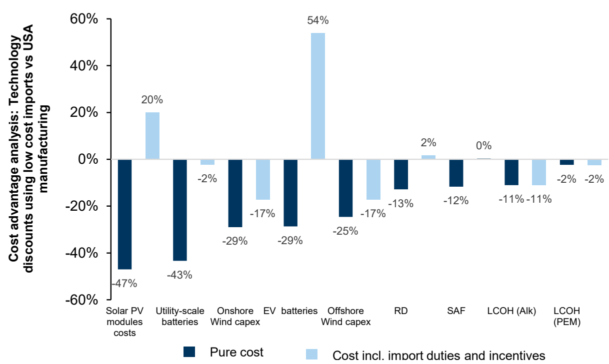
Source: Data compiled by Goldman Sachs Global Investment Research

Exhibit 2: ...that continues to gain cost competitiveness with production costs up to 60% cheaper in China, vs. Western local manufacturing
Technology cost discounts of low-cost imports vs. European manufacturing



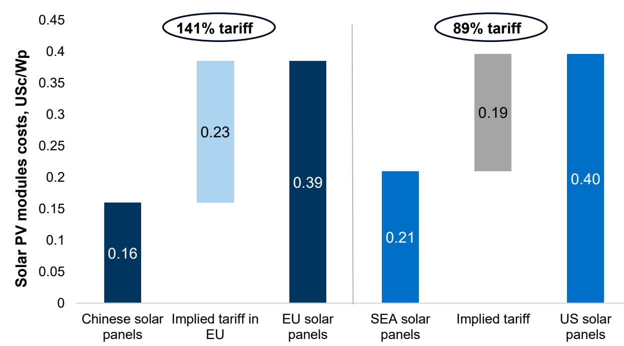
Source: Goldman Sachs Global Investment Research

Exhibit 3: IRA incentives and tariffs can significantly impact relative cost positioning, with local EV battery manufacturing in the US being the most prominent example
Technology cost discounts of low-cost imports vs. USA manufacturing



Source: Goldman Sachs Global Investment Research

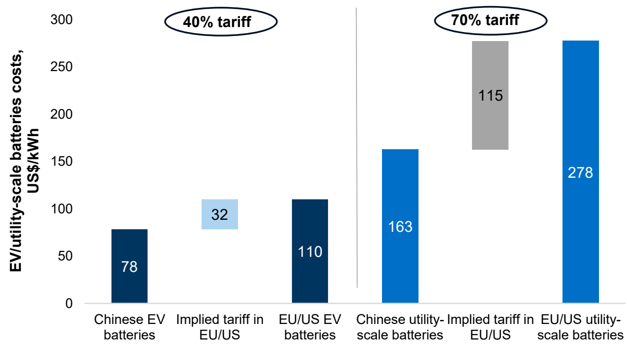
Exhibit 4: Our analysis implies a 115% average import tariff is needed for Western clean tech production to be competitive in solar panels...
Cost of Chinese imports and EU/US production and implied tariff needed for parity, USc/Wp



Source: Goldman Sachs Global Investment Research

Exhibit 5: ...and a 55% average tariff for EV batteries

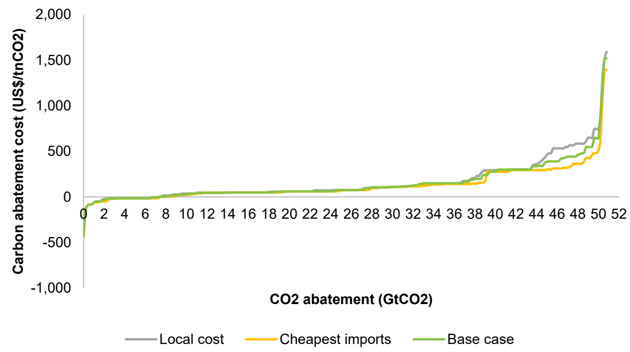
Cost of Chinese imports and EU/US production and implied tariff needed for parity, $/kwh



Source: IEA, Goldman Sachs Global Investment Research

Exhibit 6: Deglobalization could add 30% to the cost of decarbonization

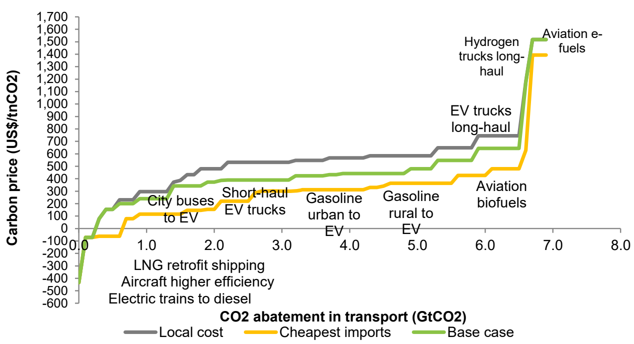
Carbon abatement cost curves for anthropogenic GHG emissions, three scenarios



Source: Goldman Sachs Global Investment Research

Exhibit 7: In transport, investment costs to decarbonize are c.40% lower for cheapest imports vs. local cost production

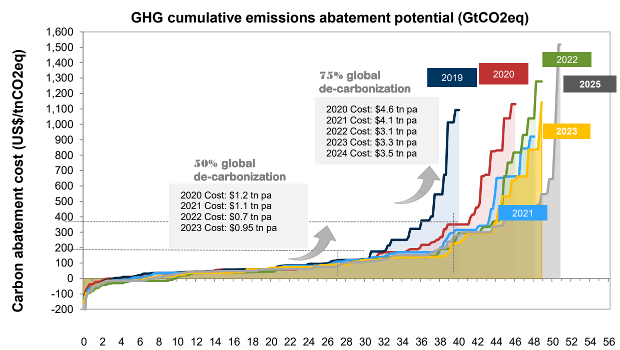
Carbon abatement cost curve for anthropogenic GHG emissions in transport sector, three scenarios



Source: Goldman Sachs Global Investment Research

Exhibit 8: Price of decarbonizing the first 50% of cost curve decreases by 7% on utility-scale batteries and solar advancements, while 75% of decarbonization costs go up by 5%

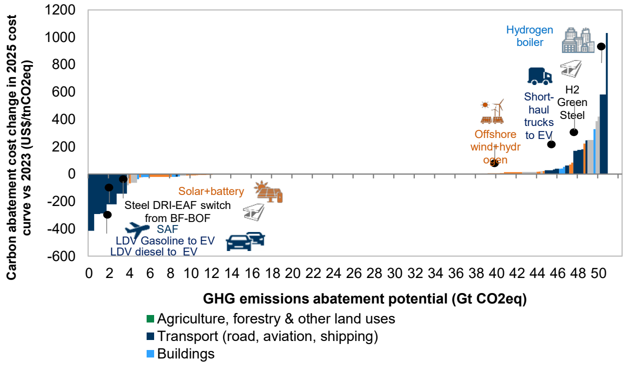
2025 vs. 2023/2022/2021/20/19 comparable carbon abatement cost curves for anthropogenic GHG emissions



Source: Goldman Sachs Global Investment Research

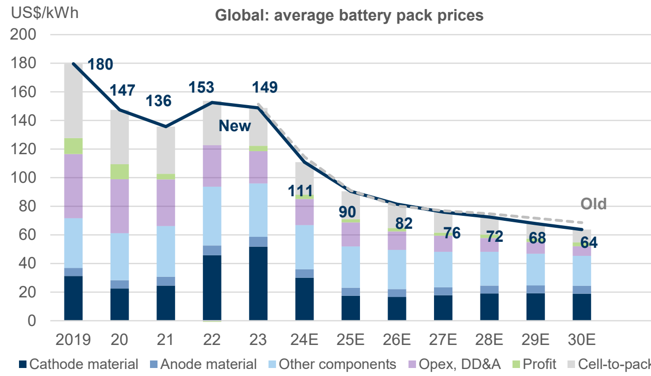
Exhibit 9: Passengar cars, biofuels, solar paired with utility-scale batteries show the biggest cost improvements yoy; hydrogen-dependent technogies and heavy transport show the biggest increase yoy

Carbon abatement cost change in the 2025 Carbonomics cost curve vs. 2023 by technology (US$/tnCO2)



Source: Goldman Sachs Global Investment Research

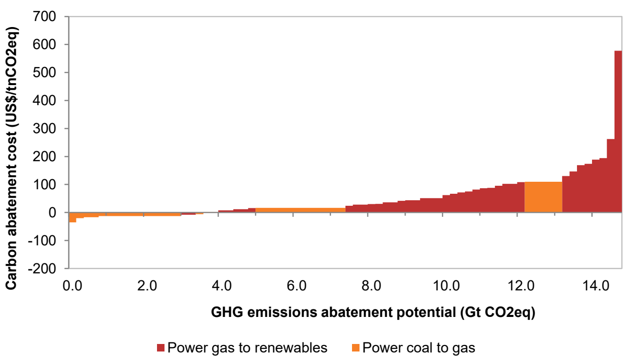
Exhibit 10: We remain constructive on battery demand in the medium term, as technological advancements contribute to lower battery prices



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

Exhibit 11: In view of growing LNG supply from 2026 and a potential restart of Russian gas flows lowering gas prices, we find that the benefit of accelerated coal-to-gas switching...

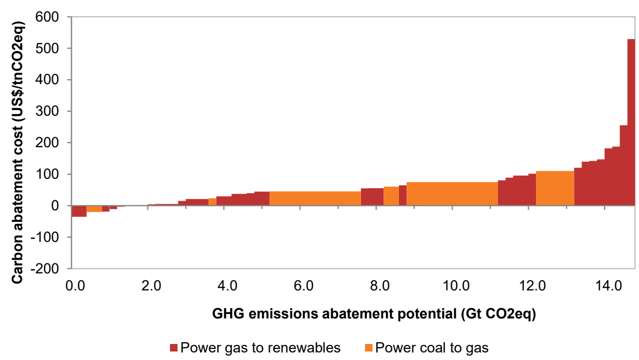
2025 conservation carbon abatement cost curve for power generation GHG emissions: lower gas prices scenario



Source: Goldman Sachs Global Investment Research

Exhibit 12: ...more than offsets the negative impact on renewable economics

2025 conservation carbon abatement cost curve for power generation GHG emissions: higher gas prices scenario

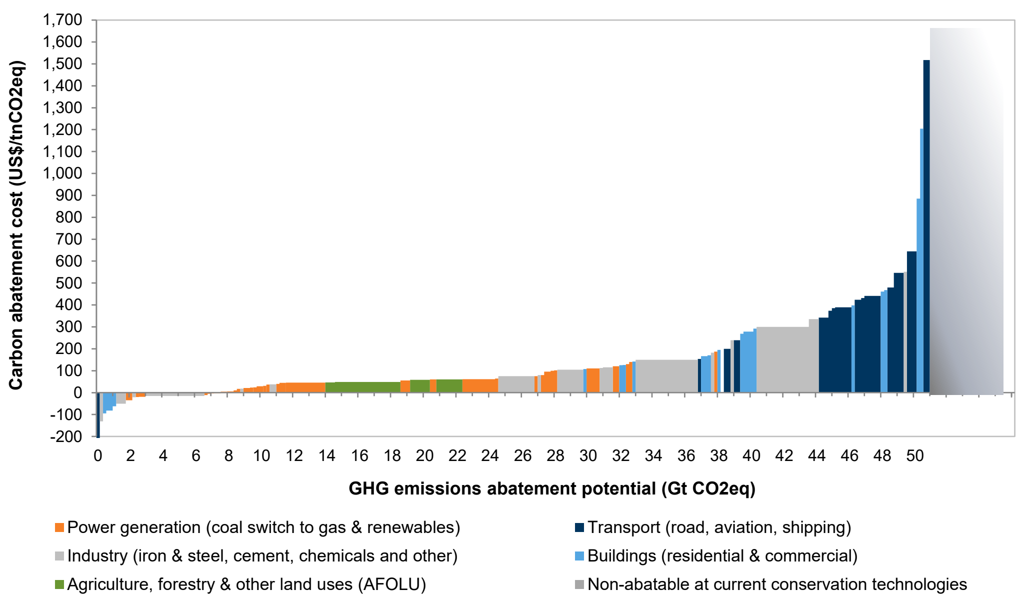


Source: Goldman Sachs Global Investment Research

2025 Carbonomics cost curve

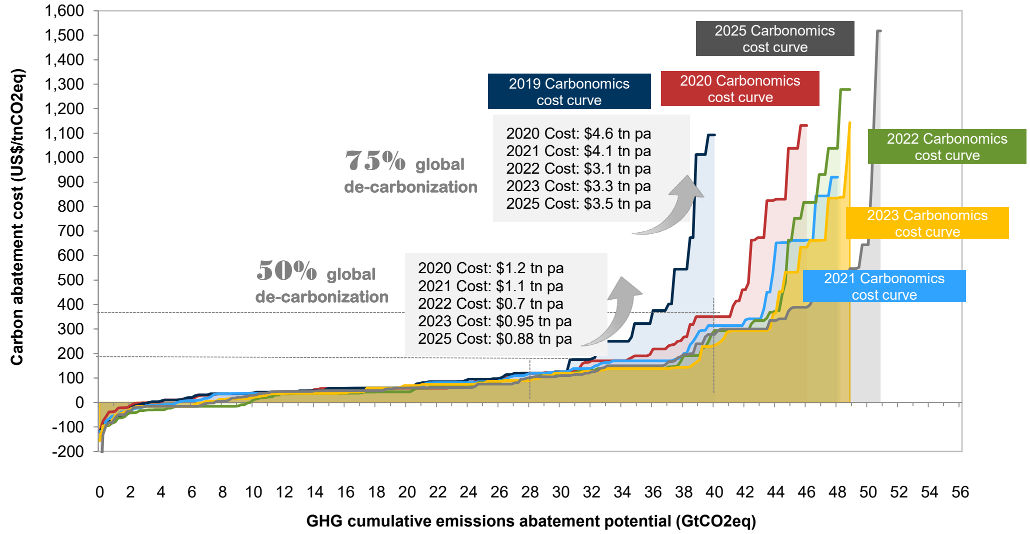
Exhibit 14 shows the 2025 Carbonomics cost curve and the 2023/2022/2021/2020/2019 comparable cost curves. Technological innovation continues to lower the cost curve of decarbonization for those technologies that are already affordable and that are gaining pace and scale: the lower half of the cost curve moves down on average by 7% yoy. However, the more-expensive technologies in hard-to-abate sectors show no meaningful momentum, and indeed are becoming more expensive, with the cost of the first 75% of the decarbonization curve rising 5% yoy. This is driven by contributions from: **(1) ongoing utility-scale batteries and solar cost deflation** driving down the lower half of the cost curve**; (2) slow cost advancements in high-cost technologies** such as heavy-duty transport and hydrogen-dependent decarbonization paths in industry, in turn owing to still-limited production scale, lifting up the upper half of the cost curve yoy; **(3) ongoing EV battery cost deflation** and **EV economies of scale** driving down EV costs for passenger cars and decreasing the implied cost of switching from ICEs, pushing down the high end of the cost curve down; and (4) **decarbonization of transport through biofuels,** which has become 40% cheaper, driven by lower renewable diesel (RD) and sustainable aviation fuel (SAF) prices, also contributing to lowering the high end of cost curve.

Exhibit 13: In this report, we update our Carbonomics decarbonization cost curve for a fifth year, capturing >100 different applications for GHG conservation technologies across all key emitting sectors globally
2025 carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and current costs, assuming economies of scale for technologies in the pilot phase



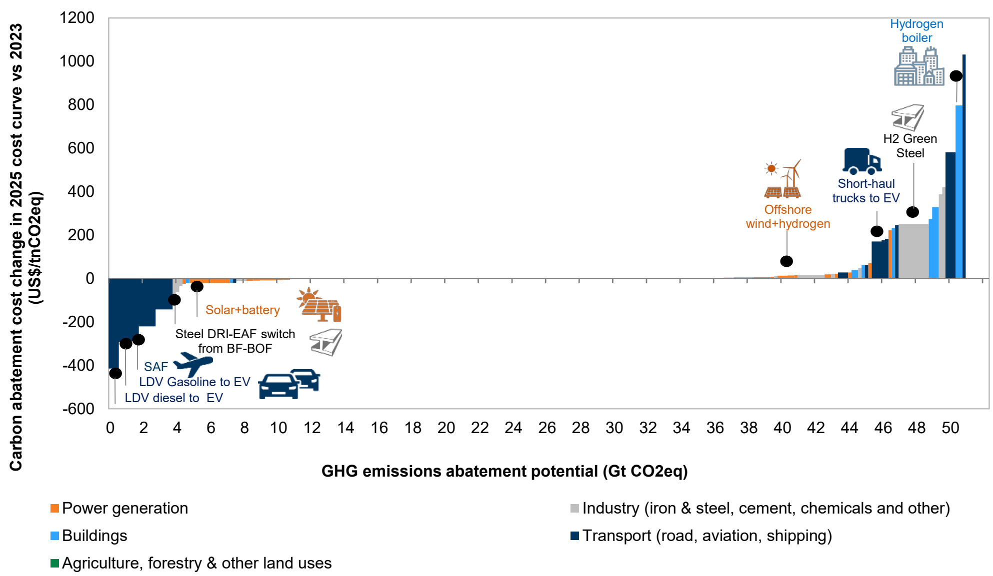
Source: Goldman Sachs Global Investment Research

Exhibit 14: Cost of decarbonizing the first 50% of the cost curve decreases by 7% on utility-scale batteries advancements, while 75% of decarbonization costs go up by 5%
2025 vs. 2023/2022/2021/20/19 comparable carbon abatement cost curves for anthropogenic GHG emissions, based on current technologies and costs, assuming economies of scale for technologies in pilot phase



Source: Goldman Sachs Global Investment Research

Exhibit 15: EV passenger cars, biofuels, and solar paired with utility-scale batteries show the biggest cost improvements yoy; hydrogen-dependent technogies and heavy transport show the biggest increase yoy
Carbon abatement cost change in the 2025 Carbonomics cost curve vs. 2023 by technology (US$/tnCO2)



Source: Goldman Sachs Global Investment Research

Transportation: shifting downwards primarily driven by cost deflation and technological innovation observed in light-duty transport and biofuels, while cost advancement in heavy-duty transport is lagging

This year, we see the transportation decarbonization cost curve shifting marginally downwards, primarily driven by ongoing **cost deflation and technological innovation observed in EV batteries,** and leading to a decrease in the carbon price of technologies dependent on EVs. According to our APAC Energy team, global average battery prices could continue to fall over the next few years. They recently revised down their updated battery pricing path on average by 3% for 2024E-30E (vs. their last update on the material pricing outlook — e.g. they lowered anode, separator and electrolyte pricing) and raised their market share forecasts for LFP batteries. They believe average global battery prices could fall towards c.US$80/kWh by 2026E, a level at which BEVs could reach ownership cost parity to gasoline-fuelled cars without subsidies in the US. We therefore use $90/kwh as our base case battery price in 2025, vs. $120/kWh in 2023, driving the average carbon abatement cost for EV passenger cars to $400/t from $645/t before.

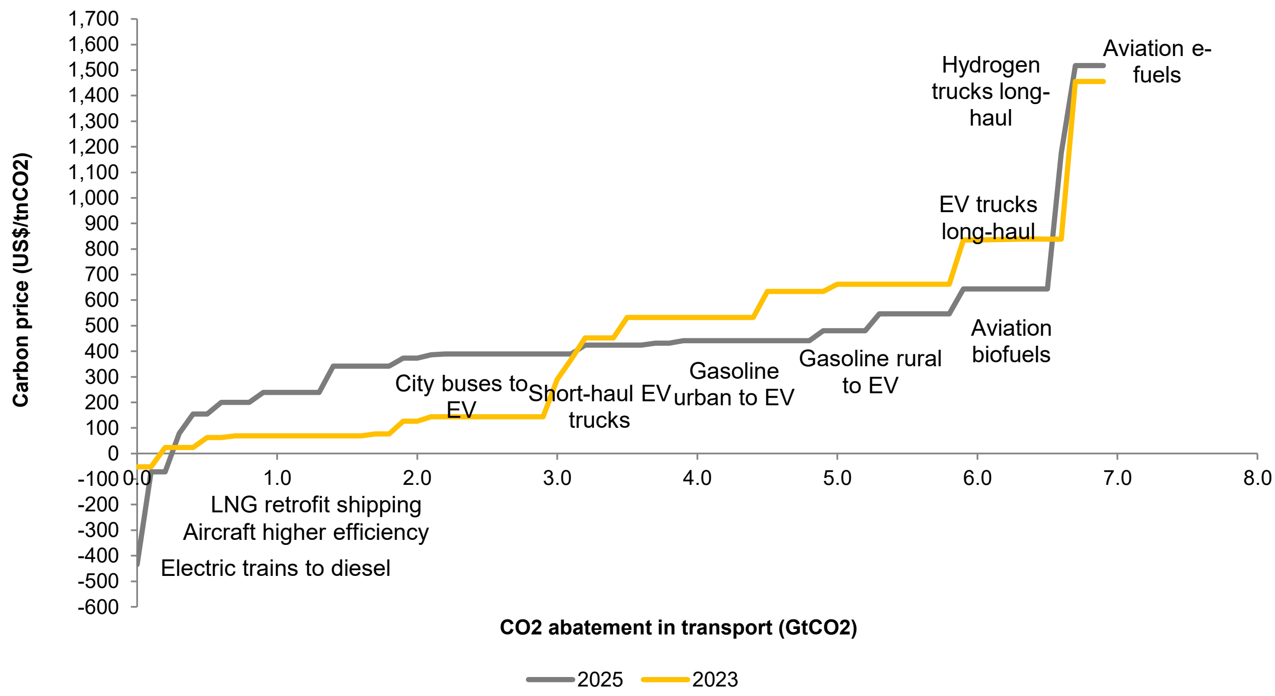
Cost advancement in heavy-duty transport is lagging: Cost advancements in the electrification of heavy-duty transport are lagging those in passenger cars, and we still see significant price premiums (2-3 times) for EV trucks and buses over diesel, despite battery cost advancements. The share of electric medium and heavy truck sales varies across regions, with China being the global leader at 6% in 2024, Europe at 2% and the US at <1%. This compares to >40% EV (BEV+PHEV) passenger car sales share in China in 2024, 25% in Europe and c.10% in the US. Limited economies of scale vs. passenger cars drive sustained price premiums, in our view. We update our price premiums for EV trucks and buses, driving up the bottom half of our transport cost curve, vs. 2023.

Among other technologies contributing to a lower carbon abatement cost in transport is **bioenergy:** in 2024-25, we see materially lower renewable diesel and SAF prices, vs. 2023, with the bio-SAF carbon abatement cost moving to $550/t from $850/t. At the same time, more nascent technologies such as e-SAF see a carbon cost increase, driven by lower fossil jet fuel prices vs. 2023.

Overall, on our estimates, the weighted-average carbon abatement cost in transport falls slightly, to $455/t from $460/t, with progress in passenger cars costs and biofuels largely but not fully offset by higher abatement costs in heavy transport.

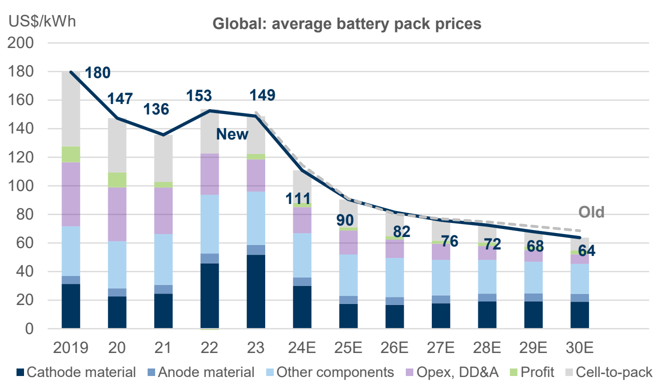
Exhibit 16: This year, we see advancements in passenger transport abatement costs and biofuels largely but not fully counterbalanced by higher abatement costs in heavy transport

2025 vs. 2023 carbon abatement cost curve for anthropogenic GHG emissions in transport sector, based on current technologies and associated costs



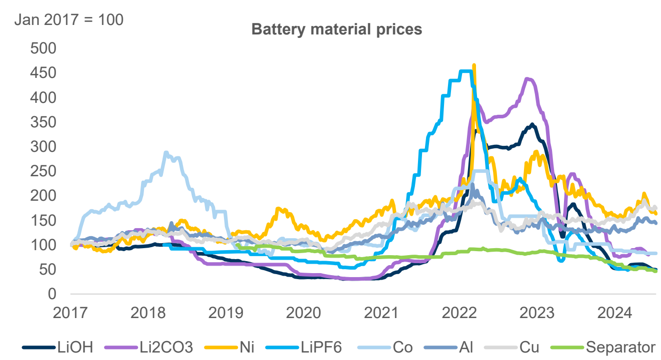
Source: Goldman Sachs Global Investment Research

Exhibit 17: We remain constructive on battery demand in the medium term, as technological advancements contribute to lower battery prices



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

Exhibit 18: Lithium prices have been falling in recent years



Source: Refinitiv, Wind

Power generation: steady decline in solar and wind LCOE yoy, but energy storage costs drive more significant shifts in renewable economics

Renewable power has transformed the landscape of the energy industry and represents one of the most economically attractive opportunities in our decarbonization cost curve. We estimate that c.30% of the decarbonization of global anthropogenic GHG emissions is reliant on access to clean power generation, including electrification of transport and various industrial processes, electricity used for heating and more.This year, the decarbonization cost curve in power was impacted by several factors: (1) the lower cost of utility-scale batteries and renewable power generation, especially solar; (2) a lower long-term gas price — we model $10/mcf in the high-cost scenario instead of $12/mcf before, making gas-to-renewables switch relatively more expensive; and (3) the upper end of the power generation cost curve moving up, mainly driven by the higher cost of green hydrogen, impacting H2CGGT and hydrogen storage.

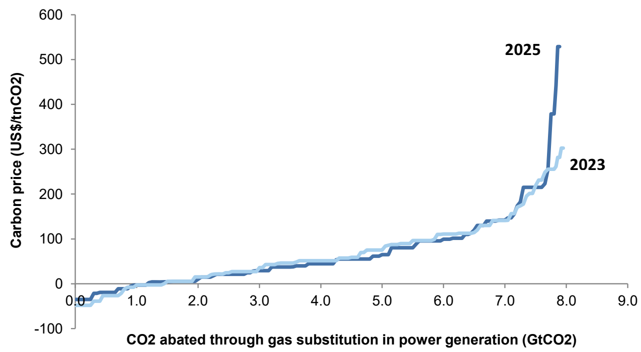
In 2024, the LCOE for renewable energy technologies such as solar PV, onshore wind, and offshore wind faced a downward trend.The costs of clean power technologies such as wind and solar decreased slightly, globally, in 2024 and are expected to fall further in 2025. In 2024, the LCOE for renewable technologies such as solar/ and onshore/offshore wind in Europe decreased by 11%/4%/3% yoy respectively, underpinned by both marginally lower interest rates and lower capital costs.The weighted average cost of capital (WACC) for new renewable power projects decreased to c.4.4% in 2024 from c.4.7% in 2023, driven by the decrease in risk-free rates in Europe and in the US.

Solar PV remains the cheapest power generation option, with the cost of a typical fixed-axis solar farm falling by 21% globally last year. Modules were sold at or below the cost of production, with no signs of overcapacity in the solar supply chain easing in 2025.The ongoing decline in equipment costs, and somewhat stickier PPA prices, suggest better economics for solar: our utilities analysts estimate the solar LCOE at c.€40/MWh in Europe, which is almost half the cost of offshore wind, as a reference, and nearly 40% of the current forward curves for 2025.The most significant change was observed in solar LCOE, with battery storage decreasing by approximately one quarter yoy, as battery prices saw their biggest annual drop since 2017 (lithium-ion battery pack prices fell 20% from 2023 to a record low of $115/kWh). Offshore wind remains expensive, with costs expected to fall over time but to remain higher than onshore options.

Overall, on our estimates, a combination of these factors contribute to a slight decrease in the weighted-average carbon abatement cost in power generation (switch from gas to renewables) of 1% on our 2025 curve, vs. 2023, from $66/t in 2023 to $65/t in 2025.

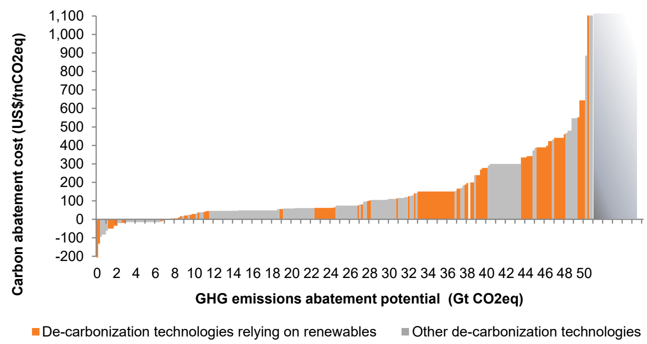
Lower gas prices could further decrease power generation decarbonization costs by 20%: As discussed earlier in *Reports of potential plan to end Russia-Ukraine war: Implications for European energy companies,* a potential Russia-Ukraine peace deal and the return of Russian gas flows through Ukraine represent downside risk to European gas prices, with summer 2025TTF prices potentially moving 36-56% below our commodities team's base case of EUR50/MWh. We therefore present a sensitivity of a power generation cost curve in this report to lower gas prices: our base case gas price assumptions are $4, $8 and $10/mcf, which result in a $62/t weighted average carbon abatement price in power generation, including both switching from coal to gas and from gas to renewables. **Under 25-40% lower gas prices assumptions of $3, $5 and $6/mcf, the average carbon abatement price decreases by 20% to $50/t:** while the gas-to-renewables switch becomes more expensive (by 23%, to $80/t from $65/t before), the coal-to-gas switch price decreases dramatically (by c.80%, to $13/t from $58/t), driven by the high sensitivity of the coal-to-gas switch to changes in gas prices.

Exhibit 19: We see a slight fall in the weighted-average carbon abatement cost in power generation of 1% on the 2025 curve
Power generation switch from natural gas to renewables (and storage) de-carbonization cost curve 2025 vs. 2023



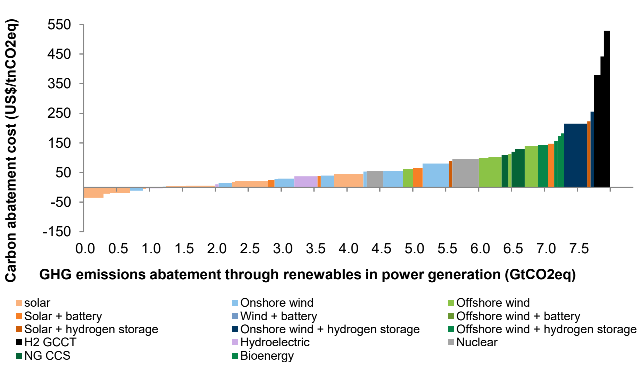
Source: Goldman Sachs Global Investment Research

Exhibit 20: Access to low-carbon power more broadly is vital for the decarbonization of c.30% of current global anthropogenic GHG emissions across sectors (such as electrification of transport, industry, buildings)
2025 conservation carbon abatement cost curve for anthropogenic GHG emissions, with orange indicating renewable power-reliant technologies



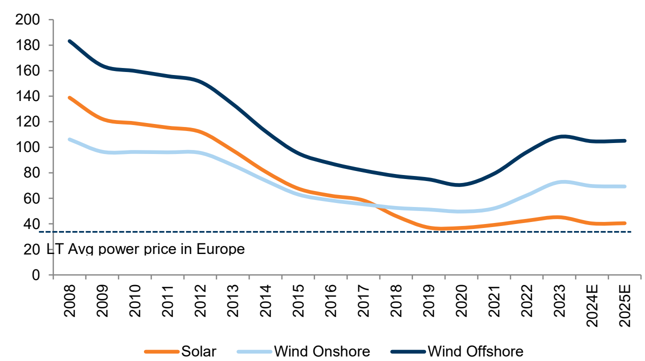
Source: Goldman Sachs Global Investment Research

Exhibit 21: The higher end of the power generation is mainly driven by the higher cost of green hydrogen, impacting H2CGGT and hydrogen storage
2025 conservation carbon abatement cost curve for power generation GHG emissions



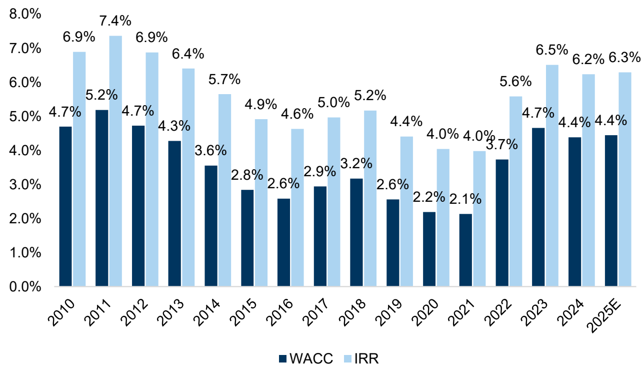
Source: Goldman Sachs Global Investment Research

Exhibit 22: Renewable power LCOEs have decreased slightly across technologies...
LCOE for solar PV, wind onshore and wind offshore for select regions in Europe (€/MWh)



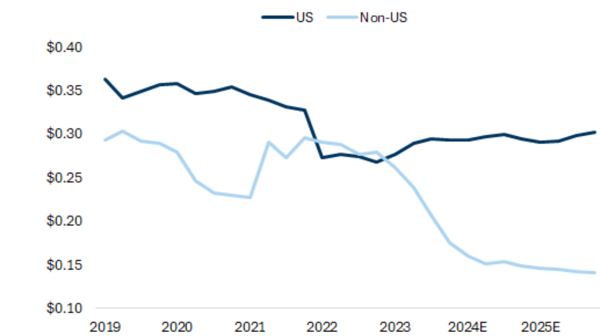
Source: Goldman Sachs Global Investment Research

Exhibit 23: ...underpinned both by marginally lower interest rates and lower capital costs
RES WACC and IRR in Europe,%



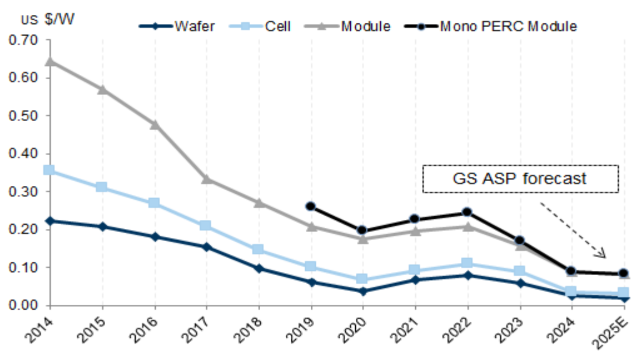
Source: IRENA, Goldman Sachs Global Investment Research

Exhibit 24: Solar modules were sold at or below the cost of production, with no signs of overcapacity in the solar supply chain easing in 2025
Domestic vs. non-domestic module ASPs



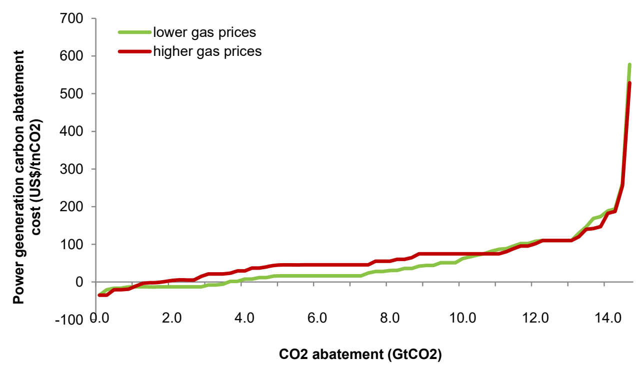
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 25: We forecast 8%-15% declines in average wafer, cell and module ASPs in 2025
Solar ASPs, $ per watt



Source: PVinsights, Goldman Sachs Global Investment Research

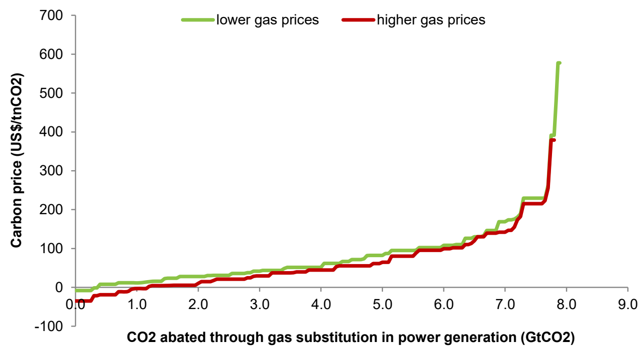
Exhibit 26: Lower gas prices could further decrease power generation decarbonization costs by 20%
2025 conservation carbon abatement cost curve for power generation GHG emissions: gas price sensitivity



Includes abatement through gas-to-renewables switch and coal-to-gas switch

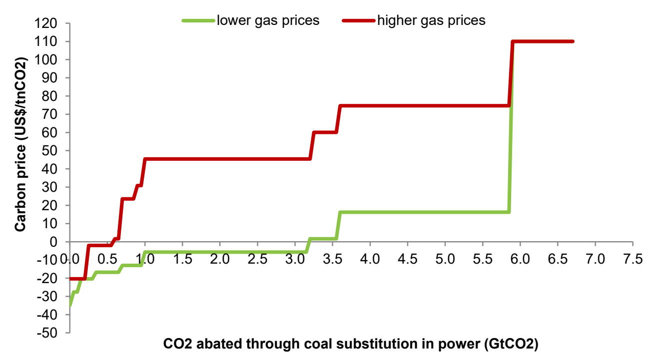
Source: Goldman Sachs Global Investment Research

Exhibit 27: With lower gas prices, a gas-to-renewables switch becomes 23% more expensive
2025 conservation carbon abatement cost curve for power generation GHG emissions: gas-to-renewables switch



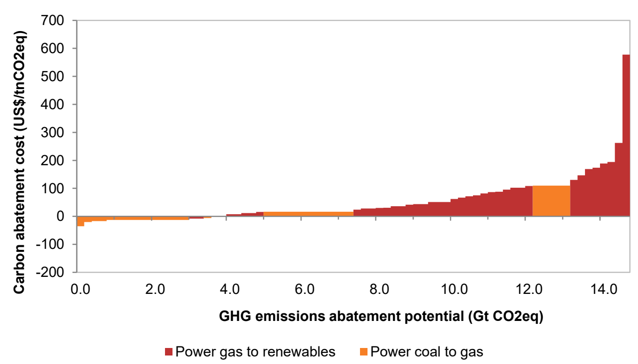
Source: Goldman Sachs Global Investment Research

Exhibit 28: Yet, the coal-to-gas-swith price decreases dramatically
2025 conservation carbon abatement cost curve for power generation GHG emissions: coal-to-gas switch



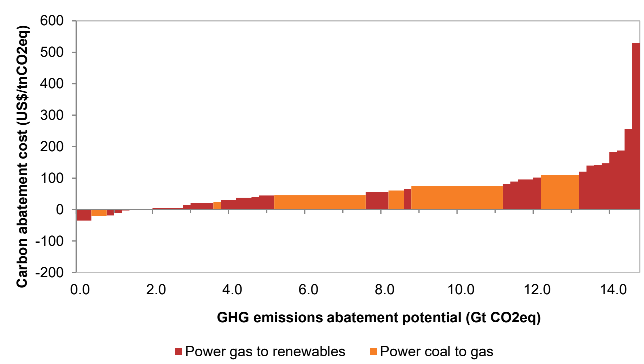
Source: Goldman Sachs Global Investment Research

Exhibit 29: In view of growing LNG supply from 2026 and a potential restart of Russian gas flows lowering gas prices, we find that the benefit of accelerated coal-to-gas switching...
2025 conservation carbon abatement cost curve for power generation GHG emissions: lower gas prices scenario



Source: Goldman Sachs Global Investment Research

Exhibit 30: ...more than offsets the negative impact on renewable economics
2025 conservation carbon abatement cost curve for power generation GHG emissions: higher gas prices scenario



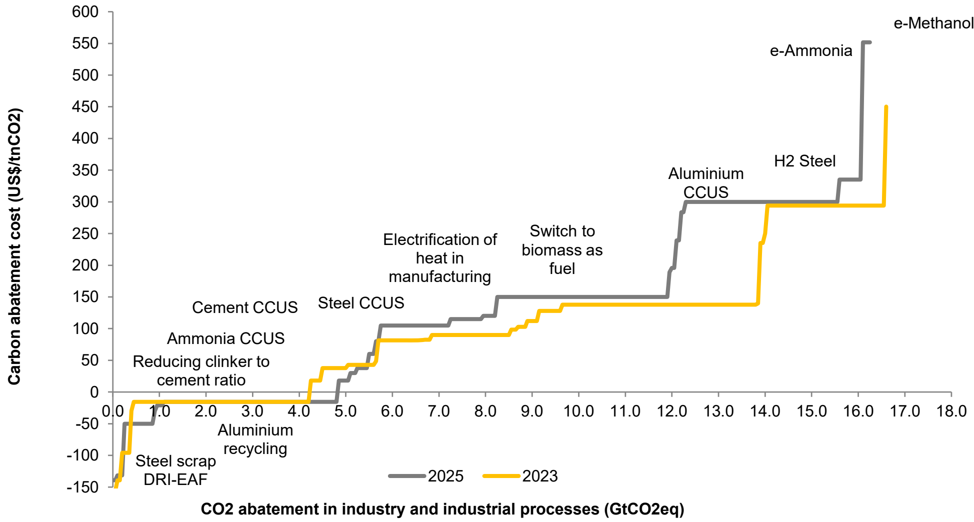
Source: Goldman Sachs Global Investment Research

Industry: Remains one of the most challenging to decarbonize

The carbon abatement cost curve for GHG emissions in the industry sector has moved upwards, with the weighted-average carbon abatement cost increasing by 25% to $130/t in 2025 from $104/t in 2023, primarily driven by higher abatement costs of hydrogen-dependent technologies ($420/t in 2025 from $112/t in 2023): we now model $5/kg for hydrogen-dependent technologies from $3/kg before (H2 steel, e-ammonia, e-methanol) and increase capex assumptions for these technologies driven by slower-than-expected cost advancement and adoption pace in green hydrogen space.

Exhibit 31: We see little progress in industry, where the average decarbonization cost is up by 25%, driven by higher abatement costs of hydrogen-dependent technologies

2025 vs. 2023 carbon abatement cost curve for anthropogenic GHG emissions in industry sector, based on current technologies and associated costs



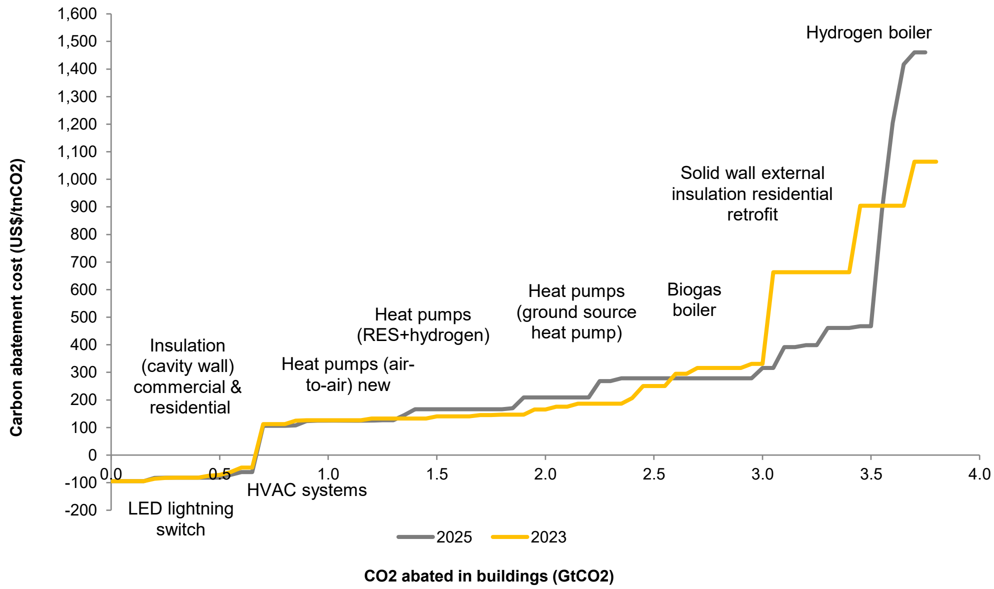
Source: Goldman Sachs Global Investment Research

Buildings: cost curve moves lower as we assume higher share of heat pumps vs. hydrogen boilers driving buildings decarbonization

In buildings, we saw heat pumps installation accelerating in the US in 2024, supported by the introduction of IRA tax credits. At the same time, adoption of technologies such as hydrogen boilers remains very limited, owing to high costs and a lack of infrastructure. We now model $8/kg for the hydrogen retail price, from $6/kg before, which together with a capex increase results in an increase in average carbon abatement cost for hydrogen boilers to $1,400/t from $900/t before. At the same time, as the adoption of air-to-air heat pumps increases, their carbon abatement costs decrease, to $195/t from $220/t we estimate. Given the significant cost difference between the two technologies, relatively higher availability of heat pumps and slower-than-previously-expected hydrogen market development, we now assume c.55% of buildings emissions will be abated through heat pumps installation (40% before) and only 5% will be abated though hydrogen-dependent technologies (20% before). Owing to reallocation of carbon abatement shares to cheaper technologies, i.e. from hydrogen boilers to heat pumps, our carbon abatement cost curve for GHG emissions in the buildings sector has moved downwards, with the weighted average carbon abatement cost decreasing by c.10%, to $243/t in 2025 from $275/t in 2023.

Exhibit 32: Owing to the reallocation of carbon abatement shares to cheaper technologies, our carbon abatement cost curve for GHG emissions in the buildings sector has moved downwards with the weighted-average carbon abatement cost decreasing by c.10%

2025 vs. 2023 carbon abatement cost curve for anthropogenic GHG emissions in buildings sector, based on current technologies and associated costs



Source: Goldman Sachs Global Investment Research

Power generation: solar panels, wind turbines, utility-scale batteries

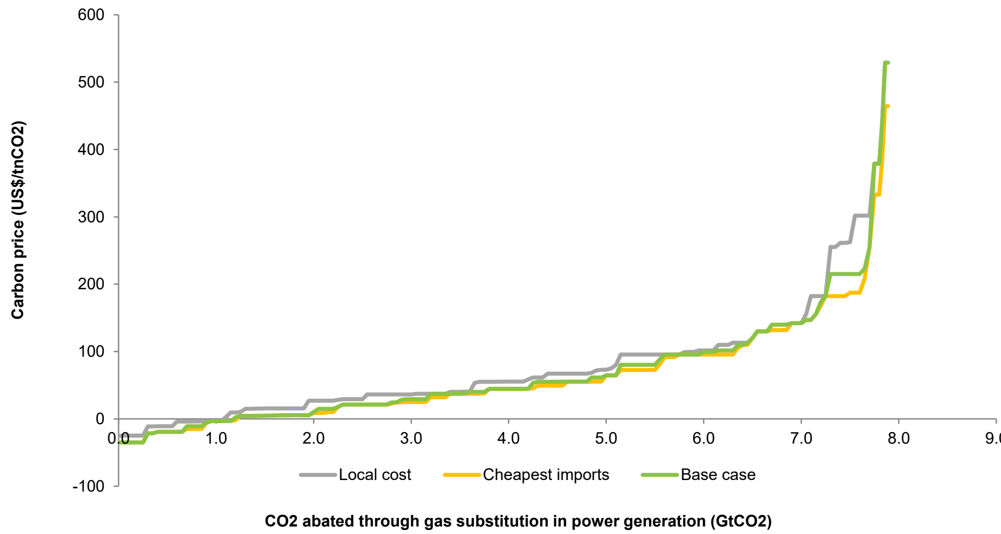
Power generation cost curve in three scenarios

We look at the power generation sector's carbon abatement cost curve in three different scenarios: our base case, on the basis of the cheapest imports, and at the local cost of production.

We have developed three scenarios for the LCOE of solar, onshore wind and offshore wind, each based on varying capital cost assumptions. The differences in capital costs arise from the origin of key components, i.e. if produced locally in Europe/the US or imported from lower-production-cost countries. For solar power, the scenarios reflect different production costs of PV modules, which vary depending on whether they are manufactured locally or imported from cheaper regions. **We conclude that the solar LCOE is 24% lower in the cheapest imports scenario than a local cost of production scenario, ignoring any tariffs and incentives**. For onshore and offshore wind, the variations stem from different costs for wind turbines. Similar to solar power, the pricing of these components varies, depending on whether manufactured locally or imported. **We conclude that onshore/offshore wind's LCOE is 7%/5% lower in the cheapest imports scenario than a local cost of production scenario, ignoring any tariffs and incentives**. For solar power, our base case scenario assumes electricity production based on imported components, as currently both the EU and US are heavily reliant on solar module imports from China and SEA, producing only around 8%/11% locally. For wind power, our base case scenario assumes electricity production based on domestically manufactured components, since Europe and the US are 97%/60% self-sufficient respectively for wind equipment. Additionally, we model three scenarios for energy storage, to account for the intermittency of renewables, such as hydrogen storage for all three renewable power sources, and utility-scale battery storage for solar power generation. **Overall, for power generation (switch from gas to renewables), the weighted-average carbon abatement cost stands at $62/t in the cheapest imports scenario, $65/t in our base case, and $77/t in the local cost of production scenario, implying a c.25% premium for local production compared to the cheapest imports.**

Exhibit 33: Overall, for power generation, the weighted average carbon abatement cost stands at $62/t in the cheapest imports case, $65/t in the base case and $77/t in the local cost of production case, implying a c.25% premium for local production compared to the cheapest imports

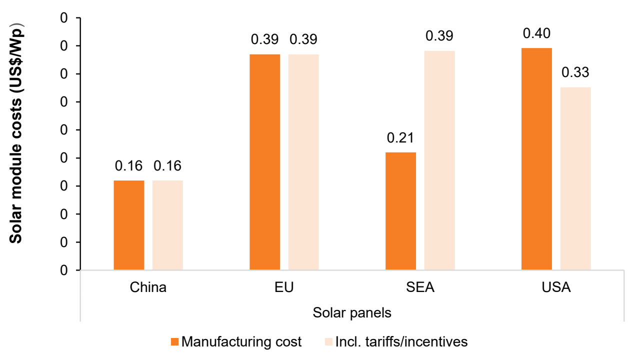
Carbon abatement cost curve for anthropogenic GHG emissions in power generation sector in three scenarios



Source: Goldman Sachs Global Investment Research

Exhibit 34: For solar power, the scenarios reflect different production costs of PV modules, which vary depending on whether they are manufactured locally or imported from cheaper regions

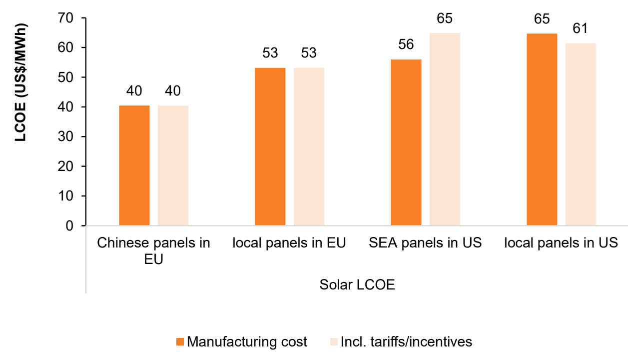
Solar module costs depending on the place of manufacturing, US$/Wp



Source: Goldman Sachs Global Investment Research

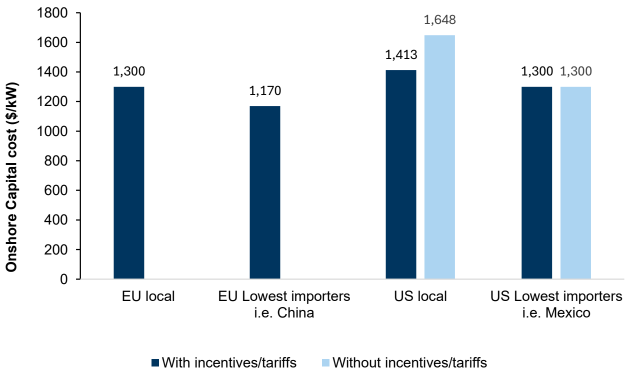
Exhibit 35: Solar LCOE is 24% lower in the cheapest imports scenario than local cost of production, not taking into account tariffs and incentives

Solar LCOE depensing on the origin of solar modules, US$/MWh



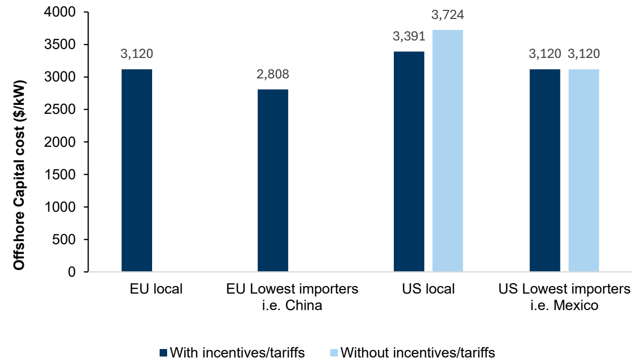
Source: Goldman Sachs Global Investment Research

Exhibit 36: For onshore and offshore wind, the variations stem from different costs of wind turbines...
Onshore wind capex depending on the origin of wind components, US$/kW



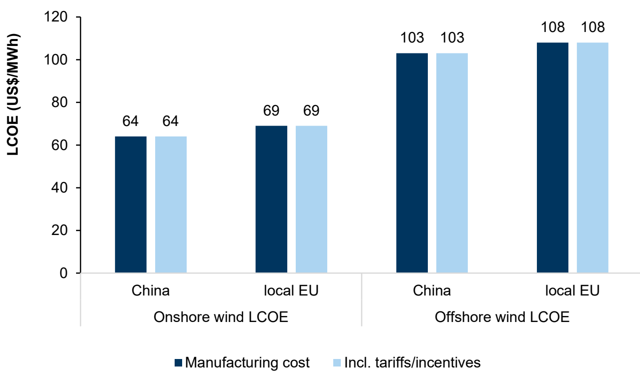
Source: Goldman Sachs Global Investment Research

Exhibit 37: ...resulting in different total capital costs
Offshore wind capex depending on the origin of wind components, US$/kW



Source: Goldman Sachs Global Investment Research

Exhibit 38: Onshore/offshore wind LCOE is 7%/5% lower in the cheapest imports scenario than local cost of production, not taking into account tariffs and incentives
Onshore/offfshore wind LCOE depending on the origin of solar modules, US$/MWh



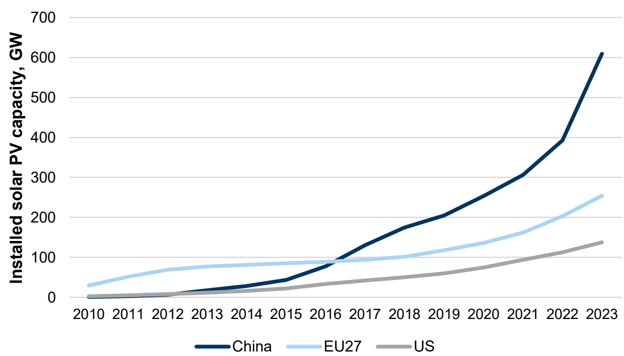
Source: Goldman Sachs Global Investment Research

Solar panels

The US has seen a rapid expansion of solar power capacity over the last decade, driven by growing demand for renewable energy and supportive government policies. As of 2023, solar energy accounted for 5.6% of total electricity generation in the US, with installed solar capacity reaching over 135 GW. According to the EIA, the US installed 15.6 GW of solar capacity in Q1/Q2 2024, a 55% increase from the record achieved in Q1/Q2 2023. In 2024, about 42 GW of US solar PV capacity has been installed, up c.25% yoy. Since the Inflation Reduction Act's (IRA) passage, more than 85 GW of manufacturing capacity have been added across the solar supply chain (from facilities announced pre- and post-IRA), out of 335 GW announced, including nearly 35 GW of new module capacity. Despite the significant growth in solar capacity, the US relies heavily on imported solar panels, primarily from Southeast Asian countries. **In 2023, c.55 GW of solar modules were imported into the US, while 7 GW were manufactured**

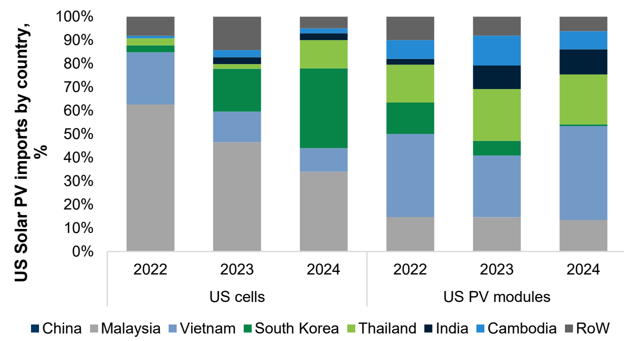
domestically, which accounts for c.11% of total solar module shipments. The key solar module suppliers to the US are Vietnam (40% of total imports in 2024), Thailand (21%), Malaysia (13%), India (11%) and Cambodia (8%). These countries have become key suppliers after the US imposed tariffs on Chinese solar products in 2018 under the Section 201 trade remedy.

Exhibit 39: China, Europe and the US have the greatest solar PV capacity globally
Installed solar PV capacity, GW



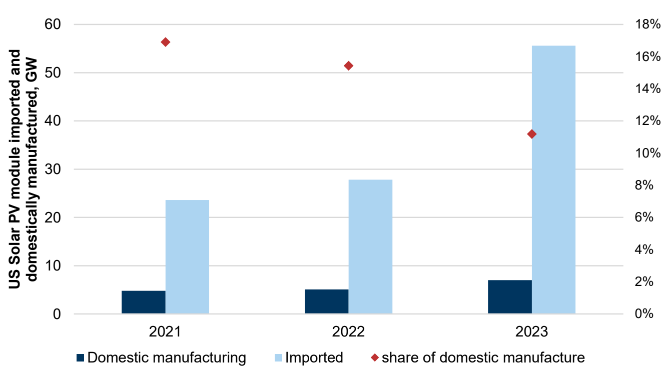
Source: IRENA

Exhibit 40: The US heavily relies on imported solar panels, primarily from Southeast Asian countries
US solar PV components imports by country, %



Source: Bruegel

Exhibit 41: In 2023, c.55 GW of solar modules were imported by the US, while 7 GW were manufactured domestically, which accounts for c.11% of total solar module shipments
Comparison of US solar PV modules imported vs. domestically manufactured, GW

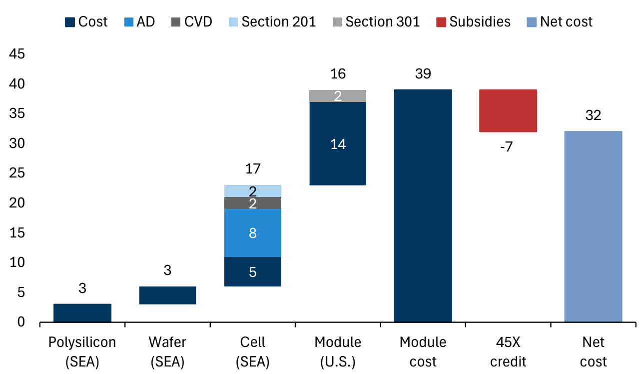


Source: EIA

Domestic manufacturing to pick up in 2025... Since the passage of the IRA (and before), onshoring of the solar supply chain and the push for self-reliance have been central themes among advocates of renewable energy growth. Over the past year, the Biden administration had introduced significant policy measures aimed at protecting and expanding domestic manufacturing, the impact of which, we believe, is going to play out in 2025. Key policy changes, such as the removal of Section 201 bifacial exemption, the update to Section 301 tariffs on solar cells, and the most recently announced preliminary AD/CVD determinations on solar imports from four Southeast Asian countries, have collectively driven higher ASPs in the US, compared to global markets. Furthermore, we believe a key investor focus will be on whether the IRA's tax credits will remain intact, and if so, if they will continue to drive investments and incentivize both local and international suppliers to establish or expand domestic production capacity.

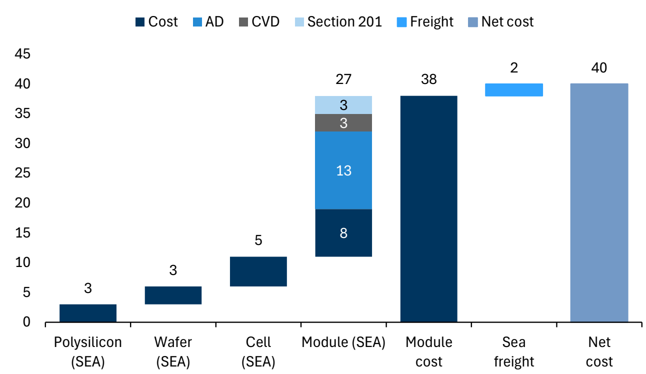
US tariff policies support the local supply chain. To safeguard domestic solar manufacturers from unfair trade practices, the US DoC has announced preliminary AD/CVD duties on solar imports from four Southeast Asian countries. Over the past year, other policy measures have also been implemented to strengthen the US supply chain, promote energy independence, and protect domestic manufacturers from low-cost imports. Furthermore, the newly elected President has proposed an additional 10% tariff on all imports from China, which could increase cost pressures on imported products. Collectively, these initiatives have kept US module ASPs at levels higher than anywhere else globally, establishing the US as a critical market for the renewable energy sector. Looking ahead through 2025, policy efforts could unlock further investment and growth opportunities in the space.

Exhibit 42: US ASPs are likely to increase with tariffs and AD/CVD in place...
US module assembly all-in cost, 2024 (EXW U.S. ¢/W)



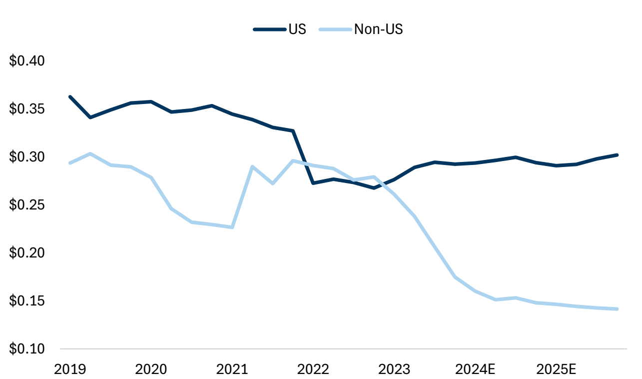
Source: ACORE, CEA, Goldman Sachs Global Investment Research

Exhibit 43: ...with solar imports, on the other hand, becoming even more expensive
Southeast Asia all-in module cost, 2024 (DDP-port U.S. ¢/W)



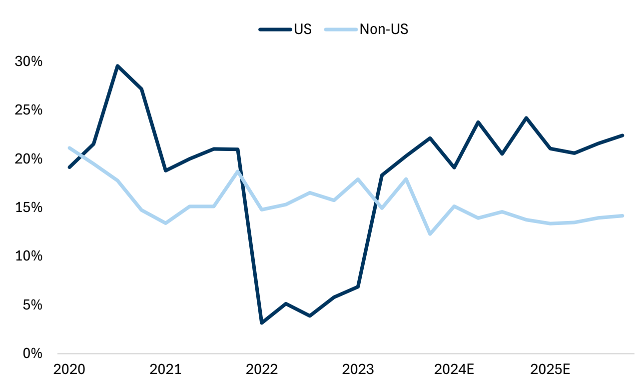
Source: ACORE, CEA, Goldman Sachs Global Investment Research

Exhibit 44: ASPs in the US have substantially deviated from ROW prices, and we expect the difference to grow further in the near term
Domestic vs. non-domestic module ASPs



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 45: The gross margin story for domestic and non-domestic manufacturers looks similar to the ASP scenario, owing to IRA incentives
Domestic vs. non-domestic module gross margins

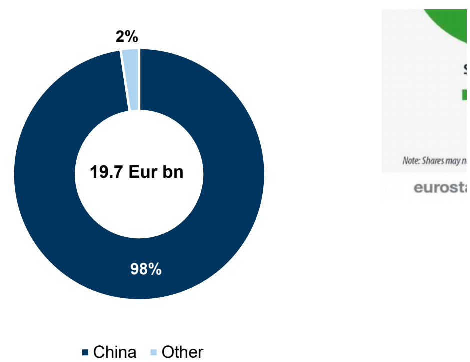


Source: Company data, Goldman Sachs Global Investment Research

Europe

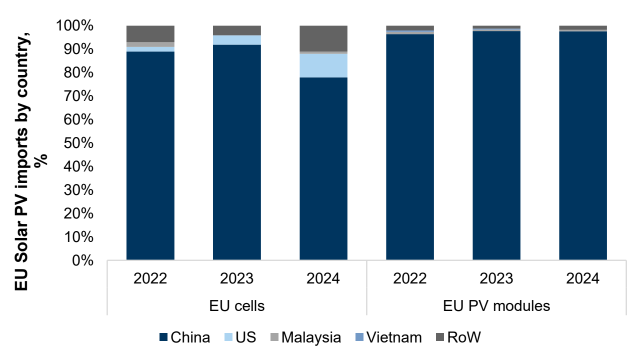
Solar energy, and in particular the deployment of photovoltaics, is currently the fastest-growing renewable energy sector in the EU, leading to record numbers of annual installations over the last three years (around 28 GW in 2021, 41 GW in 2022 and 56 GW in 2023). However, the bulk of the demand for solar modules in Europe is covered by imports. Currently, 98% of the solar panels imported into the EU come from China. The European Union has set a goal of at least 30 GW of European solar manufacturing, at each stage of the value chain, by 2030. The EU Solar Strategy aims at deploying over 320 GW of solar photovoltaic ("solar PV") by 2025, more than double 2020, and almost 600 GW by 2030. With this ambition in mind, the European Solar PV Industry Alliance aims at **scaling PV manufacturing in the EU to 30 GW across the whole supply chain by 2025**. Additionally, under the Net-Zero Industry Act, the EU established a benchmark to achieve 40% of its annual deployment needs for strategic technologies, including solar PV, through domestic manufacturing. In 2023, EU solar panel manufacturing capacity amounted to 26 GW for polysilicon, 1.3 GW for wafers, 2 GW for cells and 15 GW for modules. Manufacturing facilities are located across Europe, but they are concentrated especially in Germany, followed by France and Italy. However, Europe-produced solar PV currently meets **less than 2% of Europe's demand for solar, highlighting the region's continued reliance on Chinese imports.**

Exhibit 46: Currently, 98% of the EU's solar panels...
EU partners for imports of solar panels, 2023



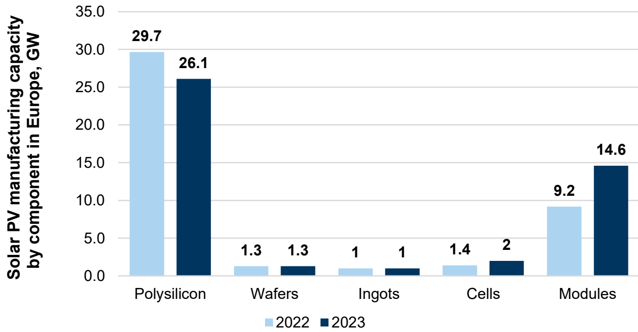
Source: European Commission

Exhibit 47: ...are imported from China
EU solar PV components imports by country, %



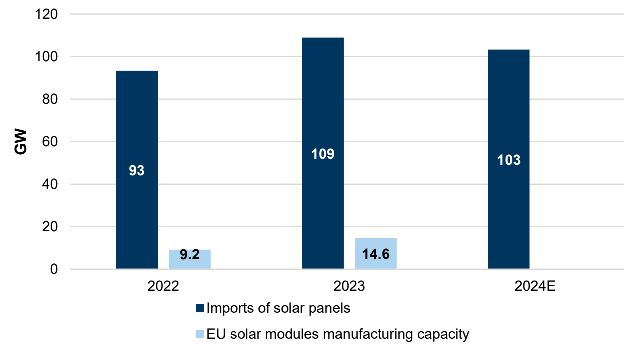
Source: Bruegel

Exhibit 48: In 2023, EU solar panel manufacturing capacity amounted to 26 GW for polysilicon, 1.3 GW for wafers, 2 GW for cells and 15 GW for modules
EU27, Norway and Switzerland solar manufacturing capacity, GW



Source: SolarPowerEurope

Exhibit 49: Europe-produced solar PV currently meets less than 2% of Europe's demand for solar, highlighting the region's continued reliance on Chinese imports
Comparison of EU solar PV modules imported from China vs. EU solar domestic manufacturing capacity, GW



Source: Ember, SolarPowerEurope, Goldman Sachs Global Investment Research

Prices for solar modules vary significantly between those manufactured in Europe and those produced in China, primarily due to differences in production costs, market demand and supply chain logistics. Price differences between the analyzed regions mainly depend on material and labour costs, as well as equipment and building depreciation costs. In China, production costs for solar PV modules are significantly lower, ranging between $0.15 and $0.19 per watt, owing to economies of scale, lower labour costs and more affordable raw materials. **Solar panel production in the EU incurs a cost premium of €0.20-0.25/Wp (150%-170%) compared to China, driven by higher expenses in labour, utilities and equipment depreciation.**

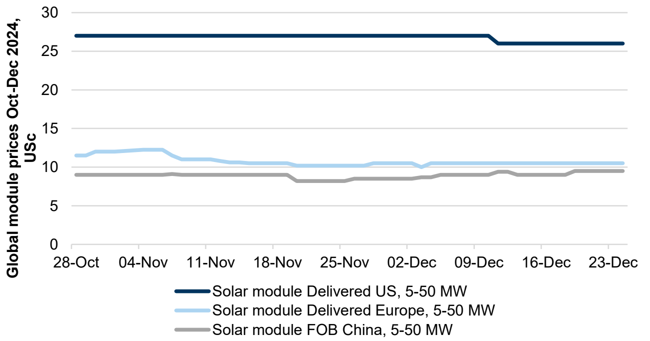
However, the European solar module manufacturers have recently faced a particular challenge, owing to a combination of import dependency and a sharp drop in the price of imported panels. In 2023, the solar photovoltaic sector in the EU and globally saw the prices of the panels fall sharply, from c.€0.20/W to less than €0.12/W.

As of January 2025, the global spot solar PV module price is c.0.09c/W, which is below the estimated Chinese manufacturing cost, owing to overcapacity, intense competition and weaker demand. Manufacturers are cutting prices to offload excess inventory and retain market share. Additionally, declining raw material costs such as polysilicon further reduce prices. Moreover, government subsidies and global trade dynamics have distorted the market, pushing companies to sell below cost to penetrate foreign markets.

The European Union does not impose tariffs or specific policy measures against the import of Chinese solar panels. While the EU has expressed concerns about its dependence on Chinese imports for solar PV technology, no new tariffs have been implemented. In 2024, the EU rejected calls from the solar panel sector to enact tariffs on cheaper Chinese imports, emphasizing the need for affordable solar panels to achieve its green energy transition goals. Historically, the EU imposed anti-dumping and anti-subsidy measures on Chinese solar panels between 2013 and 2018, with tariffs averaging 47.6%. These measures were lifted in September 2018 to facilitate the EU's renewable energy objectives. Despite the absence of current tariffs, the EU remains attentive to the challenges posed by the influx of cheaper Chinese solar panels. In September 2023, members of the European Parliament raised concerns about the significant increase in Chinese solar modules offered at prices below production costs, highlighting potential threats to the European solar industry.

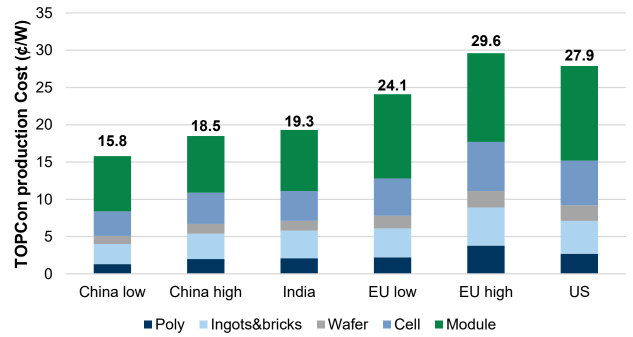
Exhibit 50: As of January 2025, the global spot solar PV module price is c.0.09c/W, which is below the estimated Chinese manufacturing cost, owing to overcapacity, intense competition and weaker demand

Global Solar PV module prices, US cents/W



Source: S&P Global Market Intelligence

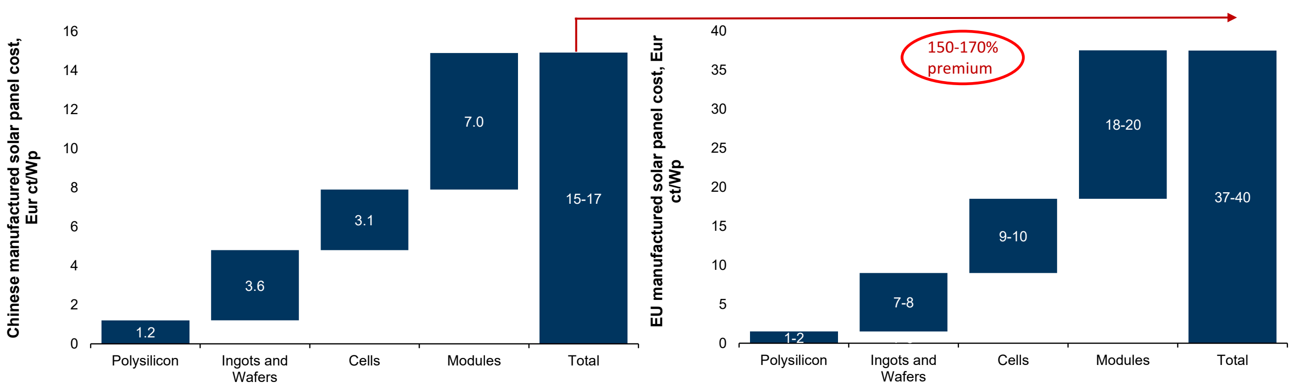
Exhibit 51: TOPCon solar module production cost (cents/W)



Source: ETIP PV

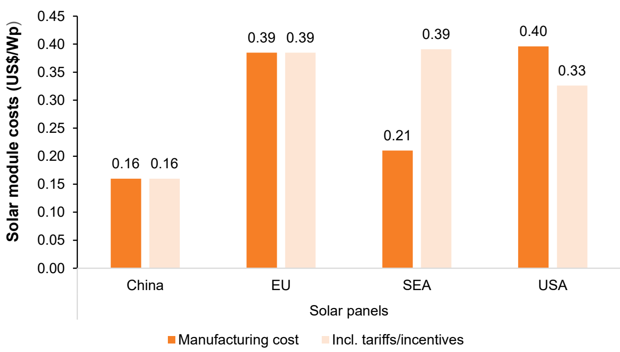
Exhibit 52: Solar panel production in the EU incurs a cost premium of €0.20-0.25 /Wp (150%-170%) compared to China, driven by higher expenses in labour, utilities and equipment depreciation

Costs of the production of solar PV panels in China vs. EU, € cents/Wp



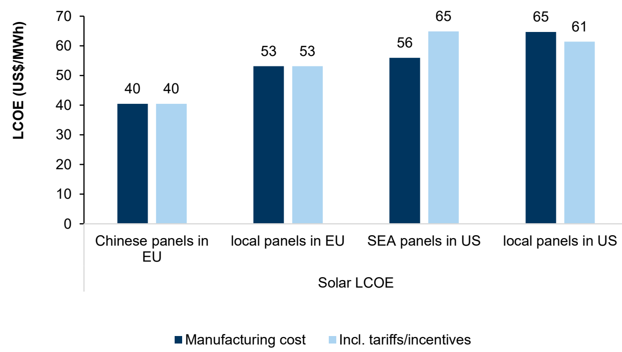
Source: Roland Berger

Exhibit 53: Solar module production costs vary significantly in the East and West...
Solar module costs depending on the place of manufacturing, US$/Wp



Source: Goldman Sachs Global Investment Research

Exhibit 54: ...leading to different LCOEs
Solar LCOE depensing on the origin of solar modules, US$/MWh



Source: Goldman Sachs Global Investment Research

Utility-scale batteries

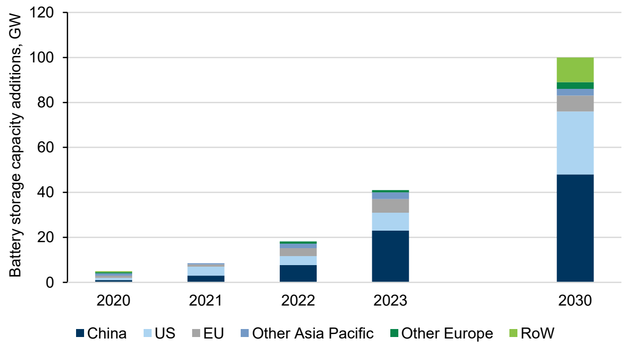
LFP batteries dominate the battery storage market today and are produced almost exclusively in China: Global installed battery storage capacity additions accelerated in 2023 to 41 GW from <20 GW in 2022, with 65% of capacity additions for utility-scale batteries (connected directly to the grid) and 35% for behind-the-meter energy storage (installed at residential, commercial or industrial end-user locations). 55% of 2023 capacity additions occurred in China, 20% in the US and 15% in Europe. Nevertheless, battery storage represents only 7% of total lithium-ion batteries in use, with >90% coming from EV demand. While energy density is of utmost importance for EV batteries, it is less critical for battery storage, leading to a significant shift towards LFP batteries, which now account for 80% of total battery storage (2023). LFP batteries are currently produced almost exclusively in China, with the US and Europe currently relying on imports from China on grid-scale batteries. The IEA expects global installed battery storage capacity to increase from 86 GW in 2023 to 760-1,200 GW by 2030, with China accounting for 50% of installed capacity, the EU the US 40%, and rest of the world 10%. The IEA expect China capacity additions to accelerate from 23 GW in 2023 to over 45 GW by 2030, supported by province-level regulation that requires the pairing of wind and solar PV projects with energy storage, and more generally by the rising flexibility needs associated with the increasing share of variable renewables in its power system.

The costs for utility-scale battery storage projects can vary widely, depending on specific site conditions, technology choices and regulatory regimes. In the IEA's STEPS scenario, the total upfront costs of utility-scale battery storage (including the battery plus installation, other components and developer costs) with four-hour duration are projected to decline from a global average of US$290/kWh in 2022 to an average of US$175/kWh in 2030, a reduction of 40% over the period.

China is the lowest-cost region for new battery storage projects today and is projected to remain so through to 2030, per the IEA. Recent costs of utility-scale battery storage projects in the US and Europe are at the higher end of the range today, but broader markets and more extensive deployment should drive down future costs.

Exhibit 55: The strong increase in annual battery storage capacity additions recorded over the last years has been driven almost entirely by China, the EU and the US

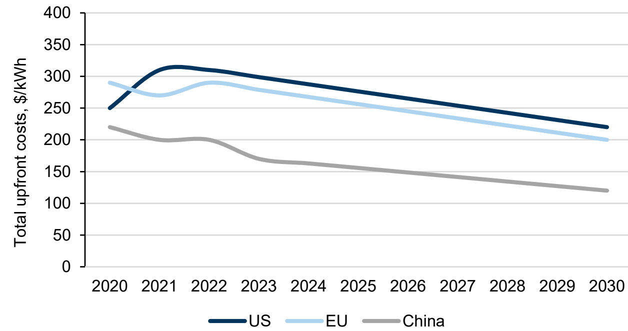
Battery storage capacity additions worldwide, GW



Source: IEA

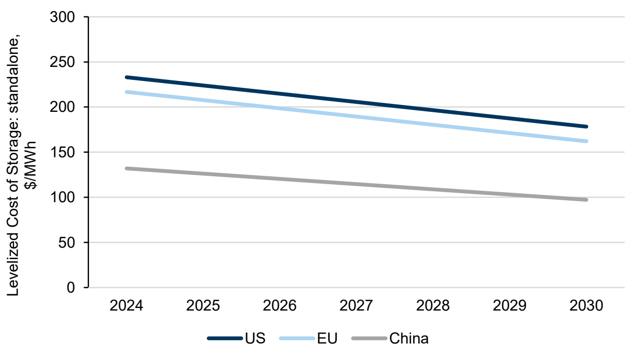
Exhibit 56: China is the lowest-cost region for new battery storage projects today and is projected to remain so through to 2030

Total upfront costs of utility-scale batteries, $/kWh



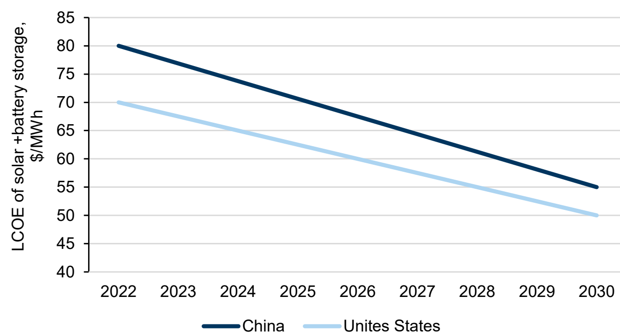
Source: IEA

Exhibit 57: Levelized cost of storage for utility-scale standalone 4h, $/MWh



Source: Goldman Sachs Global Investment Research

Exhibit 58: LCOE of solar +battery storage, $/MWh



Source: IEA

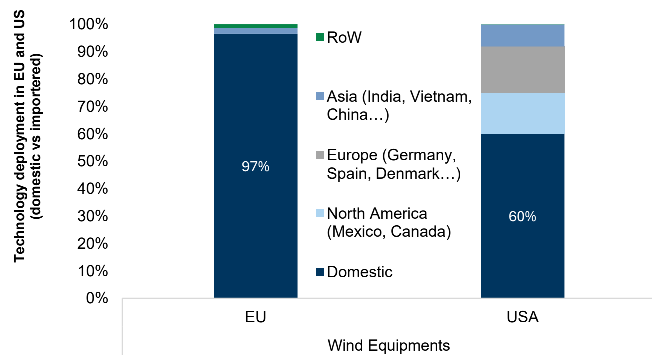
Wind turbines

Europe and the US are 97% and 60% self-sufficient respectively for wind equipment

Europe has traditionally been a major producer of wind turbines and components, being home to several of the world's leading companies. At present, domestic production covers around 90% of the blades deployed in the Europe, and all the nacelles and towers.

US demand for wind turbines is currently met by a mixture of domestic and imported components. There is a well-established nacelle and tower manufacturing industry, which supplied over 90% of the nacelles and about 80% of the towers installed across the country in 2023. In contrast, a large share of the wind turbine blades that are installed are imported, with domestic content of only around 10% in 2023. The bulk of imported blades come from Mexico and Europe (Germany, Spain, Denmark etc.). Overall, this implies that a typical wind project in the US sources c.60% of its components (blades, nacelles, towers) domestically. The Inflation Reduction Act has provided support for domestic wind manufacturing, with tax credits for wind turbine component manufacturers, while wind project developers can apply for an increase of their tax credit of 10% if they meet domestic content requirement thresholds. To qualify, onshore projects installed before 2025 must source at least 40% of all equipment domestically (20% for offshore projects).

Exhibit 59: Europe and the US are 97%/60% self-sufficient respectively for wind equipments (blades, nacelles and towers)



Source: IEA

Steel tariffs historically have had a minimal impact on wind turbine prices, with OEMs mentioning price increases of just 1%-4% in 2018

Steel is the material that contributes the most to the final cost of wind installations, representing around 6%-8% of the total cost of onshore wind turbines. In March 2018, President Trump initially imposed a 25% tariff on imported steel from every country except Canada and Mexico. These two countries are relatively immaterial in terms of the global steel supply-demand balance, which made the tariff disruptive to US producers and particularly to wind turbine manufacturers, given steel can contribute up to 25%/90% of the weight of an onshore/offshore wind turbine respectively.

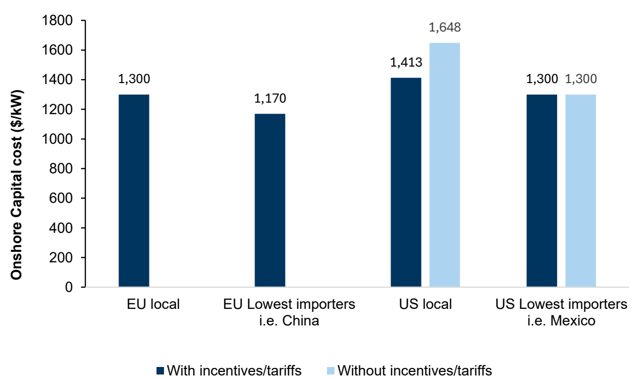
Before 2018, the price difference between European and US steel was c.$100/t with this spread widening to c.$300/t after the tariffs were implemented. This increase was equivalent to c.25% of the steel price at the beginning of 2018 (see here for more). While the tariffs are still in place, several amendments have since been made to reduce their impact on the domestic market (for example, the EU is now able to export tariff-free steel to the US up to a quota).

At the time, EU OEMs broadly spoke of a limited immediate effect, owing to steel being procured on a contracted basis, with a larger negative impact over the medium term linked to: (1) higher domestic steel prices in the US; and (2) costs associated with re-routing steel shipments. Specifically, cost impacts of 1.5%-4% were mentioned by EU OEMs owing to higher to US steel prices.

Chinese competition

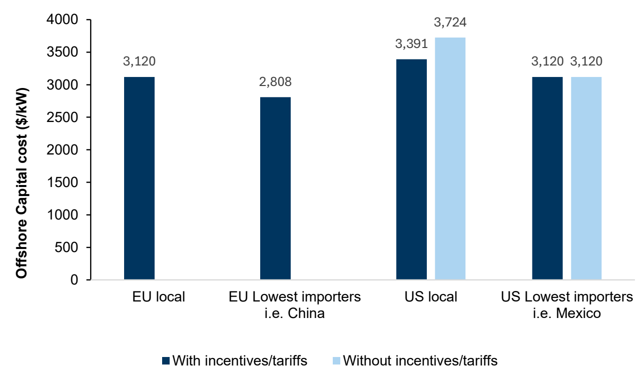
Over the past few years, the prospect of Chinese competition in wind has been a subject of debate. European turbine manufacturers have historically dominated the industry, both within Europe and globally (excluding China), while Chinese manufacturers have primarily focused on their domestic market, and currently account for only 4.2% of the global market. To date, there has been little penetration, but there has been evidence of intention. From an EU/US perspective, there is a concern that were a few developers to successfully build with Chinese turbines, this would act as a signal to the rest of the industry to shift incremental volumes to Chinese producers, given the perceived cost advantage. Industry sources have cited lower costs, more attractive contract structures (e.g. deferred payment) and turbine sizes as reasons for collaborating with Chine turbine suppliers. However, Western developers typically base investment decisions on the levelized cost of energy (LCOE), where Chinese turbines often fall short, owing to higher O&M costs, insurance premiums, and financing costs. Despite lower upfront costs, banks tend to offset the cheaper capex with higher interest rates, making the total cost comparable to Western alternatives.

Exhibit 60: Wind turbine production costs for local Western producers is competitive vs. their lowest-cost importers...
Onshore wind capex depending on the origin of wind components, US$/kW



Source: Goldman Sachs Global Investment Research

Exhibit 61: ...although the price difference against their lowest cost importers tends to be higher for offshore than onshore
Offshore wind capex depending on the origin of wind components, US$/kW

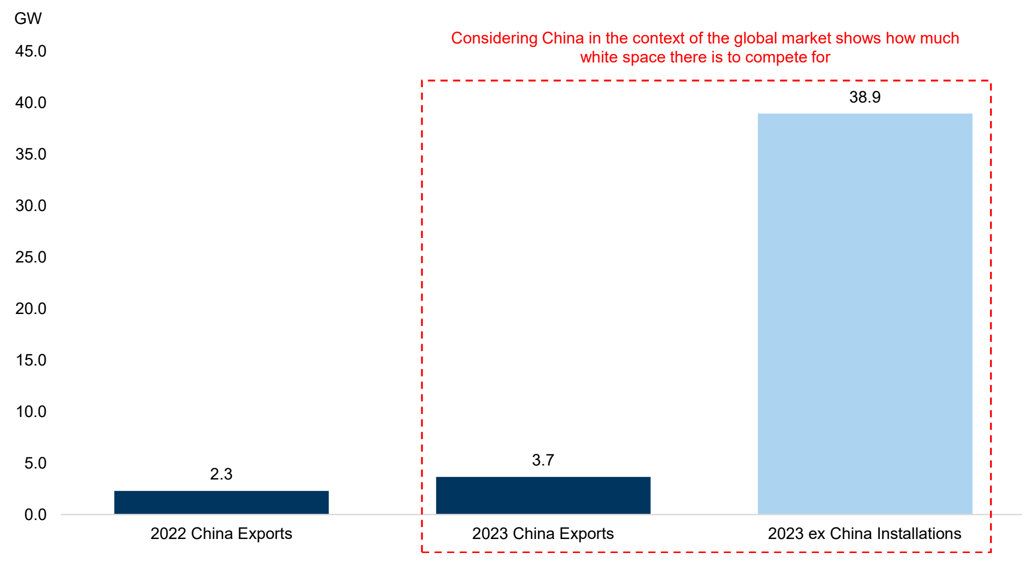


Source: Goldman Sachs Global Investment Research

Chinese competition in global context

Per the Chinese Wind Energy Association, Chinese wind turbine manufacturers exported 3.7GW of wind turbines in 2023, which was a 60% increase on 2022. However, we believe that this should be seen in the context of the global wind market, where installations were c.40GW in 2023. Put another way, we see the size of Chinese manufacturers in the Western market as still relatively small, and see no evidence to suggest that they are dominating the market.

Exhibit 62: Despite increased focus on Chinese competition, there is still plenty of space to compete for in the ex China market
GW



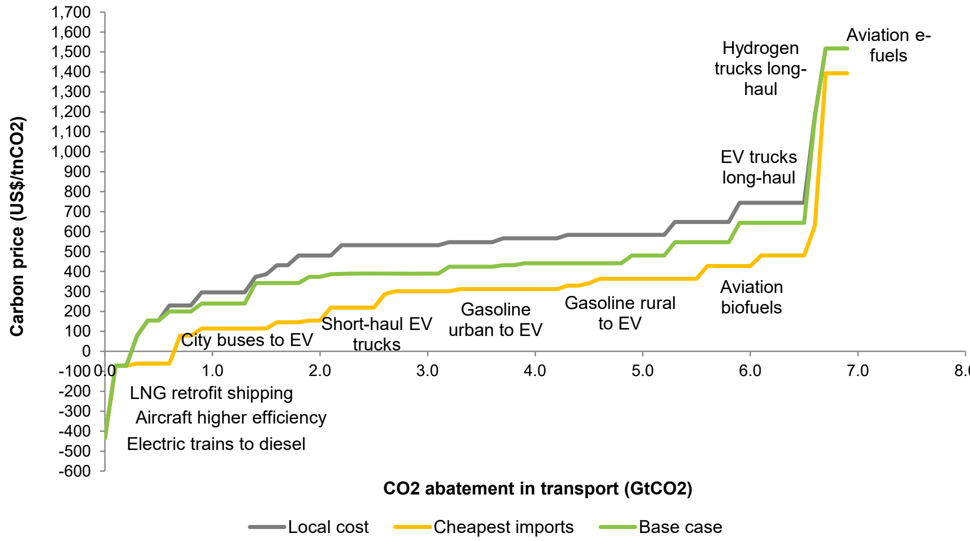
Source: CWEA, GWEC

Transport: EV batteries and biofuels

Transport sector cost curve in three scenarios

We look at the transport sector carbon abatement cost curve in three scenarios: our base case, on the basis of the cheapest imports, and in terms of the local cost of production. EV cell pack and biofuels production costs are the main variables in the three scenarios. For EV cell pack costs, we use $90/kWh as our base case value, $80/kWh in the cheapest imports scenario (the cost of importing from China into the US/Europe in the absence of tariffs) and $110/kWh as the average domestic NCM production cost in the US and Europe. **For passenger cars,** the weighted-average carbon abatement cost varies from $400/t in our base case to $310/t in the cheapest imports case and $575/t in the local cost of production case. For heavy-duty trucks and buses (including hydrogen trucks), we estimate that the average carbon abatement cost varies from $460/t in the base case to $120/t in the cheapest imports case and $520/t in the local cost of production case. For renewable diesel production costs, we assume $1,800/t as base case value and the local cost production value, and $1,540/t for the cheapest imports scenario (the cost of importing from China into the US/Europe in the absence of tariffs). For SAF production costs, we assume $2,100/t as our base case value and local cost production value, and $1,820/t for the cheapest imports scenario (the cost of importing from China into the US/Europe in the absence of tariffs). **For biofuels,** the weighted average carbon abatement cost varies from $442/t in our base case and the local cost of production case to $348/t in the cheapest imports case. **Overall, for the transport sector, the weighted-average carbon abatement cost stands at $308/t in the cheapest imports case, $455/t in the base case and $548/t in the local cost of production case, implying a c.80% premium for local production compared to the cheapest imports.**

Exhibit 63: In transport, the carbon price difference between local cost production and cheapest import is significant at 80%
Carbon abatement cost curve for anthropogenic GHG emissions in transport sector in three scenarios



Source: Goldman Sachs Global Investment Research

EV batteries

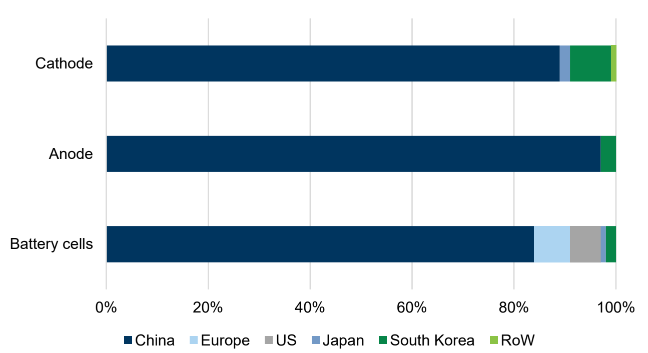
China dominates the global EV batteries market currently and will likely do so in 2030: China has almost 85% of battery cell manufacturing capacity and accounts for 90% of cathode and 98% of anode active material global manufacturing capacity (Exhibit 64). The only countries with significant shares of cathode active material manufacturing capacity outside China currently are South Korea (9%) and Japan (3%). Battery production in China is more integrated than in the United States or Europe, given China's leading role in the upstream stages of the supply chain. Different supply chains are, however, required for different chemistries. **China is home to almost 100% of LFP production capacity** and **more than 75% of the installed lithium nickel manganese cobalt oxide (NMC)** and other nickel-based chemistries **production capacity,** compared to **20% in South Korea.** LFP is the most prevalent chemistry in the Chinese electric car market, while NMC batteries are more common in the European and American electric car markets.

The US is strengthening its local battery supply chain with potential self-sufficiency being reached in 1-2 years: Production in the United States reached 70 GWh of EV batteries in 2023 and 1.2 million EVs, according to the IEA. The share of imports among EV batteries demand in the US was 30% in 2023, primarily coming from China, Japan and South Korea. In response to China's dominance of the global battery supply chain, and the country's competitive cost positioning on the global supply curves, the US government passed the 2022 IRA. This offers significant tax credits to incentivize the local EV supply chain to phase out battery materials, components and cells from China. For example, Section 45X of the IRA has reshaped the battery cost curve in the US domestic market, by lowering costs of domestically manufactured batteries by

US$45/kWh (US$35/kWh for cell and US$10/kWh for modules) against potential exports from China. As a result of such policies, which strengthen local battery supply, our APAC Energy team expects US capacity expansion to accelerate and catch up with local demand growth in 1-2 years (Exhibit 66).

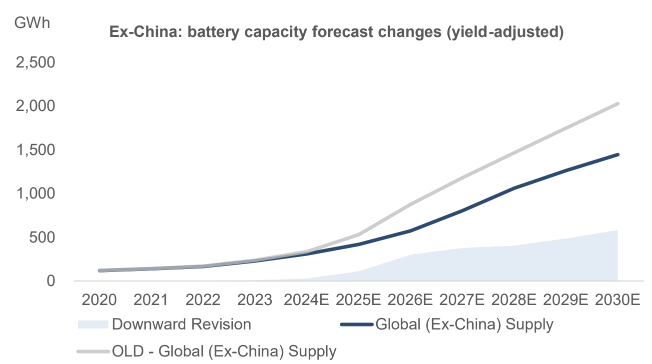
Europe still likely an end market for excess Chinese battery supply, with the region expected to be 20%-30% short EV batteries until the end of the decade: Production in Europe reached 110 GWh of EV batteries in 2023 and 2.5 million EVs, according to the IEA. In Europe, the largest battery producers are Poland, which accounted for about 60% of all EV batteries produced in the region in 2023, and Hungary (almost 30%). Germany leads the production of EVs in Europe and accounted for nearly 50% of European EV production in 2023, followed by France and Spain (with just under 10% each). The share of imports in EV batteries demand in Europe was 20% in 2023, primarily coming from China. Following recent newsflow on project delays our APAC Energy team expect European capacity expansion to moderately lag local demand growth, requiring 20%-30% of demand to be met through imports (Exhibit 67).

Exhibit 64: China dominates the global EV batteries market currently
Geographical distribution of global battery supply chain



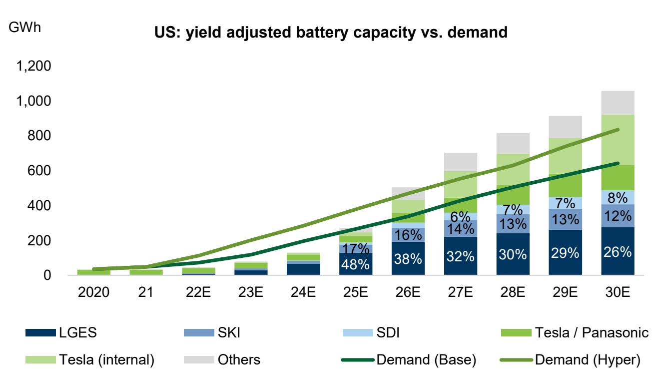
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 65: Ex-China battery capacity projections are decreasing amid new capacity delays and cancellations



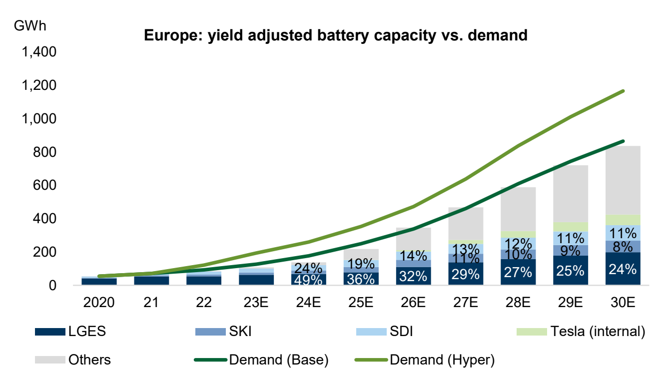
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 66: We expect the US to reach self-suffiency in 1-2 years



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 67: We expect Europe to be 20%-30% short EV batteries by the end of the decade

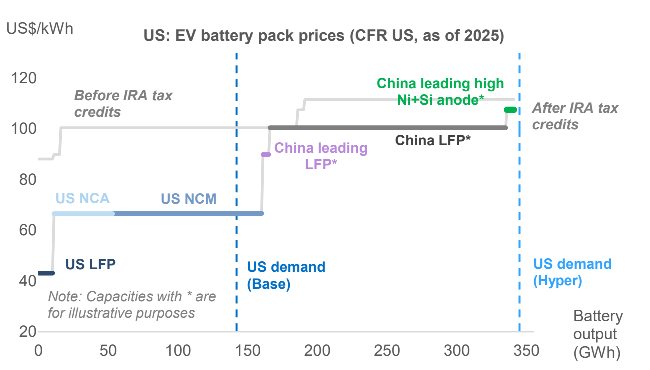


Source: Company data, Goldman Sachs Global Investment Research

US versus China import production costs: Chinese Tier 1 producers, along with a few leading ex-China producers, occupy the lower-end of the energy-density-adjusted battery cost curve (Exhibit 70). The US IRA has encouraged the local EV supply chain to phase out battery components and cells from China, by offering tax credits for companies that manufacture cells in the US. The US IRA's section 45X effectively lowers the US domestic battery cost curve by US$45/kWh against Chinese exports (Exhibit 68) to $45-65/kWh versus $90-110/kWh cost of Chinese imports that are additionally subject to a 38.4% import tariff rate: a 3.4% general tariff on Li-ion battery imports, the 25% Section 301 tariff for Chinese batteries and additional 10% post the recent tariff increase on Chinese goods.

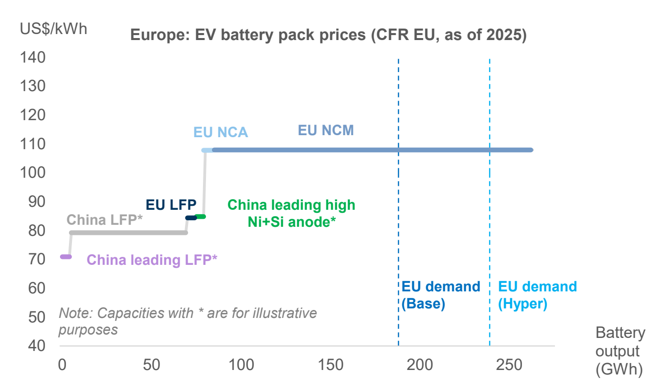
Europe versus China import production costs: In Europe, LFP imports from China are the most cost-effective solution (Exhibit 69) at $70-80/kWh, given a much lower (1.3%) import tariff rate on EV batteries vs. the US, while cost of domestic NCA/NCM production is at roughly $110/kWh. Our APAC Energy team argue that Europe remains an attractive export destination for Chinese oversupply, given limited trade barriers to discourage Chinese flows, rising demand for LFP batteries from the European mass market, and strong relationships between European OEMs and Chinese T1 battery makers, meaning LFP battery exports from China remain the most cost-effective solution in Europe. They estimate additional costs of only US$2-3/kWh for selling Chinese-made batteries in Europe, factoring in freight costs and import duties, compared with c.US$12/kWh in additional costs to enter the US market. Furthermore, to date Europe has not formulated local content requirements for EV subsidies, whereas the US IRA credits of US$45/kWh is subsidizing locally manufactured batteries.

Exhibit 68: The US IRA's section 45X effectively lowers the US domestic battery cost curve by US$45/kWh against Chinese exports



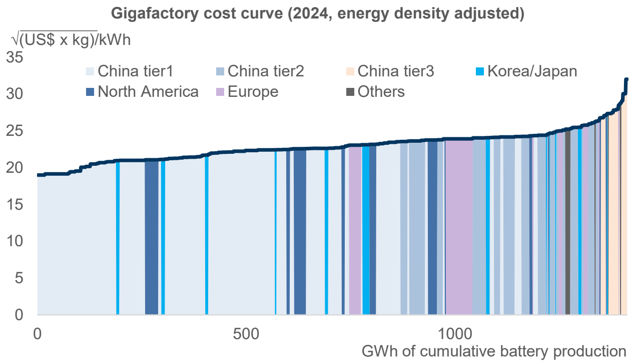
Source: Company data, Wood Mackenzie, SNE Research, BNEF, Goldman Sachs Global Investment Research

Exhibit 69: In Europe, LFP imports from China are the most cost-effective solution



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

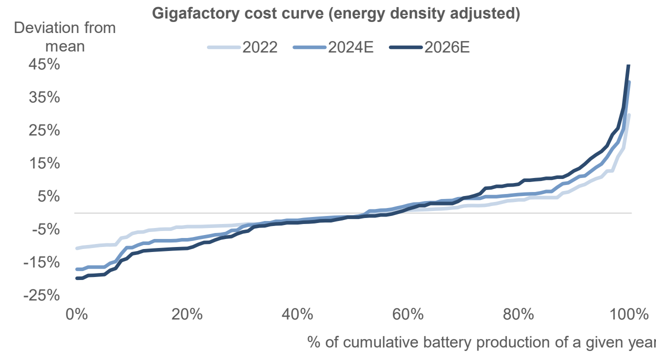
Exhibit 70: Chinese Tier 1 producers, along with a few leading ex-China producers, occupy the lower end of the energy-density-adjusted battery cost curve



The energy-density-adjusted cost takes the square root of the "monetary cost (US$/kWh) x weight cost (kg/kWh)" of a certain battery pack

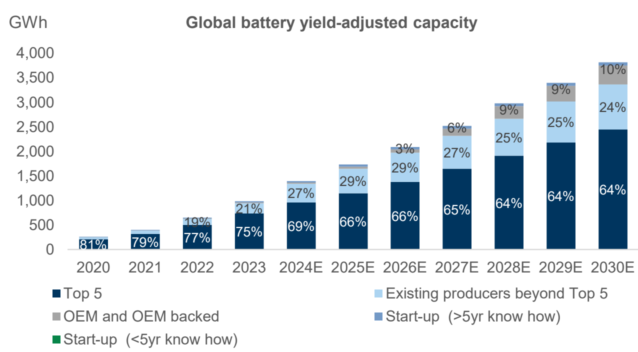
Source: Wood Mackenzie, ICCSINO, Goldman Sachs Global Investment Research

Exhibit 71: Rapid improvement by leaders in battery energy density could lead to a steeper cost curve



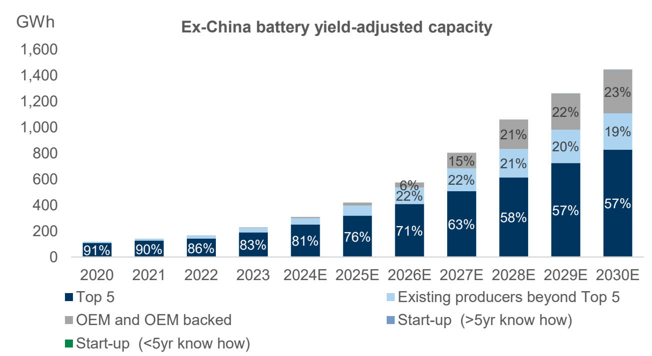
Source: Wood Mackenzie, ICCSINO, Goldman Sachs Global Investment Research

Exhibit 72: Top 5 producers (CATL, LGES, BYD, Panasonic, Samsung SDI) could maintain leadership in the global market...



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 73: ...and the ex-China market

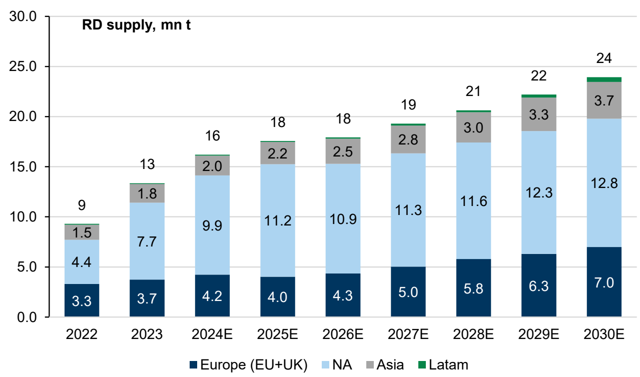


Source: Company data, Goldman Sachs Global Investment Research

Renewable diesel (RD)

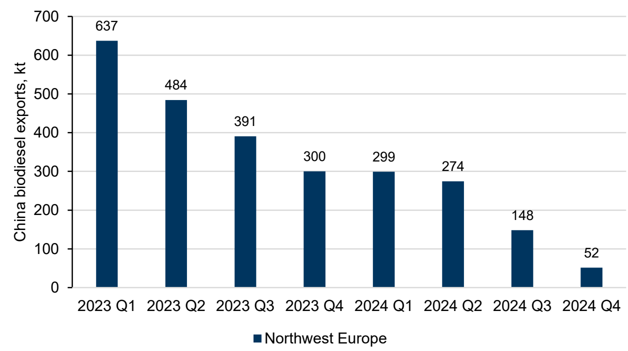
60% of **renewable diesel** is currently produced in North America, primarily in the US, 30% in Europe and 10% in Asia, primarily Singapore and China; i.e., 90% of renewable diesel is produced in the regions with existing biofuels mandates. The most notable inter-regional trade is as RD Singapore exports to the US (1.3 mtpa or 8% of global supply in 2024), Chinese RD exports to Europe (0.4-0.5 mn t in 2024, on our estimates, or 2% of global supply) and some renewable diesel exports from the US to the UK, as seen in 2024. US producers have significantly expanded their RD production capacity, from 4 mn t in 2021 to c.12 mn t in 2024, leaving the US as the largest RD producing country. Europe is the second largest RD producing region, with the Netherlands, Finland, Italy, Sweden, Spain and France leading the way.

Exhibit 74: 60% of renewable diesel is currently produced in North America
Renewable diesel supply, mn t



Source: Goldman Sachs Global Investment Research

Exhibit 75: China's biodiesel and RD exports declined significantly post import duties introduction
China biodiesel+RD exports to Europe, kt



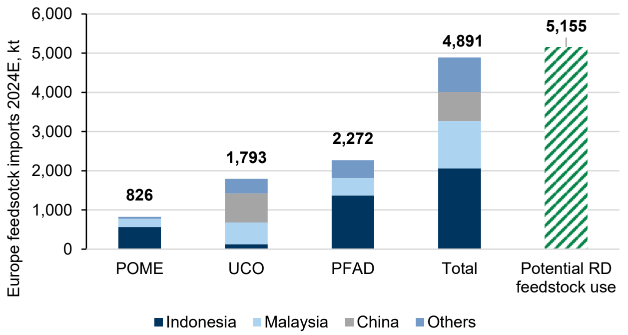
Source: Argus, Goldman Sachs Global Investment Research

Europe was 95% self-sufficient in 2024 in terms of renewable diesel consumption, on our estimates, given decreased imports of biodiesel and renewable diesel from China and sluggish demand. Going forward, we expect imports to increase from 2025, given regulatory demand support, RED3 adoption and redirection of Asian exports from the US to Europe, post a switch from blender's tax credit (BTC) to production tax credit (PTC): this should result in c.60% average self-sufficiency in 2025-2030, on our estimates. Europe also imports feedstock for renewable diesel production, which accounts for 70%-90% of total feedstock needs, on our estimates, in particular palm oil residues (POME and PFAD) and used cooking oil, mainly from Indonesia, Malaysia and China (Exhibit 76). China used cooking oil (UCO) accounts for c.14% of total feedstock needs for European renewable diesel production (based on 2024E 4.4 mn t RD production and an 85% feedstock yield).

There have been several developments in trade policies affecting feedstock and renewable diesel in Europe. In August 2023, the EU launched an investigation into allegations of unfairly traded biodiesel from China, and in July 2024 imposed provisional anti-dumping duties (final duties in February 2025) of between **10% and 35.6% on Chinese biodiesel (FAME) and HVO:** the 35.6% duty is effective for biodiesel and HVO from Chinese producers, while 40 companies that cooperated with the investigation benefited from a lower 21.7% duty, with EcoCeres Group granted discounted duty of 10%. Provisional measures took place from August 16, which were replaced with definitive measures from February 2025. At the same time, China removed a 13% tax rebate for UCO exports effective December 2024. According to newsflow, **key Chinese UCO producers set initial December and January contract UCO prices at $1,000-$1,050/mt, an increase of $100-$150/mt over previous rates.** Above that, in January 2025, Indonesia, the largest exporter of POME and PFAD to Europe, put export restrictions on UCO and palm oil residues (POME) to retain sufficient feedstock in the country to achieve its new 40% blending mandate. UCO and POME exporters will now have to secure an export allocation from the government. This could limit supply of POME oil to the European market.

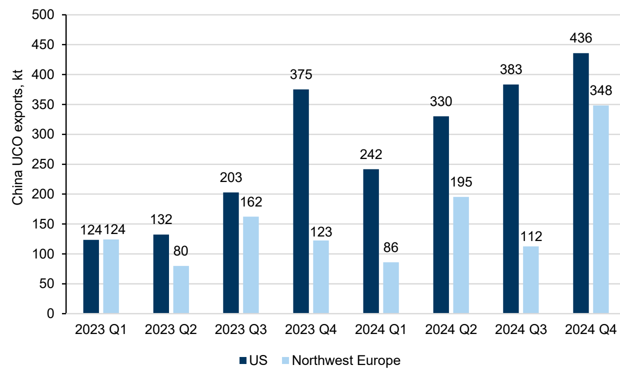
Differences in production costs and implications for Carbonomics cost curve: There is limited transparency in terms of differences in the levelized cost of RD production in China and Europe. However, we attempt to quantify this by making several key assumptions: Stratas' assessment shows that collecting UCO in Asia is around a third cheaper than in Europe; Reiters Scientific shows that UCO collector margin can vary between 33%-66%; based on our project database, we estimate RD plant capex in China at $800/t, while in Europe it is $1,200/t; and we assume processing costs in China to be 30% lower than in Europe owing to lower personnel and overhead costs. Our theoretical LCOE analysis of RD production in China yields a c.$1,500/t price at a 15% target return. In Europe, LCOE might be $300/t higher than in China at $1,800/t, primarily given a higher feedstock cost.

Exhibit 76: Europe imports feedstock for renewable diesel production, which accounts for 70%-90% of total feedstock needs, on our estimates
2024E European imports of biofuel feedstock, kt



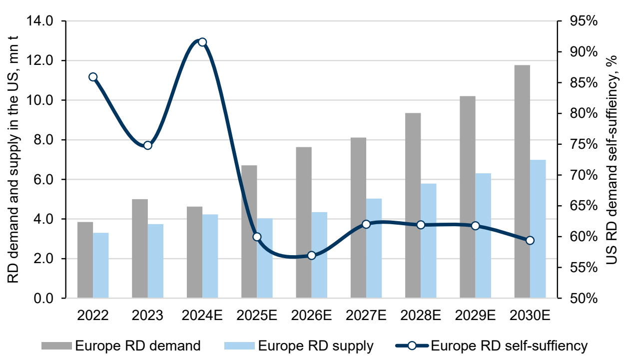
Source: Argus, S&P, Goldman Sachs Global Investment Research

Exhibit 77: China's exports of UCO to the US were increasing in 2024, yet we expect this to reverse post 45Z guidance publication where China UCO-based RD will not receive the credit
China UCO exports to Europe and US



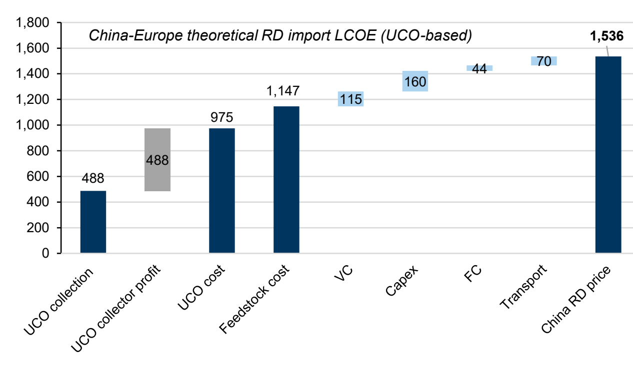
Source: Argus, Goldman Sachs Global Investment Research

Exhibit 78: We expect Europe RD self-suffiency to decrease as demand returns to growth in 2025, with SE Asia (Singapore) being the potential marginal supplier
Europe renewable diesel self-sufficiency



Source: Goldman Sachs Global Investment Research

Exhibit 79: Our theoretical LCOE analysis of RD production in China yields a c.$1,500/t price at a 15% target return
China-Europe theoretical RD import LCOE (UCO-based)

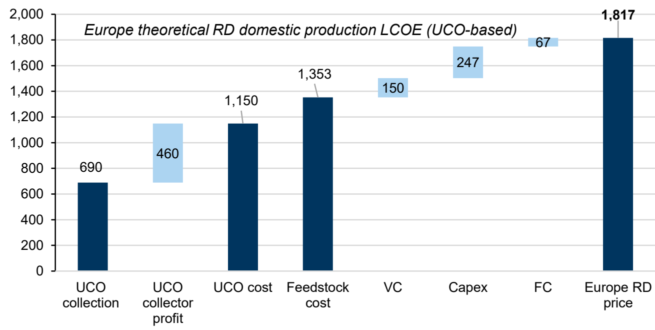


Based on 15% hurdle rate

Source: Goldman Sachs Global Investment Research

Exhibit 80: In Europe, LCOE might be $300/t higher, at $1,800/t, primarily given a higher feedstock cost

Europe theoretical RD domestic production LCOE (UCO-based)

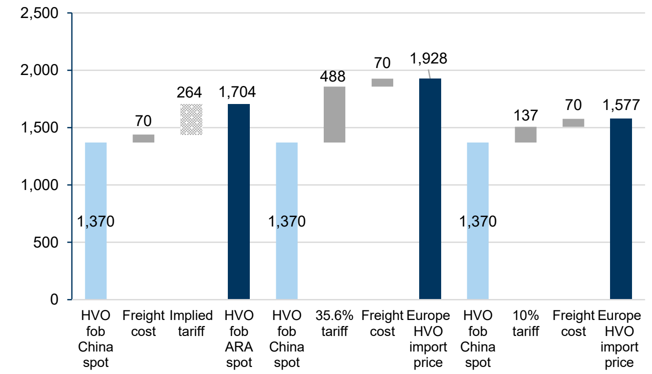


Based on 15% hurdle rate

Source: Goldman Sachs Global Investment Research

Exhibit 81: Current tariffs on China HVO to Europe imports vary from 10% to 35.6%

Bridge between China HVO and Europe HVO import price



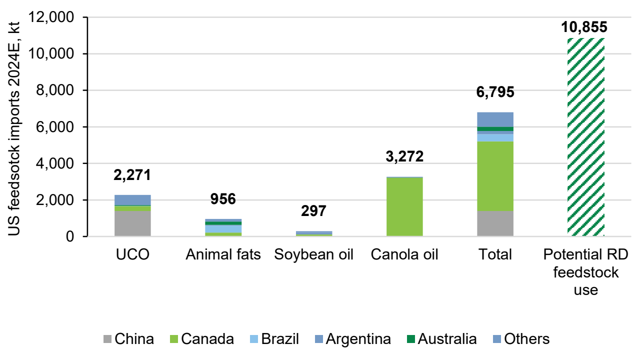
Spot prices as of Feb'19, 2025

Source: Argus, European Commission, Goldman Sachs Global Investment Research

The US was roughly 85% self-sufficient in 2024 consuming a total of 10.8 mn t RD, on our estimates, and importing around 1.6 mn t of RD: 1.3 mn t from Neste's Singapore and Rotterdam plants and 0.3 mn t from Canada's Braya refinery (link, link). The US also imports feedstock for renewable diesel production, which accounts for 50%-60% of total feedstock needs, on our estimates, in particular canola oil from Canada, used cooking oil from China and animal fats from South America and Canada (Exhibit 82). The US imported 1.4 mn t of UCO from China in 2024E, on our estimates, which makes up 13% of total feedstock needs for US renewable diesel production (based on 2024E 9.2 mn t RD production and an 85% feedstock yield). The US also imports canola oil from Canada as biodiesel/renewable diesel feedstock, which makes up 30% of total feedstock needs. The ramp-up of RD capacities launched in 2023/24, and switch from BTC to PTC which favours domestic producers, should drive an increase in US self-sufficiency, in our view, with a partial offset coming from RD facilities switching to SAF production, resulting in c.95% average self-sufficiency in 2025-2030, on our estimates.

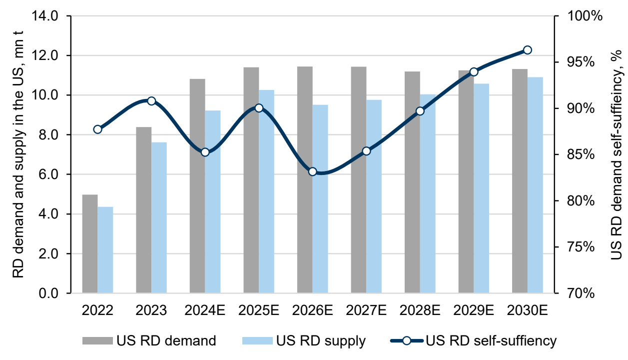
With the new administration in the US in place since January 2025, new import tariffs are planned for imports from China, Mexico and Canada: specifically, an additional 10% tariff on all imports from China, on top of existing tariffs, and a 25% tariff on all products from Mexico and Canada. This could redirect Chinese UCO flows from the US to Europe. Above this, biofuels made from imported UCO will not qualify for the 45Z tax credit under the GREET model, owing to concerns about transparency over sources of UCO imports and growing concerns of mislabeled UCO. We believe UCO imports will be partially redirected to Europe and partially used domestically in China for growing biofuels production. **Therefore, any additional tariffs on imports from China will likely not change renewable diesel landscape in the US materially, in our view, given 45Z guidance that disincentivizes imports of renewable diesel in general, and UCO from China in particular.**

Exhibit 82: The US imports feedstock for renewable diesel production, which accounts for 50%-60% of total feedstock needs, on our estimates
2024E US imports of biofuels feedstock, kt



Source: Argus, Goldman Sachs Global Investment Research

Exhibit 83: US RD market self-sufficiency should increase in 2025 on BTC-to-PTC switch; further out it will depend on SAF-RD price dynamics and producers' switch from RD to SAF production
US renewable diesel supply, demand and self-sufficiency

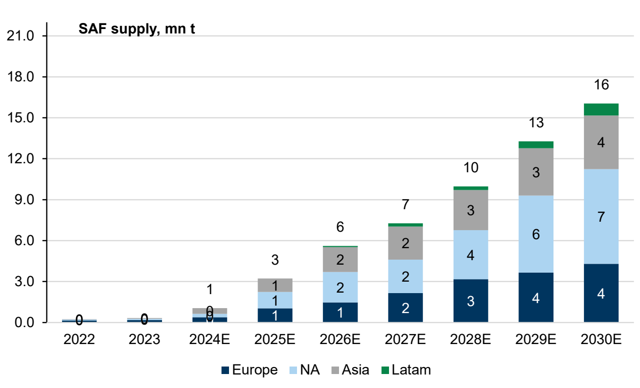


Source: Goldman Sachs Global Investment Research

SAF

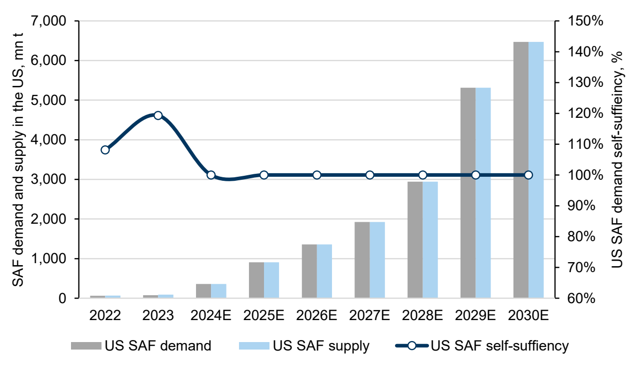
While renewable diesel has been produced for more than 10 years, the SAF industry is at much more nascent stage, with global SAF sales amounting to <1mn t in 2024, on our estimates, given the primarily voluntary nature of demand. From 2025, a SAF mandate starts in the EU and UK, which we expect to result in >3x market growth. We forecast c.3 mn t of production in 2025, roughly evenly split between Europe, Asia and the US. We expect SAF produced in Europe and the US to be largely consumed locally, while SAF produced in Asia (Singapore, China) should primarily be exported (with some part consumed locally).

Exhibit 84: We expect SAF supply to be more evenly split between North America, Europe and Asia
SAF supply, mn t



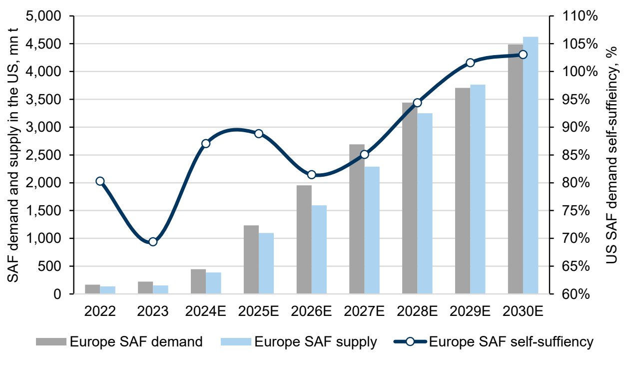
Source: Goldman Sachs Global Investment Research

Exhibit 85: We currently assume US SAF will be self-suffient this decade given BTC to PTC switch and still voluntary demand
US SAF supply, demand and self-sufficiency



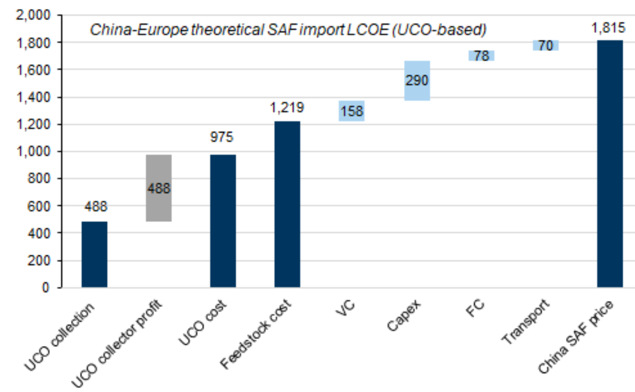
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 86: We expect European SAF self-sufficency to vary between 80% and 100% in 2025-2030 with some imports from SE Asia (Singapore)
Europe SAF supply, demand and self-sufficiency



Source: Company data, Goldman Sachs Global Investment Research

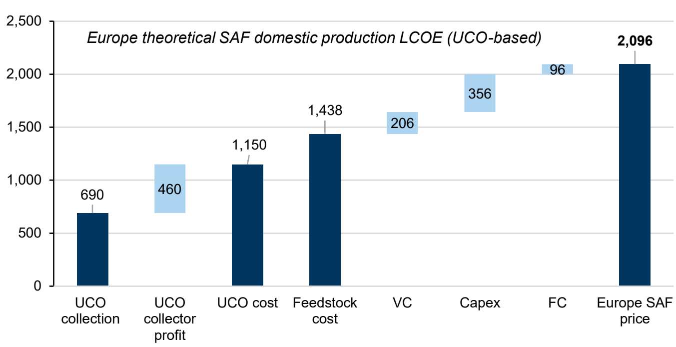
Exhibit 87: We estimate China having production costs at $1,815/t due to access to UCO feedstock and lower variable costs
China-Europe theoretical SAF import LCOE (UCO-based), $/t



Based on 15% hurdle rate

Source: Argus, Goldman Sachs Global Investment Research

Exhibit 88: Meanwhile, Europe SAF production costs are closer to $2,100/t driven by higher feedstock and variable costs
Europe theoretical SAF domestic production LCOE (UCO-based), $/t



Based on 15% hurdle rate

Source: Argus, Goldman Sachs Global Investment Research

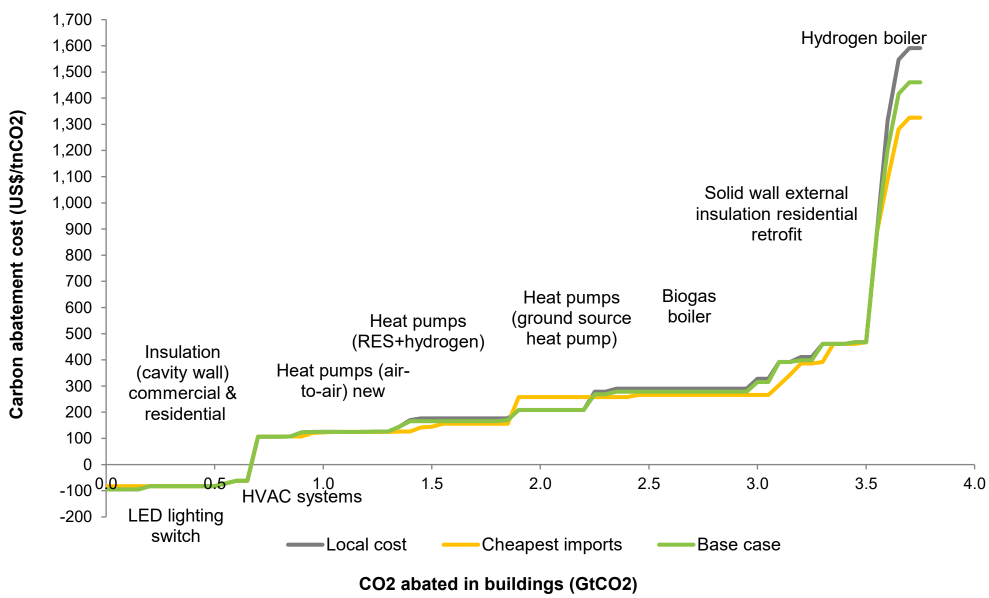
Green hydrogen: electrolysers

Buildings and industry cost curves

Both the buildings and industrial sectors rely on hydrogen as a key technology for decarbonization. The levelized cost of hydrogen (LCOH) is therefore the main variable impacting the price of the decarbonization technologies available, such as switching to a hydrogen boiler from a gas boiler in buildings, switching to H_2 DRI-EAF from the BF-BOF steel making route, and using green ammonia and green methanol production in industry. We look at the industry/buildings sectors' carbon abatement cost curves in three scenarios: our base case, a cheapest imports scenario, and a local cost of production scenario. For the H_2 price, we assume \$5.2/kg in our base case and apply a -/+10% discount/premium for the cheapest imports scenario and local production cost scenario.

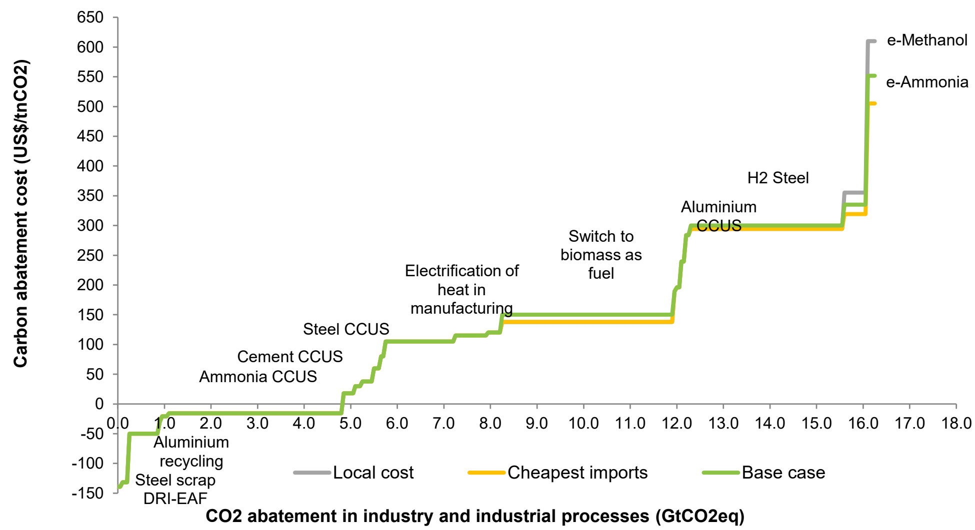
Overall, for **Industry, the weighted-average carbon abatement cost does not vary significantly across three scenarios, being in the range of \$130-132/t.** For **Buildings, the weighted-average carbon abatement cost stands at \$234/t in the cheapest imports case, \$243/t in the base case and \$254/t in the local cost of production case.**

Exhibit 89: The LCOH is the main variable that impacts the price of the decarbonisation technologies such as switching to a hydrogen boiler from a gas boiler in buildings...
Carbon abatement cost curve for anthropogenic GHG emissions in buildings sector in three scenarios



Source: Goldman Sachs Global Investment Research

Exhibit 90: ...switching to H2 DRI-EAF from the BF-BOF steel making route, and using green ammonia and green methanol in Industry
Carbon abatement cost curve for anthropogenic GHG emissions in industry sector in three scenarios



Source: Goldman Sachs Global Investment Research

Electrolyser manufacturers currently focus their operations within their home countries, but future expansion plans may lead to their presence in international markets

Global announced electrolyser capacity reached 25 GW in 2023, with 6.5GW reaching FID in the last 12 months. This capacity is heavily underutilized, with only 2.5 GW of output in 2023. Considering projects with FID or under construction, capacity could have reached more than 40 GW/yr in 2024. **China is the current global leader in electrolyser manufacturing capacity, holding c.60% of global capacity and securing over 40% of global FIDs for new projects.** This leadership is supported by China's mass production capabilities, which have helped reduce costs. Many large Chinese manufacturers, previously focused on solar panels, have shifted toward electrolyser production.

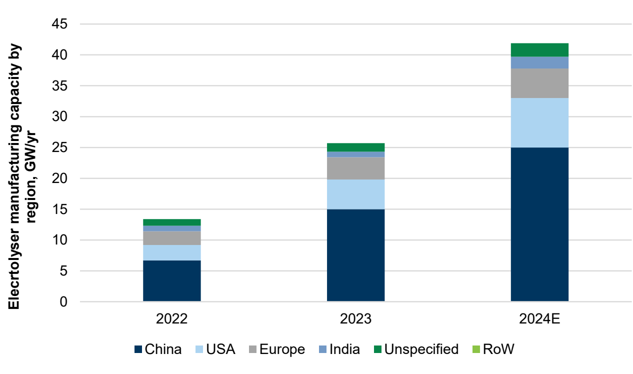
Chinese companies are significantly increasing their manufacturing capacity to meet the growing domestic demand for electrolysers, with most of the expansions taking place in China. European manufacturers are also entering the Chinese market, primarily through partnerships and JVs with local firms, such as the collaboration of John Cockerill with Chinese partner Cockerill Jingli Hydrogen (CJH) to develop a plant in Suzhou, and collaboration of HydrogenPro from Norway with Tianjin Mainland. Similar to Chinese companies, **leading manufacturers in Europe and the US tend to have most of their production domestically based**. As of now, the international trade of electrolysers remains limited: only about 1.4 GW of the global installed water electrolyser capacity has been shipped across borders, accounting for less than 20% of the total.

In Europe, electrolyser manufacturing is gaining momentum, but its capacity remains far below that of China. Over the past year, Europe's FIDs for electrolyser projects have quadrupled, surpassing 2 GW of new capacity. Europe is actively expanding its domestic electrolyser manufacturing capacity to support the production of green hydrogen. **As of 2023, Europe holds c.15% of global electrolyser manufacturing capacity and supplies almost all the elctrolysers needed within the European market. Domestic electrolyser manufacturers currently dominate sales to European hydrogen projects, accounting for 80%-90% of sales since 2022, far exceeding the Net Zero Industry Act target of 40%.** However, funding seems concentrated in a limited number of countries in the EU.

Foreign companies (mainly Chinese) currently dominate electrolyser manufacturing globally, which means more non-European electrolysers could end up being used in European projects over time. The influx of cheaper electrolyser imports from countries such as China has raised concern among European manufacturers. In the first European hydrogen bank auction, around 15% of the submitted projects planned to use Chinese electrolysers. Industry leaders have called on the EU to implement measures that ensure a level playing field, such as introducing "made in Europe" requirements in the second EU hydrogen bank auction to protect domestic technology and reduce reliance on non-European imports. The new eligibility criteria for the second auction include limiting electrolyser stack sourcing from China to a maximum of 25% (in MWe), along with other manufacturing steps, as well as requiring mandatory compliance with European and international safety and cybersecurity standards.

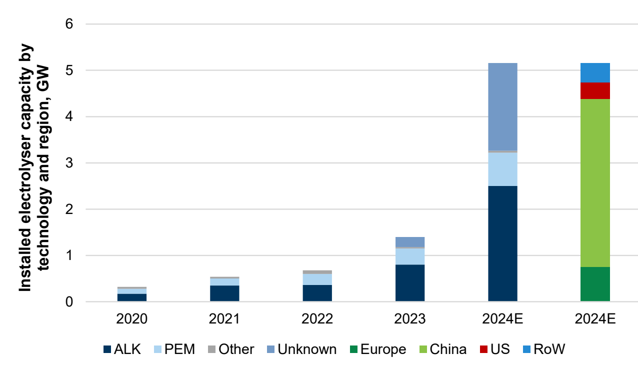
As of 2023, the US has c.20% of global electrolyser manufacturing capacity, with existing and planned electrolyzer installations (including firm announcements and those under construction) totaling approximately 4.5 GW as of May 2024.

Exhibit 91: China is the current global leader in electrolyser manufacturing capacity...
Electrolyser manufacturing capacity by region, GW/yr



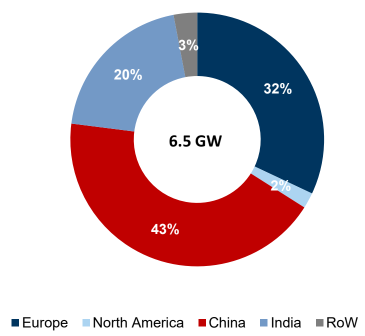
Source: IEA

Exhibit 92: ...holding c.60% of the global total...
Installed electrolyser capacity by technology and region, GW



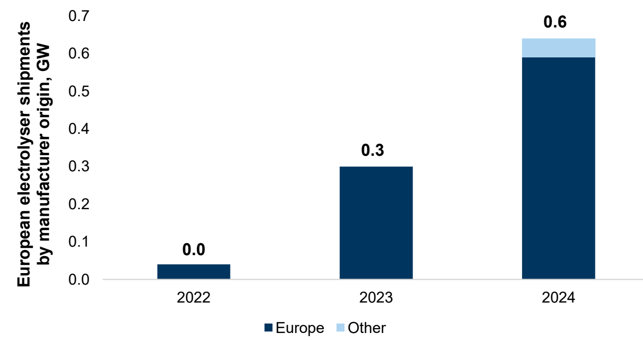
Source: IEA

Exhibit 93: ...and securing over 40% of global FIDs for new projects
Electrolysis capacity that reached FID between September 2023 and August 2024, by region and sector



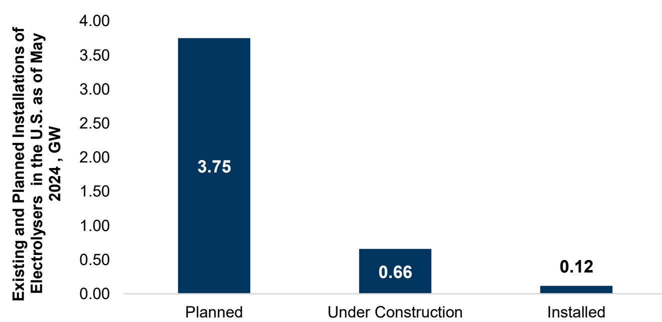
Source: IEA

Exhibit 94: Domestic electrolyser manufacturers currently dominate sales to European hydrogen projects, accounting for 80%-90% of sales since 2022
European electrolyser shipments by manufacturer origin, GW



Source: BloombergNEF

Exhibit 95: In the US, existing and planned electrolyzer installations (including firm announcements and those under construction) totaled approximately 4.5 GW as of May 2024



Source: DOE

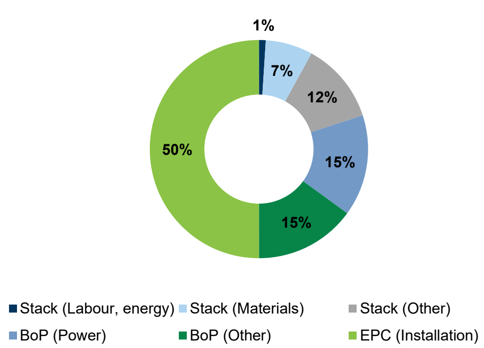
Western electrolysers are currently more expensive than Chinese ones but higher energy efficiency and durability can make up for the cost difference

As mentioned above, China has emerged as the main electrolyser manufacturer (it accounts for around 60% of planned electrolyser manufacturing capacity globally). Electrolyser capex consists of the upfront costs incurred to build and commission an electrolyser system. This includes the electorlyser stack (core components like electrodes, membranes and catalysts), the balance of plant (BoP), installation and integration costs, EPC services and contingency costs for unforeseen expenses. Chinese alkaline electrolysers (BoS+BoP) are up to four times cheaper than Western equivalents, however when factoring in installation costs, EPS and contingency, the overall price difference becomes much smaller. **The price of exported, Chinese ALK installed electrolysers are roughly 40% cheaper than the cost of ALK electrolyser prices in Germany while Chinese PEM installed electrolyser export prices are not much different from Western counterparts.**

The cost of an installed water electrolyser has increased in the past years, with inflation affecting materials and labour costs, and higher interest rates. In 2023, the capital cost for an installed electrolyser (including the equipment, gas treatment, plant balancing, and engineering, procurement and construction cost, and contingencies) ranged between US$2,000/kW for alkaline and US$2,450/kW for PEM electrolysers, according to the IEA. Alkaline electrolysers manufactured in China are cheaper than those produced in Europe or North America in terms of capex, and can reach around US$750/kW-1,300/kW for an installed system.

Despite being cheaper to buy, the performance inferiority of Chinese electrolysers means their LCOH would actually be comparable to the western ones. Chinese electrolysers are less efficient and reliable with shorter lifespans and reduced performance. European machines are more advanced in handling heat and gas flow, which improves efficiency and provides an economic advantage. They also feature better control systems that distribute loads more evenly and slow down wear and tear, resulting in longer operational lifetimes. Chinese electrolysers use thicker separators in their stacks (1mm compared to under 0.5mm in Western machines), which reduce current density and efficiency. Additionally, Chinese manufacturers often rely on lower-grade materials, like porous nickel for electrodes, whereas European elecrtolysers use more advanced, high-performance nickel-based alloys. In Exhibit 99 we present a comparison of Chinese and Western electrolysers. In Exhibit 100, we compare the LCOH of these across two markets: Europe and the US. On our estimates, **using exported Chinese ALK electrolysers results in an LCOH that is c.8%-11% lower than when using Western electrolysers, while Chinese PEM electrolysers result in similar LCOH to Western ones.**

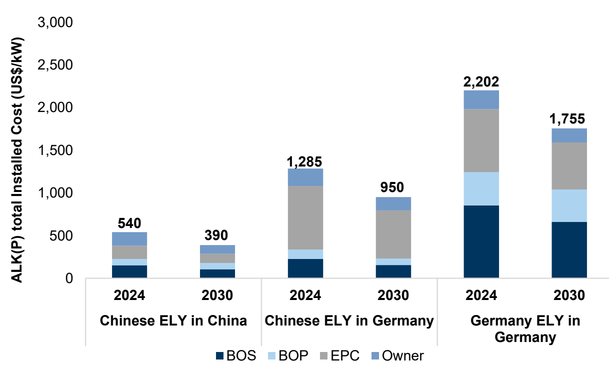
Exhibit 96: Electrolyser capex by component, %



Source: Goldman Sachs Global Investment Research

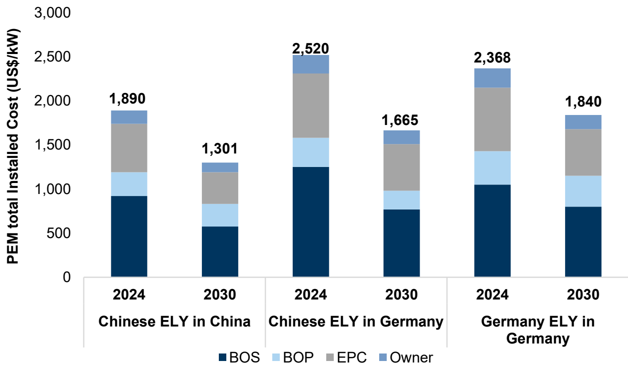
Exhibit 97: The prices of exported, Chinese ALK installed electrolysers are roughly 40% less than the cost of ALK electrolysers in Germany...

Alkaline electrolyser total installed cost, US$/kW



Source: Wood Mackenzie Lens Hydrogen

Exhibit 98: ...while Chinese PEM installed electrolyser export prices are not much different from Western counterparts
PEM electrolyser total installed cost, US$/kW



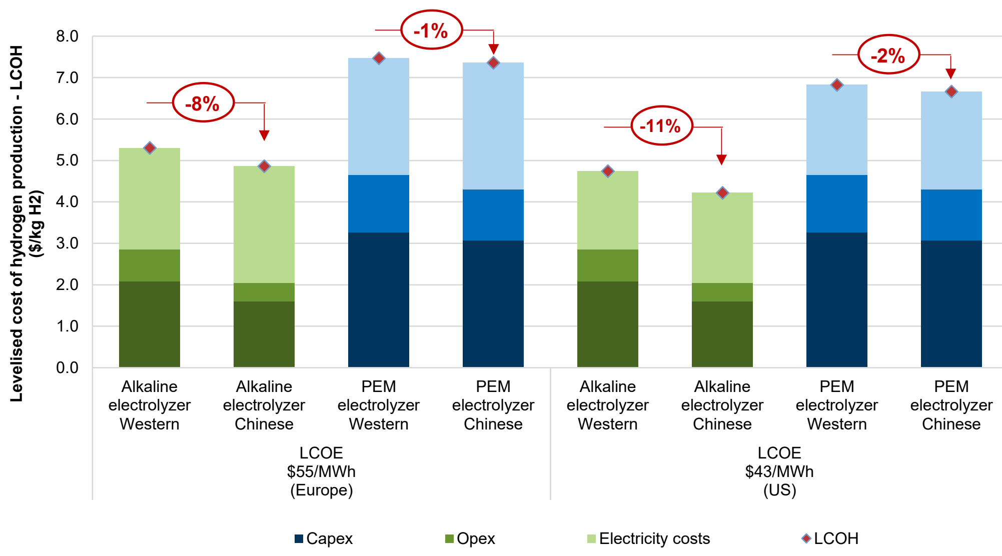
Source: Wood Mackenzie Lens Hydrogen

Exhibit 99: Comparison of Chinese and Western electrolysers

Criteria	Chinese	Western (EU/US)	Remarks
Capex (USD/kW), incl. installation	US$ 750-1,300/kW (ALK) US$ 2,000-2,700/kW (PEM)	US$ 1,800-2,200/kW (ALK) US$ 2,300-3,000/kW (PEM)	Chinese manufacturers achieve lower capex due to economies of scale and cheaper components. While Western manufacturers focus more on quality and realibility.
Energy Efficiency	65-70% (ALK); 55-60% (PEM)	68-73% (ALK); 60-70% (PEM)	Chinese electrolysers often have thicker separators in their stacks (around 1 mm) compared to Western designs (<0.5mm). This results in lower current densities and reduced efficiency.
Durability (hours)	60,000-70,000 (ALK) 50,000-60,000 (PEM)	60,000-100,000 (ALK) 50,000-90,000 (PEM)	Western electrolysers, esp. alkaline, tend to have longer durability, reducing replacement costs over time.
Delivery time	3-6 months	6-12 months	Chinese manufacturers typically have shorter lead times due to larger production capacity.

Source: Goldman Sachs Global Investment Research

Exhibit 100: Using exported Chinese ALK electrolysers results in an LCOH that is c.8%-11% lower than when using Western electrolysers, while Chinese PEM electrolysers result in similar LCOH to Western
LCOH depending on the electorlysers origin, $/kgH2



Source: Goldman Sachs Global Investment Research

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Reg AC

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