Goldman Sachs

Carbonomics

The Future of Energy in the Age of Climate Change

Climate change is re-shaping the energy industry through technological innovation and capital markets pressure. Our **cost curve of de-carbonization** shows an abundance of large, low-cost investment opportunities in power generation, industry, mobility, buildings and nature-based solutions. However, these will not be sufficient to mitigate the worst effects of climate change. Reducing net carbon emissions on this scale requires carbon pricing, technological innovation and a growing role for CO2 sequestration. **Capital markets are taking a leading role** in financing the energy transition, while tightening financing for hydrocarbon assets. This is likely to drive the **energy transition through higher energy prices,** lowering the systemic risk of stranded assets. A new Age of Restraint on new hydrocarbon developments is leading to **consolidation and higher barriers to entry** in the oil & gas industry, with Big Oils transitioning to **Big Energy** and **non-OPEC oil supply growth terminating by 2021.**

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This is a redacted report

The following is a redacted version of the Goldman Sachs Research report "Carbonomics: The Future of Energy in the Age of Climate Change" that was originally published on Dec. 11, 2019 (42pgs). All company references in this note are for illustrative purposes only and should not be interpreted as investment recommendations.

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Carbonomics PM Summary: All the Rules on Energy Investing Change in the Age of Climate Change

Climate change is re-shaping the energy industry through technological innovation and capital markets pressure, as we analyse in this report. Our modeling of the cost curves for carbon conservation (technologies for not emitting CO2) and sequestration (natural or artificial processes to remove carbon from the atmosphere) show large investment opportunities in low-cost ways to conserve (mainly in power generation, but also in buildings, industry and mobility) and sequester (forests and pastures) carbon today that should make a meaningful impact to global net emissions. However, as the conservation cost curve becomes steeper, the volume of low-cost conservation and sequestration is no longer sufficient to meet the scale and pace of net carbon reduction needed to mitigate the worst effects of climate change. As such, we believe that **further technological innovation will be critical to achieve net zero carbon and that emerging sequestration technologies will have an important role to play.** This report also looks at how legacy hydrocarbon businesses are changing under the pressure of capital markets. The increasingly active role of capital markets in tightening financing for hydrocarbon assets is forcing a dramatic change to the industrial landscape of the oil & gas industry, leading to consolidation and capital restraint, with important consequences for corporate returns and the outlook for oil prices in a new 'Age of Restraint'.

The cost curve of de-carbonization is steep, calling for more technological innovation, carbon pricing and a growing role of CO2 sequestration

We have constructed a carbon abatement cost curve for conservation technologies that are currently available at commercial scale across key industries globally: power generation, industry, transport, buildings and agriculture. The resulting carbon abatement cost curve is steep, with large investment opportunities in low-cost areas, particularly in power generation, but rapidly rising costs as we move to higher levels of de-carbonisation. At the current costs of commercially available CO2-abatement technologies, we estimate that **c.50% of current anthropogenic GHG emissions can be abated at an implied CO2 price of less than US$200/tnCO2eq** (ton of carbon dioxide equivalent, including the impact of other greenhouse gases, such as methane and nitrous oxide, converted in terms of the amount of CO2 that would create the same amount of warming). Carbon prices of less than US$100/tnCO2eq would transform the power generation industry from carbon-intensive fuels (coal and oil) to cleaner alternatives (gas, solar, wind), but would make little impact in mobility, industry or buildings, excluding technology-specific incentives. Most notably, we estimate that c.25% of total current anthropogenic GHG emissions are not abatable under currently available large-scale commercial technologies. This is why we believe that further technological innovation and greater investment in sequestration technologies will be needed in order to achieve net zero carbon emissions. Although carbon sequestration has seen a revival in recent years, it has not yet reached large-scale adoption and economies of scale that traditionally lead to a breakthrough in cost competitiveness, especially when compared with other CO2-reducing technologies such as renewables, with **investments in carbon capture, utilisation and storage (CCUS) plants over the past decade <1% of the investments in renewable power**. In particular, direct air carbon capture and storage (DACCS) has highly uncertain economics, with most estimates between $40-400/ton (at scale) and only small pilot plants currently in activity. The importance of DACCS lies in its potential to be almost infinitely scalable and standardizable, therefore potentially setting the price of carbon in a net zero emission scenario.

Capital markets are taking a leading role in financing the energy transition, while severely tightening financing for new hydrocarbon assets

Over the past eight years, **investors have taken an increasingly active role in pushing corporate management towards incorporating climate change into their business plans and strategy**. The number of **climate-related shareholder proposals** has almost doubled since 2011 and the % of investors voting in favour has tripled over the same time period. This investor pressure, however, is not evenly distributed across sectors and has a clear bias towards energy producers vs. energy consumers. Data from ProxyInsight shows 50% of proposals target the energy producers (oil & gas, utilities, coal), with a further 10% targeting financial institutions that lend to energy producers. In our view, **this is creating a severe tightening of financing conditions across the hydrocarbon industry, leading to a new age of capital constraint**: (1) Reserve-based lending to E&Ps for new oil & gas developments is down 90% from the peak. Reserve-based lending (long-term lending collateralized with the oil & gas reserves underground) was the financing of choice for E&Ps and some NOCs as international operators of mega-projects in the 2000s. High yield credit to the US E&Ps, the financing of choice of smaller US shale producers, has also dried up since the beginning of 2019, leading to a 25% fall in US shale activity ytd; (2) NOCs are moving away from aggressive international expansion as they focus on higher-return domestic investments, gas and downstream value chains. Between 2003 and 2014, oil prices rose well above the budget breakevens of OPEC countries, creating US$1.6 tn of surplus that was partially re-invested in oil & gas capex, financing the international expansion of NOCs. Since 2014, the substantial fall in oil prices has pushed NOCs to retrench to their home basins, making them net sellers of resources and incentivizing stronger collaboration with Big Oils; and (3) Big Oils' carbon reduction ambitions reduce their ability to accelerate oil field developments. As we discussed in our report Re-imagining Big Oils, we believe it is strategically imperative for Big Oils to transform into Big Energy, in line with the global ambition to contain climate change.

Tightening financial conditions on new hydrocarbon developments is leading to consolidation and higher barriers to entry in the traditional oil & gas industry

The period between 2004-16 saw two oil & gas revolutions, fuelled by cheap financing, leading to industry fragmentation and a compounded 10% cost inflation. The first oil & gas revolution (2004-13) was driven by National Oil Companies (**NOCs**) that deployed their rising free cash flow into rapid international expansion, with a combination of exploration and M&A activities. The second oil & gas revolution (2009-16) was led by US exploration & production companies, unlocking 100+ bn bls of **US shale oil** resources. We believe these revolutions are over, with the market turning away from resource expansion in the wake of the low carbon transition, and financial conditions tightening across the industry. **Since 2014, the industry structure started to rationalize into a more concentrated one, with a small group of companies (the new 'Seven Sisters') emerging as structural winners**, continuing to sanction projects consistently through 2014-18. The three drivers of tighter financial conditions for new oil fields outlined above are raising the barriers to entry while increasing the equity risk premium on new long-cycle developments, leading to a more concentrated industry structure with higher returns and lower volume growth. Over the last five years, Big Oils have doubled their market share in long-cycle developments and US shale oil, re-establishing the attractive returns that were lost during the oil & gas revolutions of the 2000s. Project IRR troughed in 2006-14 at 10%-15% on the back of excessive competition. We estimate that the FIDs taken (mainly by Big Oils) from 2015 to 2020E will instead yield a profitability more consistent with what the industry saw in the 1990s: 20%-30% project IRR, which should be consistent with ROACE recovering to 15%+. **This restoration of profitability through scale, concentration and standardization is leading Big Oils to a position where they can leverage the higher returns from their traditional oil & gas business to foster innovation and investment in their transition towards Big Energy.**

Big Oils have an important role to play in the de-carbonization process, as they become Big Energy, providing technology, capital and risk management capabilities

Big Oils have shown tremendous ability to adapt to technological change in their 100+ years of history. We believe it is now strategic that they drive a low-carbon transition consistent with the global ambition to contain global warming within 2° C. We believe **Big Oils have many tools to achieve this transition towards Big Energy and become broader, cleaner energy providers, such as**: a deeper presence in the **global gas and power chains**, including retail, EV charging and renewables; **biofuels**; **petrochemicals**; improved upstream and industrial operations; **nature-based solutions** and **carbon capture**. In our deep-dive analysis, 'Re-Imagining Big Oils', we discussed the options available and argue that the strategic objective can be delivered with improving corporate returns and renewed value for scale and integration. This transition will require deep cultural and corporate changes and may leave the higher carbon parts of the value chain financially stranded and underinvested, such as oil production. We estimate that this transition, if fully embraced and executed, has the potential to lead to a 20%+ reduction in greenhouse gas emissions (GHG) by 2030 in Big Oils' direct operations but also on a 'well to wheel' basis, consistent with a 2° C scenario.

Structural underinvestment in oil to bring an end to non-OPEC oil production growth from 2021

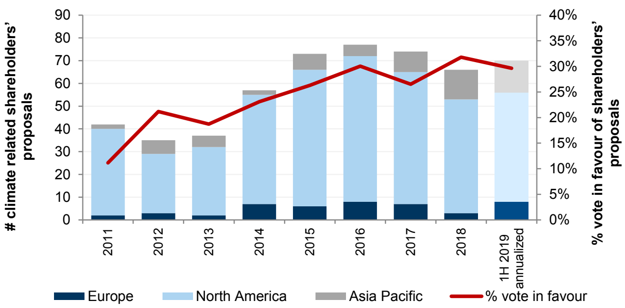
The under-investment in the oil sector that followed the 2014 oil price downturn, combined with the de-carbonization focus is, according to our Top Projects analysis, putting an end to a decade of credit-fuelled shale oil hypergrowth and **we now expect non-OPEC production to stop growing from 2021**. This comes on the back of both: (1) **a thinner pipeline of mega long-cycle developments** leading to declining production ex-shale from 2021, and (2) **a deceleration in US shale growth** owing to higher declines from a larger production base, a reduction in profitable drilling locations and slowing productivity improvements. The intensified focus on de-carbonisation and substantial tightening of financial conditions lead us to believe that this supply tightness post 2020 is structural in nature.

While de-carbonization is drastically changing the supply landscape of oil & gas, demand in the medium term remains robust under the vast majority of potential de-carbonization scenarios

While we see supply tightness post 2020 in the oil market, as a direct result of under-investment and tightening financial conditions in the industry, demand growth is currently the variable most investors are focusing on. **We analyze several scenarios of de-carbonization of transport, power generation and plastic recycling**, showing that the demand for both oil and gas is likely to remain robust under the vast majority of decarbonisation scenarios in the medium term (to 2030 for oil and to 2040 for gas). This supports our view that the capital market focus on de-carbonisation is changing the supply dynamics of the industry much faster than its demand dynamics, will result in a tight oil & gas market in the 2020s and is likely to lead to **a de-carbonization process through higher, not lower, energy prices**.

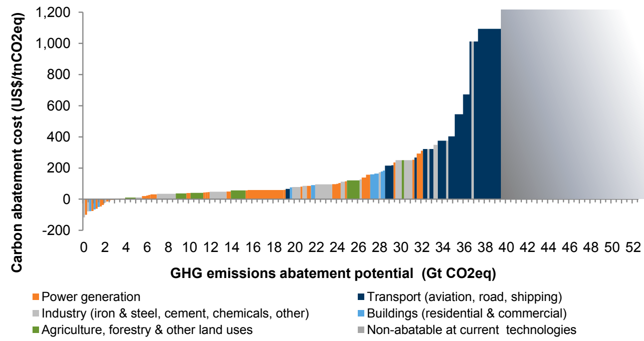
Carbonomics in 12 charts

Exhibit 1: Capital Markets are assuming a key role in the climate change debate...
Number of climate-related shareholders' proposals vs. % vote in favour



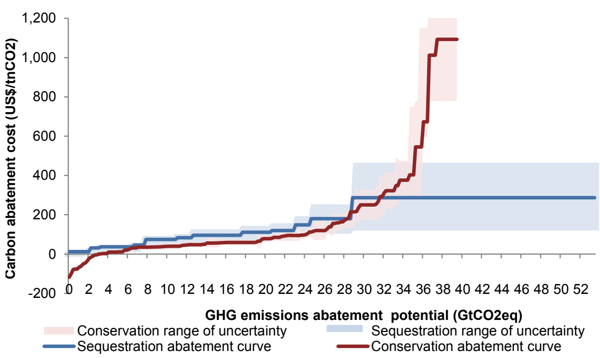
Source: ProxyInsight, Data compiled by Goldman Sachs Global Investment Research

Exhibit 2: ...as de-carbonization successfully starts in power generation, but faces a steep cost curve...
Conservation carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and associated costs



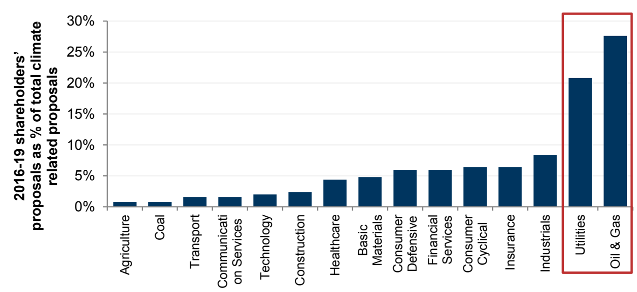
Source: Goldman Sachs Global Investment Research

Exhibit 3: ...with an important future role for technological innovation and sequestration technologies...
Sequestration and Conservation carbon abatement cost curves with associated range of uncertainty



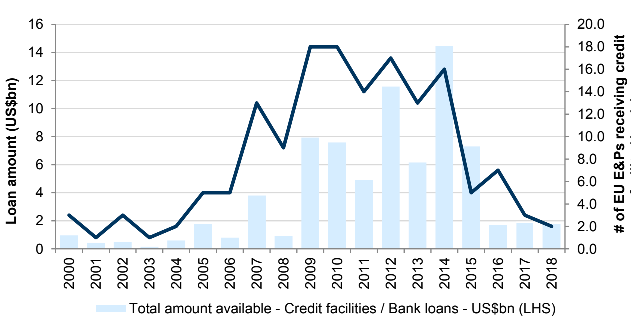
Source: Global CCS Institute, Goldman Sachs Global Investment Research

Exhibit 4: The energy sector faces increasing investor climate change activism...
Split of climate-related shareholder proposals, 2016-19 average, by industry



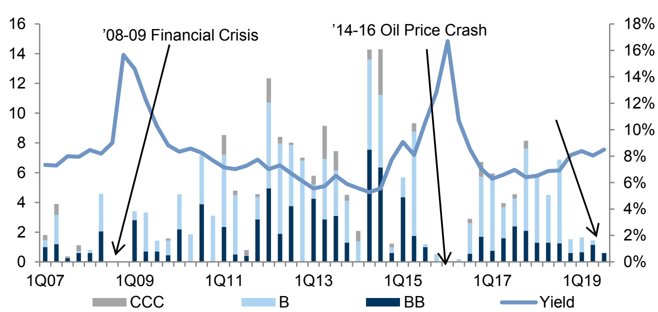
Source: ProxyInsight, Goldman Sachs Global Investment Research

Exhibit 5: ...resulting in tighter financial conditions and structural underinvestment
EU E&Ps total amount raised through credit facilities/bank loans, US$bn



Source: Bloomberg, Goldman Sachs Global Investment Research

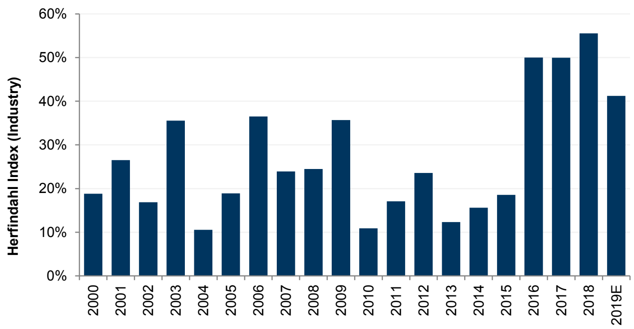
Exhibit 6: ...including US E&Ps with HY credit issuance at historically low levels
Credit issuance by HY US E&Ps (LHS US$ bn) and yield in % (RHS)



Source: Bloomberg, Dealogic, Goldman Sachs Global Investment Research

Exhibit 7: Tighter financing and higher barriers to entry are leading to industry consolidation...

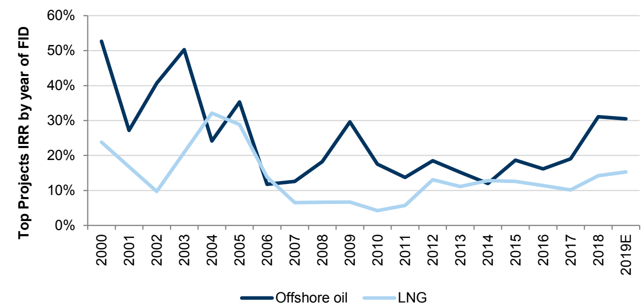
Herfindahl Index, Top Projects capex by operator at time of FID



Source: Goldman Sachs Global Investment Research

Exhibit 8: ...and rising returns for the few companies still capable of developing oil & gas new mega-projects

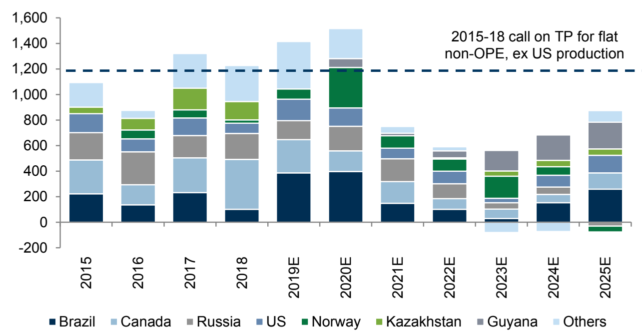
Top Projects IRR by year of FID split by winzone



Source: Goldman Sachs Global Investment Research

Exhibit 9: Structural underinvestment is starting to impact oil supply, leading non-OPEC ex-growth from 2021...

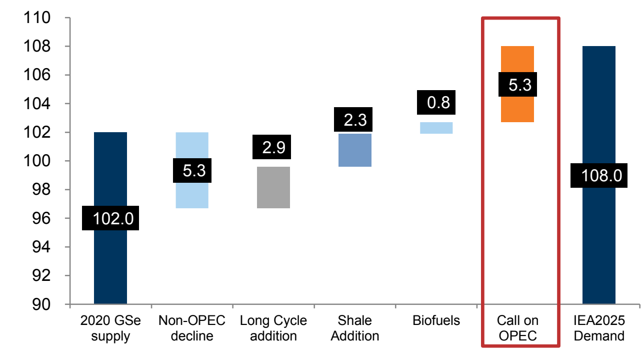
Liquids production yoy growth (kblpd) from non-OPEC excluding shale projects



Source: Goldman Sachs Global Investment Research

Exhibit 10: ...creating a large call on OPEC in the 2020s...

Key drivers of oil supply growth over 2020-25E (mn blpd)



Source: IEA WEO 2018, Goldman Sachs Global Investment Research

Exhibit 11: ...while oil demand remains robust to 2030 under most de-carbonization scenarios...

Oil demand in transport CAGR 2018-30 scenario analysis for different EV penetration and GDP scenarios

Total oil demand CAGR 2018-30 (%)

GDP growth to 2020-30 (%)	% EV penetration (EV & hybrid) by 2030: 5%	10%	15%	20%	25%	30%	35%	40%
3.9%	1.01%	0.92%	0.83%	0.75%	0.66%	0.57%	0.48%	0.39%
3.7%	0.93%	0.85%	0.76%	0.67%	0.58%	0.49%	0.40%	0.31%
3.5%	0.86%	0.77%	0.68%	0.60%	0.51%	0.42%	0.32%	0.23%
3.3%	0.79%	0.70%	0.61%	0.52%	0.43%	0.34%	0.25%	0.16%
3.0%	0.68%	0.59%	0.50%	0.41%	0.32%	0.23%	0.13%	0.04%
2.8%	0.61%	0.52%	0.43%	0.34%	0.25%	0.15%	0.06%	-0.04%
2.5%	0.50%	0.41%	0.32%	0.23%	0.14%	0.04%	-0.05%	-0.15%
2.3%	0.43%	0.34%	0.25%	0.16%	0.07%	-0.03%	-0.12%	-0.22%

** Evs penetration includes 56% EV and 44% PHEV*

Source: Goldman Sachs Global Investment Research

Exhibit 12: ...as does the demand for gas, with longer-term visibility to 2040

Natural gas demand CAGR 2018-40 in power generation under different scenarios of coal and renewables mix

Natural gas CAGR 2018-40 in power generation (%)

Coal in electricity generation mix (%) - 2040	Renewables share in electricity generation mix (%) - 2040: 40%	45%	50%	55%	60%	65%
25%	2.4%	0.6%	0.0%	-1.6%	-4.4%	-13.2%
20%	3.3%	2.4%	1.2%	0.1%	-1.6%	-4.6%
15%	4.0%	3.2%	2.2%	1.4%	0.1%	-1.7%
10%	4.6%	3.9%	3.1%	2.4%	1.4%	0.0%
5%	5.1%	4.5%	3.8%	3.2%	2.4%	1.3%

** Assumming electricity generation grows by 2% CAGR 2018-40*

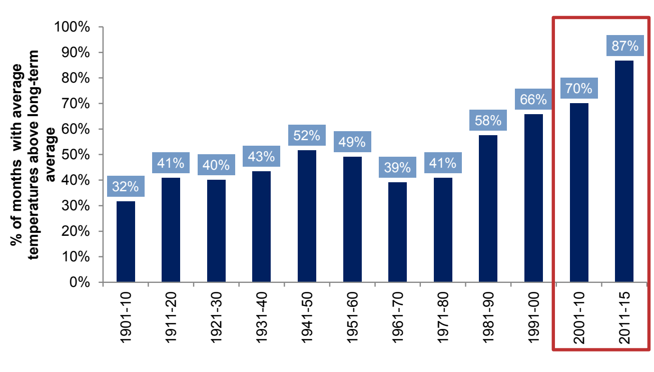
*** Renewables include solar, wind, hydro, geothermal & biomass*

Source: Goldman Sachs Global Investment Research

Higher temperatures and environmental damage enhance capital markets focus on climate change

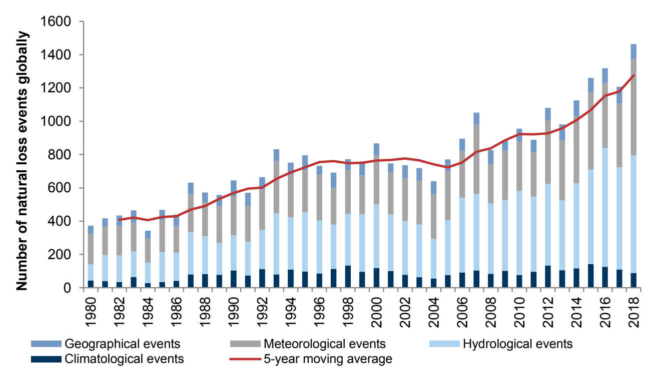
Climate change is a top of mind topic amongst policy-makers, scientists and investors and is re-shaping the future of the energy industry through financing, regulation, technological innovation and investor activism, with a seismic shift in the global landscape of capital allocation. This comes on the back of temperatures being on a persistently upwards trajectory while the frequency of natural disasters across the globe has increased materially over the past decade. While there is still debate about whether it is possible to attribute the increase in both the number and severity of these natural catastrophes directly to climate change, there is a general acceptance that the frequency of at least some of these events, such as extreme heatwaves, flooding and wildfires, have indeed a considerable correlation with global warming. The Global Markets Institute analysed the opportunities and costs of urban adaptation to climate change in 'Taking the heat: Making cities resilient to climate change'. Natural loss-related events are typically classified into four categories: (1) geophysical events (e.g. earthquakes, dry mass movements and volcanic eruption), (2) weather-related events (e.g. flooding and storm surges), (3) climatological events (e.g. heatwaves, droughts and wildfires) and (4) meteorological events (e.g. tropical storms and windstorms). The data suggests that the number of natural hazard-related insurance loss incidents is now rising at a rate of roughly 5% to 6% per annum, compared to the 10-year historical average of 2%-4%. Weather-related events are an important driver. In 2018, weather-related events alone accounted for about 90% of both the total number of natural hazards and the financial losses from such hazards (exhibit 14). What's more, over the past decade, weather-related damages have reached roughly $2.8 trillion, which is more than 30% above cumulative losses from the prior decade.

Exhibit 13: The frequency of above-average temperatures has risen substantially over the past decade...
% of months with mean temperatures above the long-term average



Source: World Bank Group, Goldman Sachs Global Investment Research

Exhibit 14: ...with the number of natural catastrophe-related loss events globally having increased materially over recent years
Number of natural loss events globally



Source: Munich Re- NatCatSERVICE (2019), Goldman Sachs Global Investment Research

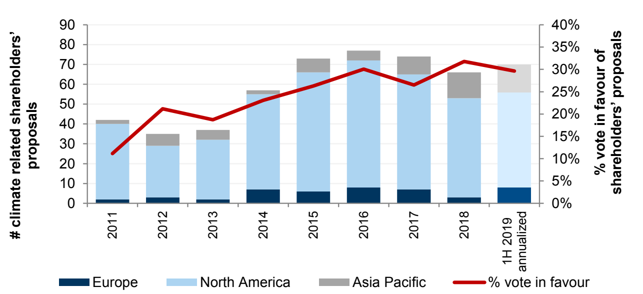
De-carbonization has structurally changed capital markets access for hydrocarbon producers

Climate change is shaping the future of the energy sector, with investors taking an increasingly active role in driving the low-carbon transition for energy companies

With current emissions on a persisting upwards trajectory, **investors are emerging with a leading role in driving the climate change debate,** pushing corporate management towards incorporating climate change into their business plans and strategy. **The number of climate-related shareholder proposals has almost doubled since 2011 and the % of investors voting in favour has tripled over the same time period**. This investor pressure, however, is not evenly distributed across sectors and has a clear bias towards energy producers vs. energy consumers. Data from ProxyInsight shows 50% of proposals target the energy producers (oil & gas, utilities, coal), while only 30% of the proposals target the sectors that account for most of the final energy consumption. In particular, transport, agriculture, basic materials and construction account for only 10% of total climate change shareholder proposals, while the focus on utility and oil & gas companies has been the highest and substantially increased over the past few years.

Exhibit 15: Shareholders are pushing energy companies to embrace the energy transition...

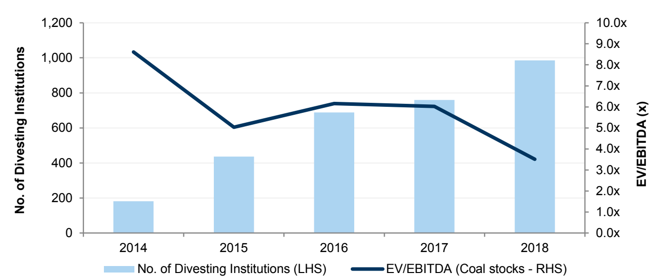
Number of climate-related shareholders' proposals vs. % vote in favour



Source: ProxyInsight, Data compiled by Goldman Sachs Global Investment Research

Exhibit 16: ...with investor divestments, already evident in the coal industry

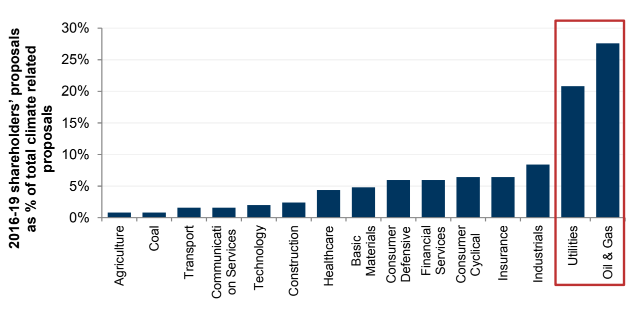
# of divesting institutions (LHS) vs. coal stocks EV/EBITDA (RHS)



Source: FactSet, DivestInvest, 350.org

Exhibit 17: The climate-related shareholder proposals have a very targeted focus on the energy sector...

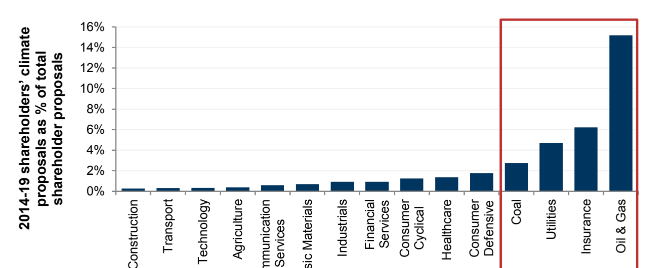
% of climate-related shareholder proposals split by industry, 2016-19



Source: ProxyInsight, Goldman Sachs Global Investment Research

Exhibit 18: ...with oil & gas having the largest proportion of climate-related proposals relative to the total shareholder proposals

% of total shareholder proposals that are climate related split by industry, 2014-19



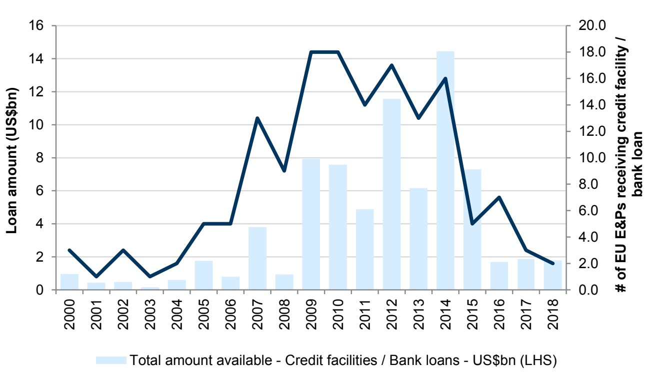
Source: ProxyInsight, Goldman Sachs Global Investment Research

Financial conditions for new oil projects have structurally tightened, increasing the risk premium for long-cycle developments, leading to a new age of capital restraint

Our annual survey of the world's most critical energy assets, Top Projects, shows tangible evidence that de-carbonization is transforming the current landscape of the industry. Capital availability for new oil developments has tightened significantly over the past five years, with the market increasingly focused on the low-carbon transition: (1) **Reserve-based lending to E&Ps for new oil & gas developments is down 90% from the peak**, with financial institutions redirecting financing towards renewable developments. Reserve-based lending (long-term lending collateralized with the oil & gas reserves underground) was the financing of choice for E&Ps and some NOCs as international operators of mega-projects in the 2000s. The banks that were most active in reserve-based lending have substantially reduced their exposure to oil & gas and are mostly looking to discontinue hydrocarbon financing over the long term. High yield credit to the US E&Ps, the financing of choice of smaller US shale producers, has also dried up since the beginning of 2019, leading to a 25% fall in US shale activity ytd; (2) **NOCs are moving away from aggressive international expansion as they focus on higher-return domestic investments, gas and downstream value chains.** Between 2003 and 2014, oil prices rose well above the budget breakevens of OPEC countries, creating US$1.6 tn of surplus that was partially re-invested in oil & gas capex, financing the international expansion of NOCs. Since 2014, the substantial fall in oil prices has pushed NOCs to retrench to their home basins, making them net sellers of resources and incentivizing stronger collaboration with Big Oils; and (3) **Big Oils' carbon reduction ambitions reduce their ability to accelerate oil field developments**. As we discussed in our report Re-imagining Big Oils, we believe it is strategically imperative for Big Oils to show that they can reduce their carbon intensity in line with the global ambition to contain global warming.

Exhibit 19: E&Ps relying on credit facilities saw their funding availability shrink materially...

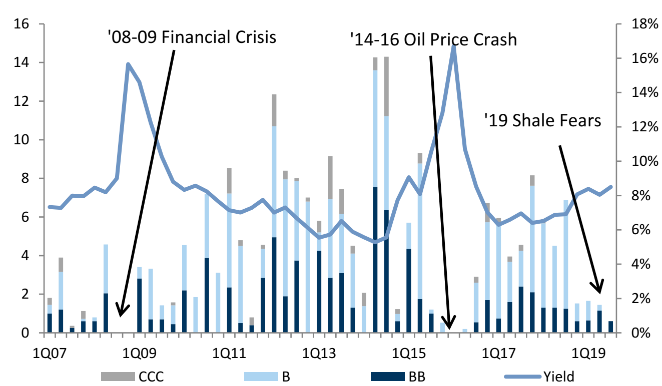
EU E&Ps total amount raised through credit facilities/bank loans, US$bn



Source: Bloomberg, Goldman Sachs Global Investment Research

Exhibit 20: ...and so have US E&Ps with HY credit issuance at historically low levels

Credit issuance per quarter by HY US E&Ps by rating (LHS US$ bln) and yield in % (RHS)



Source: Bloomberg, Dealogic, Goldman Sachs Global Investment Research

The cost of de-carbonization is steep, but offers some attractive large-scale investment opportunities

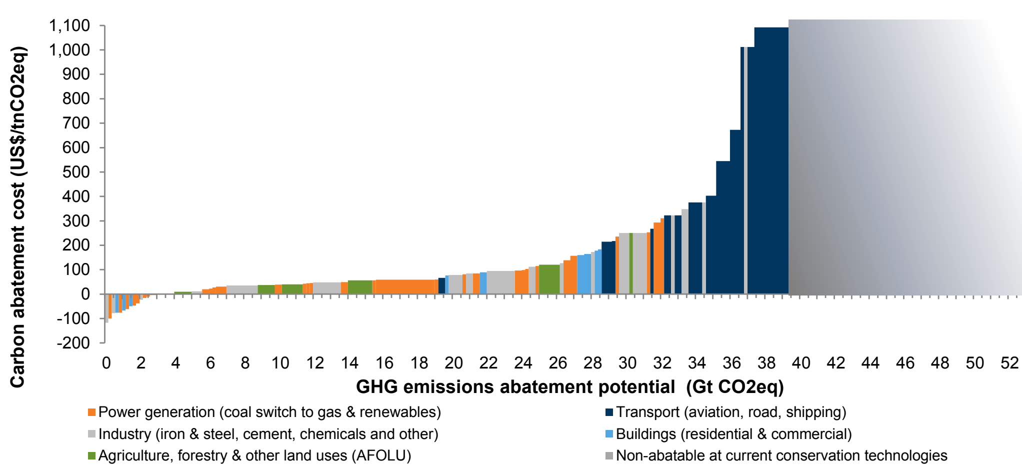
The cost curve for de-carbonization through conservation is steep...

The route to full de-carbonisation can be facilitated through two complementary paths, **conservation and sequestration**, with the former referring to technologies and efforts targeting the reduction of gross greenhouse gases emitted and the later referring to natural sinks and carbon capture and storage technologies (CCS) that aim to reduce **net emissions** by subtracting carbon from the atmosphere. The two routes to de-carbonisation are both generally accepted to be vital in achieving net zero carbon emissions as climate change pressures intensify and carbon emissions continue to overshoot the path associated with the more benign global warming paths.

The primary area of interest of policy-makers and investors alike in the climate change debate has been, to date, focused on **conservation** technologies and today's conservation efforts take many forms - from the shift of coal to gas and renewables in power generation to increased industrial and building efficiency and electrification of transport. As part of our analysis, we have constructed a carbon abatement cost curve for conservation technologies. This shows the cost curve of anthropogenic GHG emissions' reduction potential relative to the current global anthropogenic GHG emissions. In this analysis we primarily address conservation de-carbonization technologies that are currently available at commercial scale (commercial operation & development), and present the findings of this analysis at the current costs associated with each technology's adoption. We include conservation technologies across all key emission contributing industries globally; power generation, industry, transport, buildings and agriculture.

Exhibit 21: The conservation cost curve is steep, with c.75% of emissions abatable under current commercially available technologies (at prices up to US$1,200/tnCO2eq)

Conservation carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and commodity prices, assuming economies of scale for technologies in pilot phase

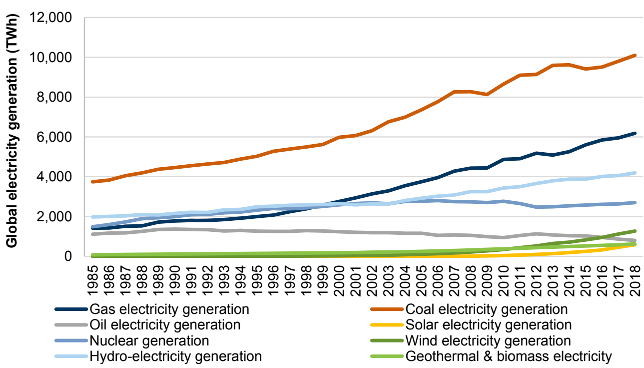


Source: Goldman Sachs Global Investment Research

…with some low-hanging fruits in power generation, but rapidly rising abatement costs particularly for transport

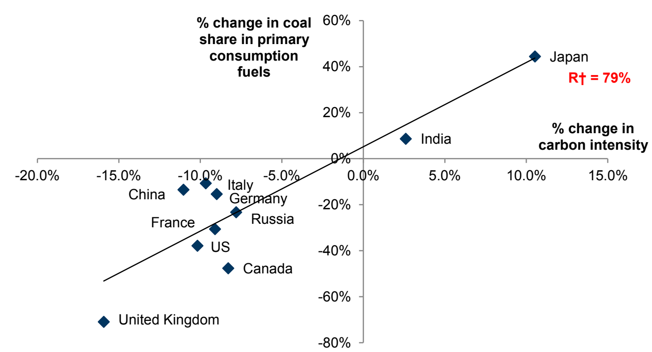
The resulting **carbon abatement cost curve for conservation technologies is very steep,** with some low-hanging fruits, particularly in power generation, but rapidly rising costs as we move to higher levels of de-carbonisation. At costs of commercially available conservation technologies, we estimate that c.50% of current anthropogenic GHG emissions can be abated at an implied carbon cost of up to US$200/tnCO2eq. Carbon prices of less than US$100/tnCO2eq (in the absence of other incentives) primarily result in a transformation of the power generation industry from carbon-intensive fuels (coal and oil) to cleaner alternatives (gas, solar, wind), but make a small dent into the transportation sector. Our correlation analysis indicates that the shift away from coal to cleaner alternatives accounts for c.80% of emissions reduction to date, yet coal consumption on a global basis is still increasing.

Exhibit 22: Global coal consumption in power generation grew again in 2017-18 after two years of decline…
Global electricity generation split by fuel (TWh)



Source: BP Statistical Review, Goldman Sachs Global Investment Research

Exhibit 23: …despite evidence suggesting that the shift away from coal explains c.80% of the reduction in carbon intensity by country since 2000.
Correlation between % change in carbon intensity and % change of coal in primary consumption fuels mix from 2000 to 2017



Source: BP Statistical Review, Goldman Sachs Global Investment Research

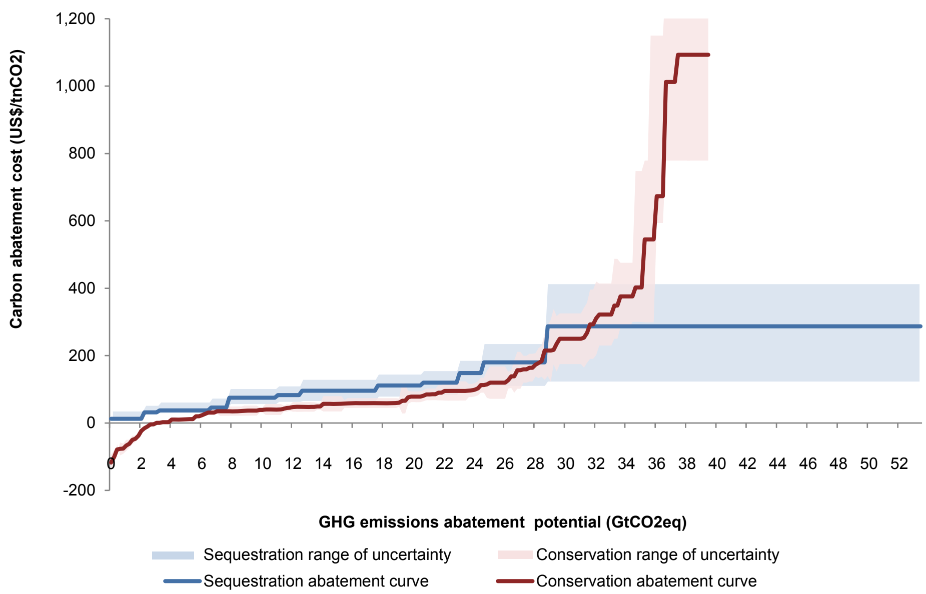
However, as we move along the curve to higher levels of de-carbonization, the marginal cost of further emissions abatement increases rapidly, with the higher end of the cost spectrum (implied carbon prices of up to US$1,200/tnCO2eq) occupied primarily by the industry and transport sectors with biofuels in aviation and shipping and the prospect of full electrification in road transport (considering both long- and short-haul electric trucks, electric buses, urban and rural electric passenger vehicles), requiring implied carbon prices of over US$300/tnCO2eq and up to US$1,200/tnCO2eq.

However, conservation efforts alone are unlikely to reach net zero carbon without carbon sequestration

There are two complementary paths to enable the world to reach net zero emissions: conservation and sequestration. We estimate that we may **not be able to abate c.25% of total current anthropogenic emissions under currently available large-scale commercial technologies.** This makes **sequestration a critical piece to the puzzle associated with solving the climate change challenge and achieving net zero carbon emissions.** The cost curve for sequestration and conservation are presented in the exhibit below. The conservation cost curve has a larger scope for low cost de-carbonization opportunities and a smaller range of uncertainty, but steepens exponentially beyond the mid-point. The sequestration cost curve on the other hand offers fewer low-cost solutions and has greater cost uncertainty, but provides tremendous long-term potential if an economic solution for direct air carbon capture is developed.

Exhibit 24: The path to de-carbonization will be driven by technological innovation and economies of scale for both conservation and sequestration initiatives

Carbon abatement cost curves (US$/tnCO2) for conservation and sequestration technologies vs. the GHG emissions abatement potential (GtCO2eq)



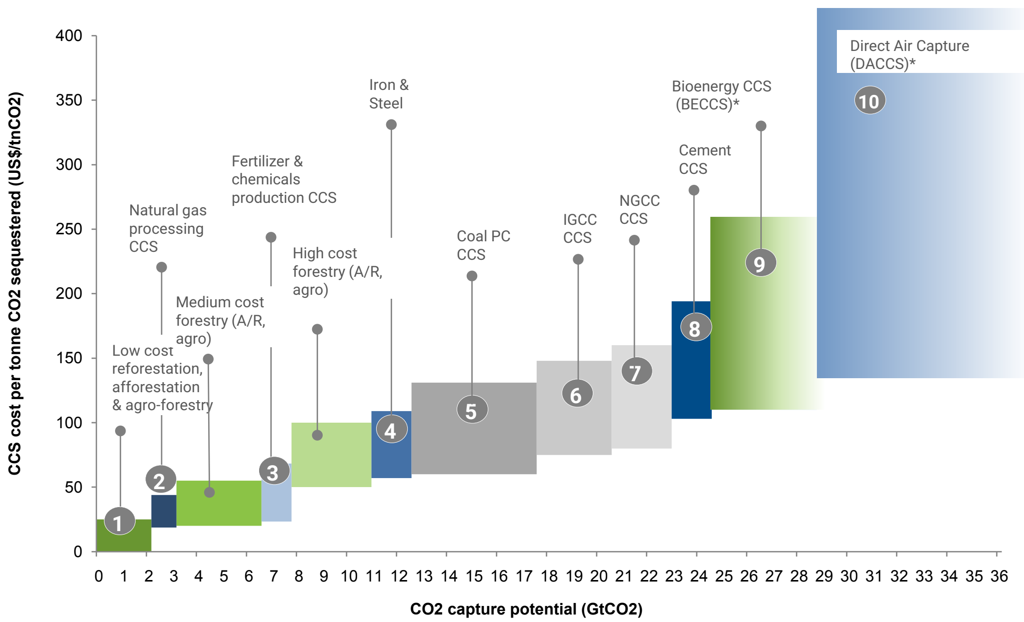
Source: Global CCS Institute, Goldman Sachs Global Investment Research

The wild card: Carbon sequestration is the key technology that could complement conservation in unlocking the full de-carbonization potential

While it is generally accepted that carbon sequestration will be vital in order to achieve net zero carbon emissions, the rate of carbon sequestration technology deployment remains, to-date, sub-scale. Carbon sequestration efforts can be classified primarily into two main categories; **natural sinks** (natural carbon reservoirs that can remove carbon dioxide with efforts including reforestation, afforestation and agro-forestry) and **carbon capture, utilisation and storage technologies (CCUS)**. As part of our analysis, we have constructed a carbon abatement cost curve for sequestration, in a similar manner to that constructed for conservation.

Exhibit 25: The carbon sequestration curve is less steep compared to the conservation curve but with a higher range of uncertainty. Direct Air Carbon Capture (DACCS) is the technology with the most uncertainty and the greatest potential

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

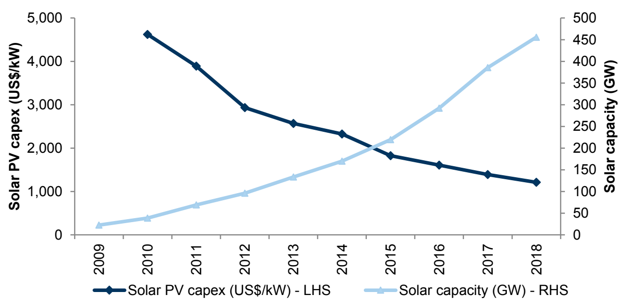


Source: Global CCS Institute, Goldman Sachs Global Investment Research

Although carbon sequestration has seen a revival in recent years, it has not yet reached large-scale adoption and economies of scale that traditionally lead to a breakthrough in cost competitiveness, especially when compared to other CO2-reducing technologies such as renewables. Despite the key role of sequestration in any scenario of net carbon neutrality, investments in CCS plants over the past decade have been <1% of the investments in renewable power. Although we are seeing a clear pick up in CCS pilot plants after a 'lost decade', we do not yet know where costs could settle if CCS attracted similar economies of scale as solar and wind. The vast majority of the cost of carbon capture and storage comes from the process of sequestration and is inversely related to the CO2 concentration in the air stream from which CO2 is sequestered. The cost curve of CCS therefore follows the availability of CO2 streams from industrial processes and reaches its highest cost with direct air carbon capture and storage (DACCS), where economics are highly uncertain, with most estimates between

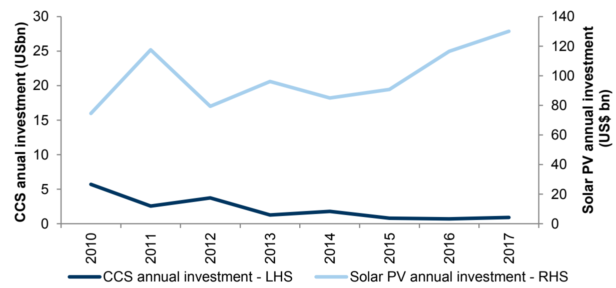
$40-400/ton and only small pilot plants currently in activity. The importance of DACCS lies in its potential to be almost infinitely scalable and standardized, therefore setting the price of carbon in a net zero emission scenario.

Exhibit 26: Solar PV cost per unit of electricity has fallen 70%+ over the last decade as cumulative solar capacity has increased exponentially...
Solar PV capex (US$/kW) vs. global cumulative solar PV capacity (GW)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 27: ...while the languishing investment in CCS sequestration technologies has possibly prevented a similar cost improvement
Annual investment in solar PV (LHS) and large-scale CCS (RHS)

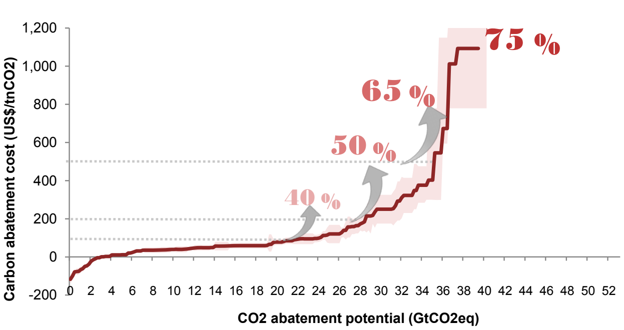


Source: Company data, IEA, IRENA, Goldman Sachs Global Investment Research

Technology-agnostic carbon pricing is key: The symbiotic relationship between carbon pricing and climate change technological innovation

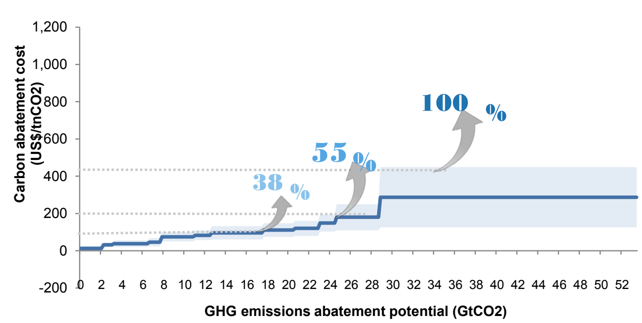
We believe that carbon pricing will be a critical part of any effort to move to net zero emissions, while incentivizing technological innovation and progress in de-carbonization technologies. The very steep carbon abatement cost curve calls for a growing need for technological innovation, sequestration technologies deployment and effective carbon pricing. The two approaches to de-carbonisation, conservation and sequestration, are both vital in achieving net zero carbon emissions as emissions continue to overshoot the path associated with the more benign global warming paths. In the short term, we believe that carbon prices should be sufficiently high to incentivize innovation and a healthy competition between conservation and sequestration technologies while longer term, such an equilibrium price of carbon is expected to decline on the back of technological innovation and economies of scale.

Exhibit 28: Conservation, while well understood and widely adopted, shows a steep cost curve with a limit in abatement potential based on current technologies...
Carbon conservation cost curve with % of total current GHG emissions abated at different price levels



Source: Goldman Sachs Global Investment Research

Exhibit 29: ...with sequestration also critical in achieving the low-carbon transition yet with a wider range of cost uncertainty given its current under-deployment
Carbon conservation cost curve with % of total current GHG emissions abated at different price levels

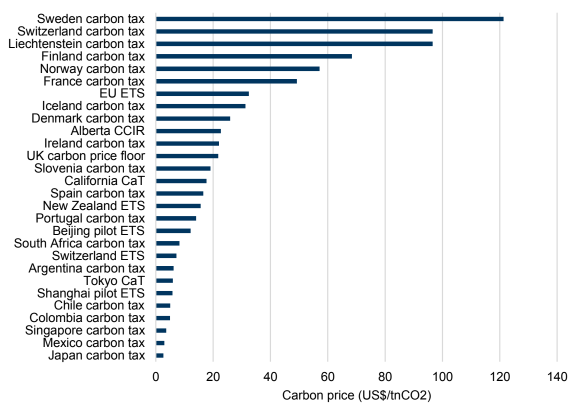


Source: Global CCS Institute, Goldman Sachs Global Investment Research

Carbon pricing initiatives are accelerating, yet still only cover c.15%-20% of total global emissions

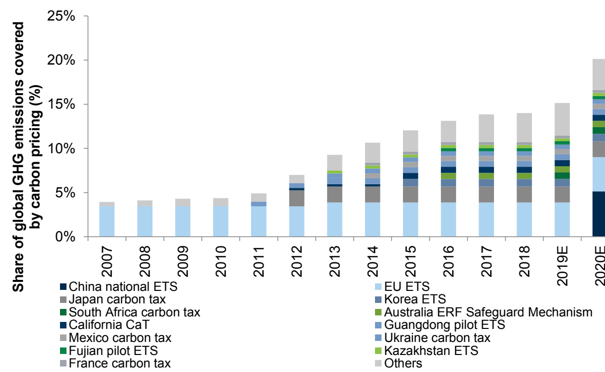
At present, 57 carbon pricing initiatives are underway, covering 46 national and 28 regional governments worldwide, mostly through cap-and-trade systems. These initiatives are gaining momentum, with China, the world's largest CO_2 emitter, expected to launch the initial phase of its own ETS roadmap in 2020. These carbon pricing systems have shown varying degrees of success in reducing carbon emissions; together, according to the World Bank Group, all of these initiatives (including China) cover 11GtCO2eq, representing c.20% of the world's total GHG emissions.

Exhibit 30: The carbon prices associated with global carbon price initiatives (carbon taxes and ETS) show a wide regional variability...
Carbon prices through taxes and ETS



Source: World Bank Group

Exhibit 31: ...with carbon pricing initiatives only covering c.20% of global GHG emissions with the addition of China by 2020E
Carbon pricing ETS initiatives' share of global GHG emissions covered (%)



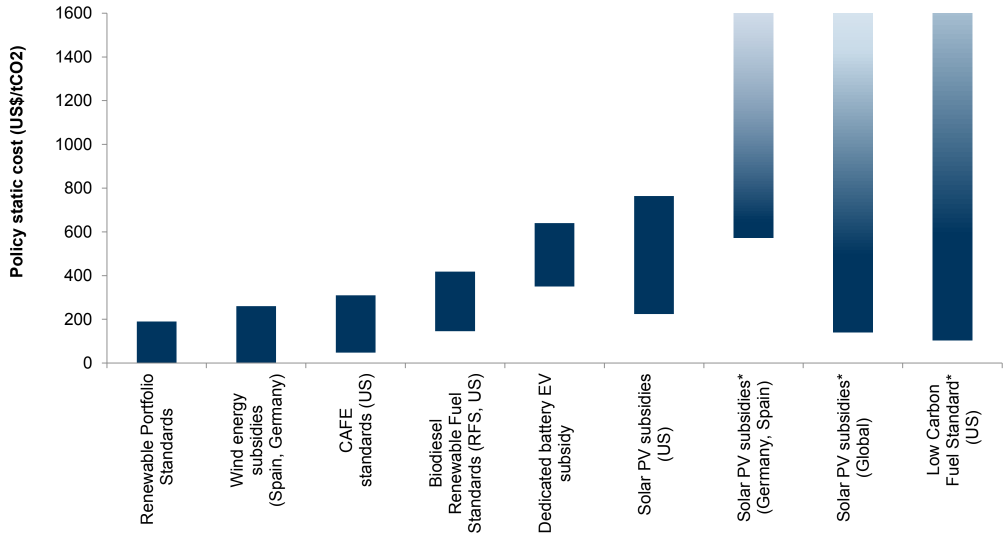
Source: World Bank Group, Goldman Sachs Global Investment Research

Governments have been successful and incentivizing specific low-carbon technologies, but efforts have been largely uncoordinated

With current emissions on a continuing upwards trajectory, a wide range of energy efficiency and low-carbon policies have been put in place in different countries over the past decade aiming to tackle the challenge of climate change. Some of them have been very targeted (e.g. ethanol/wind/solar subsidies), while others were broader (fuel standards). In aggregate, they have been successful at incentivizing clean tech developments, yet they have not necessarily been a cost-efficient way for reducing carbon emissions, and they have only fostered technological innovation in narrow areas of the low-carbon economy. The costs associated with these policy measures encompass a very wide range, from zero to US$1,000/tCO2, with several of the policies implying a cost/ton CO2 that is higher than the implied cost of alternative technologies such as sequestration. The economic studies involved in shaping the estimates presented below are primarily concerned with policy measures that were in force during the period 2010-14, with some of those sectors and technologies having experienced a substantial reduction in costs since then (solar and wind in particular), driven by accelerated capacity additions that unlocked the benefits of economies of scale.

Exhibit 32: A number of targeted low-carbon policies have been implemented over the past decade with a wide range of associated costs

Range of static carbon abatement cost of different past policies (US$/tnCO2eq)



** The upper limit of costs associated with policies has been curtailed at US$1600/tCO2 for comparison (* marked costs vary beyond that)*

Source: The Cost of Reducing Greenhouse Gas Emissions Kenneth Gillingham James H. Stock Journal of Economic Perspectives vol. 32, Copyright American Economic Association; reproduced with permission of the Journal of Economic Perspectives

Tightening financial conditions for new hydrocarbon developments is creating a new oligopoly with high barriers to entry

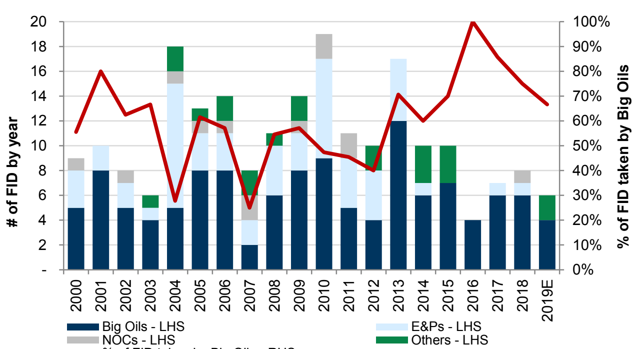
De-carbonization is transforming the structure of the oil & gas market into a concentrated industry with high barriers to entry

The period of 2004-16 saw two oil & gas revolutions, fuelled by cheap financing, leading to industry fragmentation and a compounded 10% cost inflation. The first oil & gas revolution (2004-13) was driven by National Oil Companies (NOCs) that deployed their rising free cash flow into rapid international expansion, with a combination of exploration and M&A activities. In the meantime, market perception of long-term supply shortages incentivized independent oil & gas players to step up their ambitions, becoming operators of major developments across the globe. The second oil & gas revolution (2009-16) was led by US exploration & production companies, unlocking 100+ bn bls of US shale oil resources. We believe these revolutions are over, with the market turning away from resource expansion in the wake of the low-carbon transition, and financial conditions tightening across the industry.

With shrinking funding availability owing to the financial market re-directing financing towards low-carbon projects, most companies have stopped sanctioning giant oil & gas projects since 2014, allowing only a few to regain industry leadership. Therefore, since 2014, the industry structure started to rationalize into a more concentrated one with seven companies (the 'Seven Sisters') emerging as structural winners, continuing to sanction projects consistently through 2014-18. The tighter financial conditions for new oil fields, as discussed earlier are raising the barriers to entry while increasing the equity risk premium on new long-cycle developments, leading to a more concentrated industry structure with higher returns and lower volume growth. We show in exhibit 34 that the Herfindhal index of market consolidation on FIDs increased from 10%-20% in 2010-14 to 30%-50% in 2018, consistent with an oligopoly. The Herfindahl Index is a measure of market concentration (calculated by squaring the market share of each of the companies in the industry and then summing the resulting numbers).

Exhibit 33: Big Oils have regained their Top Projects leadership in a newly consolidated market...

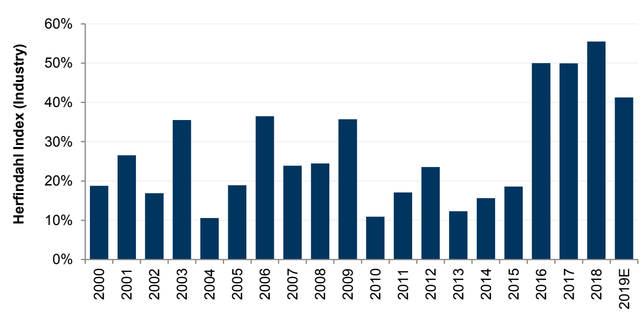
FIDs by year; Big Oils refers to ExxonMobil, Chevron, RDShell, TOTAL, ENI, BP, Equinor. Excludes NOC FIDs in their home basin



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 34: ...and the market structure for the industry is the most favourable in 20 years

Herfindahl Index, Top Projects capex by operator at time of FID



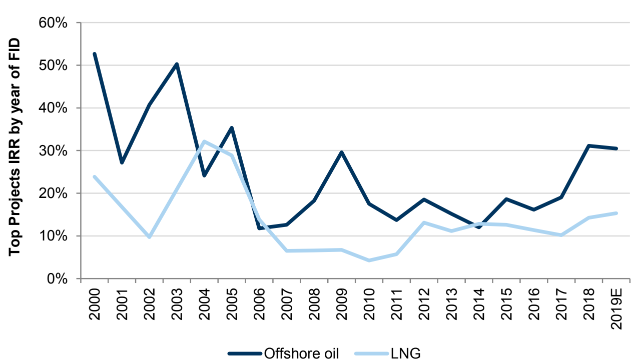
Source: Goldman Sachs Global Investment Research

This repaired, more consolidated market structure has led to a restoration of the industry's profitability

The improvement in market structure that we have examined, together with tighter financing conditions and improved negotiating positions with host governments, is leading to a material uptick in profitability of new projects. Over the last five years, Big Oils have doubled their market share in long-cycle developments and US shale oil, re-establishing the attractive returns that were lost during the oil & gas revolutions of the 2000s spawned by National Oil Companies and shale. As exhibit 35 shows, project IRR troughed in 2006-14 at 10%-15% on the back of excessive competition. This level of project IRR led Big Oils' overall ROACE (including overhead costs) to fall to single digits. We estimate that the FIDs taken (mainly by Big Oils) from 2015 to 2020E will instead yield a profitability more consistent with what the industry saw in the 1990s: 20%-30% project IRRs, which should be consistent with ROACE recovering to 15%+. **Overall, IRRs for new oil & gas mega-projects of 15%-30% are 50% higher than the returns on projects sanctioned in 2004-14.** This restoration of profitability through scale, concentration and standardisation is leading to shorter time-to-market and a more dynamic cost curve, with Big Oils in a position to leverage the higher returns from their traditional oil & gas business to foster innovation and investment in their ongoing low-carbon transition efforts.

Exhibit 35: Profitability of industry projects has returned to mid-2000 level with offshore oil projects profitability close to 30% in 2018...

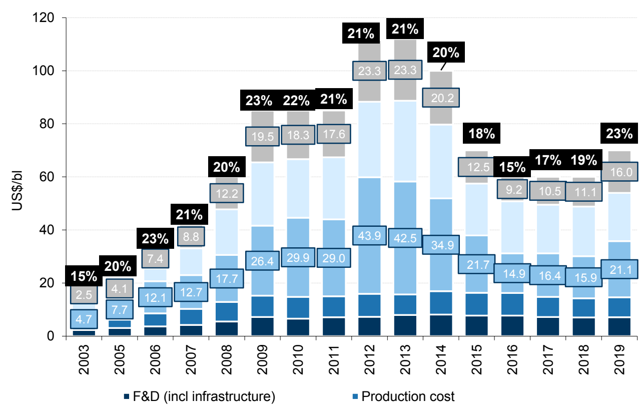
Top Projects IRR by year of FID split by winzone



Source: Goldman Sachs Global Investment Research

Exhibit 36: ...and with net margin improving to 23% Brent assumption, back to historical highs

Top Projects pre-plateau (ex unconventionals) split of revenue and net margin as a % of Brent

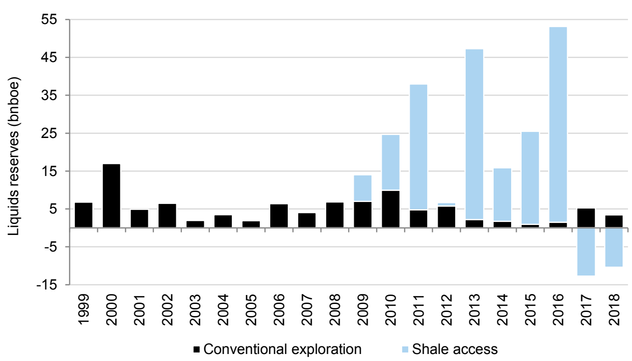


Source: Goldman Sachs Global Investment Research

De-carbonization is having an immediate impact on supply, with non-OPEC supply growth ending in 2020, on our estimates

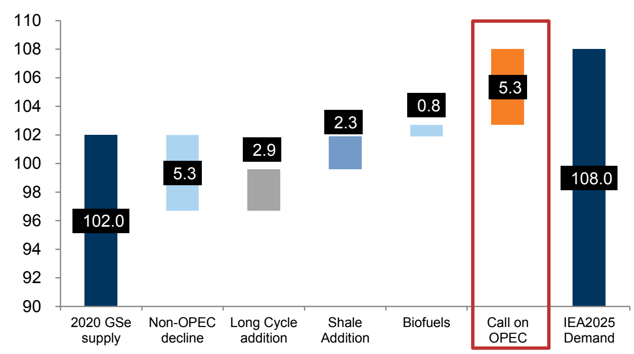
The under-investment in the sector that followed the 2014 oil price downturn, combined with intensified de-carbonization focus that led to the tightening of financial conditions in the sector is, according to our Top Projects analysis, having a strong impact on oil supply that will be felt as early as 2021. This comes on the back of both (1) **a thinner pipeline of mega long-cycle developments leading to declining production ex-shale from 2021** and (2) a **deceleration in US shale growth owing to higher declines from a larger production base, a reduction in profitable drilling locations and slowing productivity improvements.** The **intensified focus on de-carbonisation** and a substantial **tightening of financial conditions** lead us to believe that this expected **supply tightness post 2020 is structural in nature.**

Exhibit 37: The industry's drive for resource expansion seems to have come to an end...
Total liquids reserves discovered/accessed by year, based on Top Projects



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 38: ...and we expect a rising call on OPEC in the 2020s
Key drivers of oil supply growth over 2020-25E (mn blpd)



Source: IEA WEO 2018, Goldman Sachs Global Investment Research

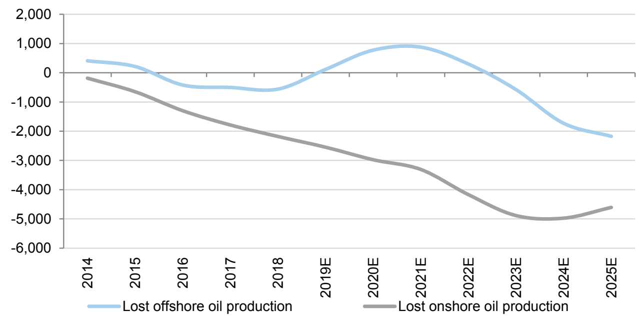
1) We see non-OPEC underinvestment in long-cycle developments leading to declining production ex-shale over 2021-23…

According to our Top Projects analysis the oil price downturn has been followed by considerable sector underinvestment with **delays in project FIDs translating into c.7 mn boepd of lost oil production from long-cycle developments** (and 2 mn boepd of lost LNG production) by 2025 (on our estimates), vs. our Top Projects expectations in 2014. This has been a direct result of falling oil prices and NOCs/international E&Ps retreating to their domestic basins to focus on balance sheet management.

Lost oil production (vs. 2014 expectations) has mainly been driven by revised production growth profiles in Iraq, Canada (oil sands projects), West Africa, GoM and Brazil (deepwater). As it normally takes five to six years from FID to plateau production, we believe **underinvestment and the abrupt slowdown in the pace of FIDs in 2015 will start to impact production growth from 2021**.

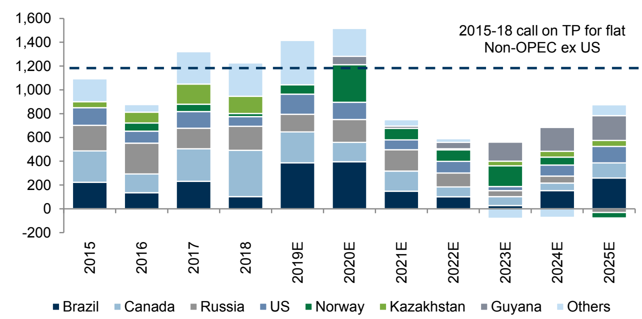
Our Top Projects database, which has historically closely tracked non-OPEC, ex-shale global oil production growth, shows that the pace of production ramp-up of **long-cycle oil mega projects is likely to slow from 1.2-1.4 mn blpd at present to 0.6-0.8 mn blpd from 2021, leading non-OPEC, ex-shale into a period of decline.**

Exhibit 39: FID postponements are likely to induce lost oil production equivalent to c.7 mn boepd in 2025E...
Top Projects lost offshore and onshore oil production from long-cycle developments in mn boepd



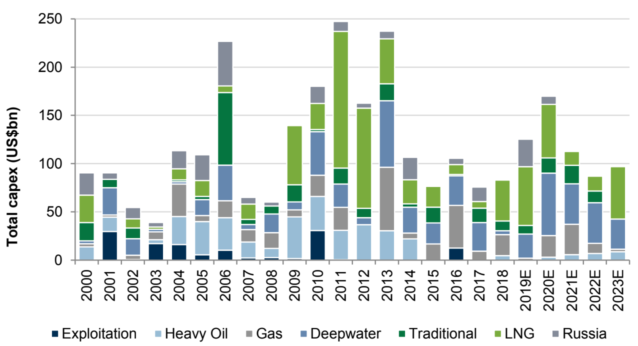
Source: Goldman Sachs Global Investment Research

Exhibit 40: ...leading non-OPEC ex-US into growth decline in 2021-23E
Liquids production yoy growth (kblpd) from non-OPEC excluding shale projects



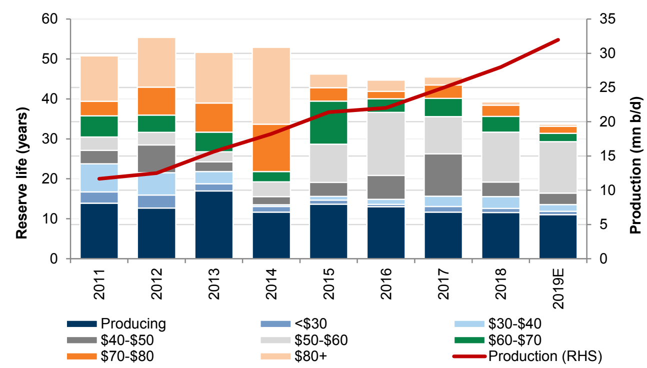
Source: Goldman Sachs Global Investment Research

Exhibit 41: This is the result of a material decline of the number of sanctioned long-cycle developments since 2014...
Top Projects capex sanctioned by year, split by winzone (US$ bn)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 42: ...with Top Projects oil reserve life falling c.20 years since 2014
Top Projects' reserve life (years) by breakeven and production

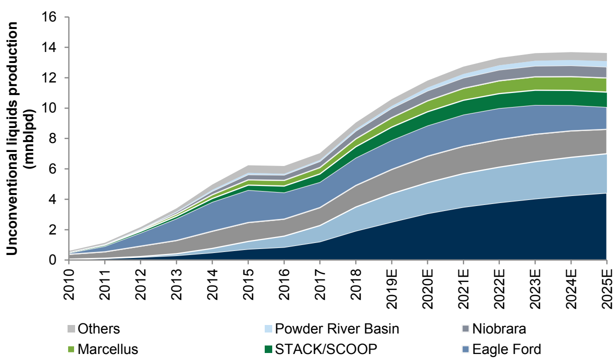


Source: Goldman Sachs Global Investment Research

(2) We expect a deceleration in shale growth with higher decline rates, slowing productivity improvements and lower resource life

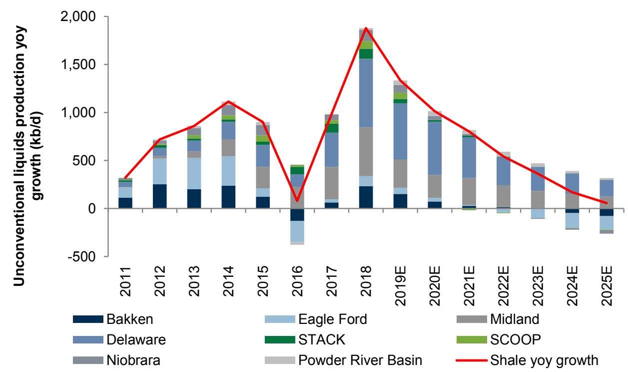
We estimate that a combination of factors outlined in the sections that follow, including accelerated well decline rates from a larger production base, a halt in length-adjusted well productivity improvements and reduced availability of profitable drilling locations/acreage revealed by our geospatial analysis, will result in a **material slowdown in US shale growth post 2020**, corresponding with the maturing of the most prolific areas in Bakken/Eagle Ford and a higher underlying decline in all basins, including Permian. Overall, we see **US shale production growth decelerating from >1.9 mn blpd in 2018 to c.1.4 mn blpd in 2019 and c.1.1 mn blpd in 2020 before declining substantially from 2021.**

Exhibit 43: The majority of liquids production growth from US shale is attributed to the Big Four basins and dominated by Permian…
Unconventional liquids production by shale play (mn blpd)



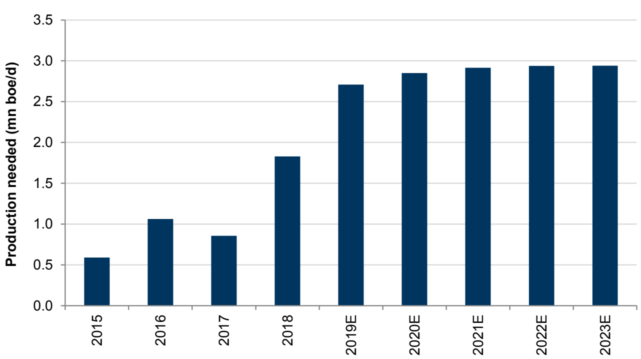
Source: Goldman Sachs Global Investment Research

Exhibit 44: …but we forecast a material deceleration in growth in the 2020s across basins
Unconventional liquids production growth yoy (kb/d) by basin



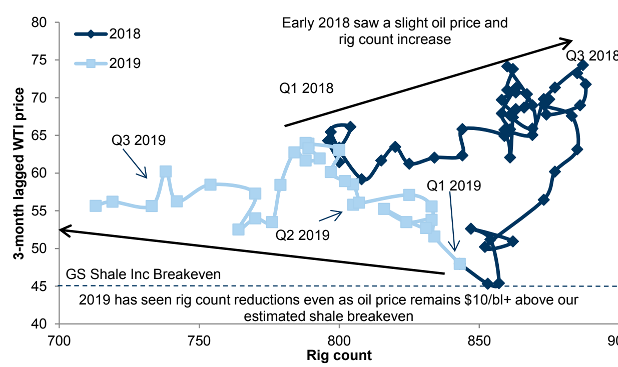
Source: Goldman Sachs Global Investment Research

Exhibit 45: We estimate that c.3 mnblpd of new production will be needed to keep production flat from 2020 onwards...
Production required to maintain flat production annually (mln blpd) in the big four US shale basins



Source: Goldman Sachs Global Investment Research

Exhibit 46: …at a time when shale activity is decreasing despite a range-bound oil price that remains above shale breakeven
Rig count vs. 3-month lagged WTI oil price

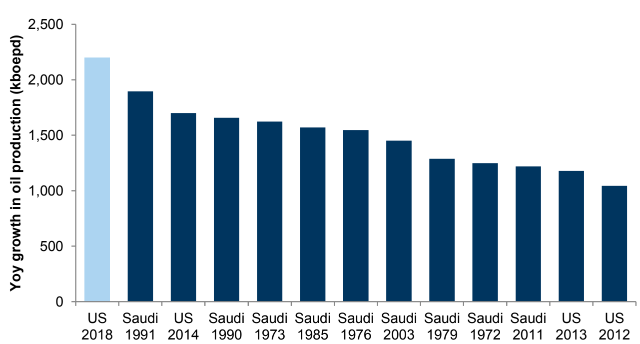


Source: Baker Hughes, Goldman Sachs Global Investment Research

The shale treadmill accelerates with steeper decline rates from a higher production base

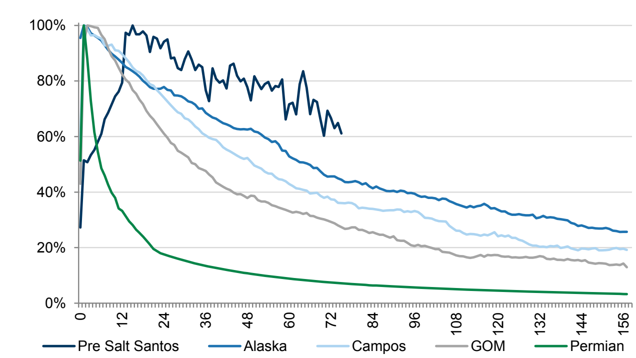
The US saw record-breaking growth in liquids production in 2018 at c.2.2 mn b/d. This level of growth surpassed our expectations, with almost all of the beat driven by shale where production growth (which was higher than anticipated) was geographically broad-based with all the major shale basins contributing. This was driven by a vast shale resource base, a well-equipped US services sector, a fragmented network of operators, and relatively low base decline rates. The mechanics of shale production involve drilling tens of thousands of wells at low cost, each of them with moderate peak production and a rapid decline, creating a unique dynamic. While this has enabled substantial production growth to date, by 2021, we see shale moving into maturity, with **higher decline rates from a larger production base resulting in slower incremental growth**. The geology of shale, with high initial well productivity and rapid decline rates (a 70% decline rate in year 1 is not uncommon, as shown in exhibit 48), provides different growth and decline rate characteristics vs. conventional reservoirs. Growth can be very rapid in the early years of a basin, but as the production base becomes larger, so do decline rates, especially following a couple of years of very intensive developments, when a large part of the production base is made up of high-decline wells in their first 1-2 years of life. Effectively, **as shale rapidly increases its global market share,** we believe **higher activity would be needed to maintain flat production - the shale treadmill is accelerating.**

Exhibit 47: 2018 was a record year of production growth for the US…
Yearly increase in liquids production historically (kboepd)



Source: EIA, IEA, BP Statistical Review

Exhibit 48: …yet the well characteristics of shale are very different from traditional long-cycle developments, with a very steep rate of decline
Decline rates with peak production rebased to 100%

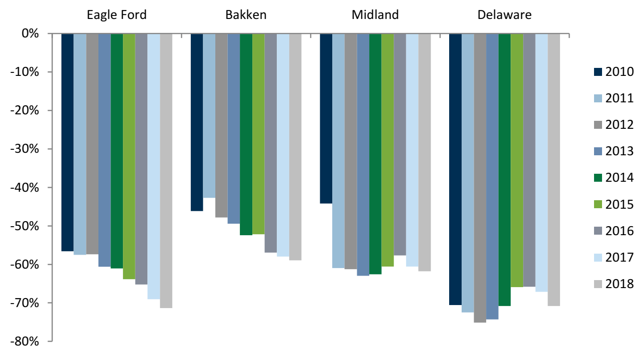


Source: ANP, Alaska DoE, BOEM, Goldman Sachs Global Investment Research

Our well analysis of the Big Four basins shows a trend of accelerated decline rates in individual wells. While wells continue to achieve higher 1-month production rates (partly owing to increased proppant loading, longer lateral length and high grading), decline rates between months 1 and 12 have been accelerating in all basins since 2015.

Exhibit 49: All four major US shale basins have seen accelerated initial decline rates vs. 2015....

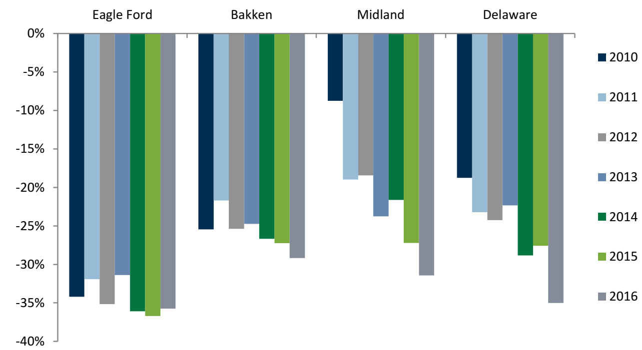
Decline in % seen between months 3 and 12 of production



Source: IHS, Goldman Sachs Global Investment Research

Exhibit 50: ...and between months 24 and 36, particularly in the Permian basin

Decline in % seen between months 24 and 36 of production



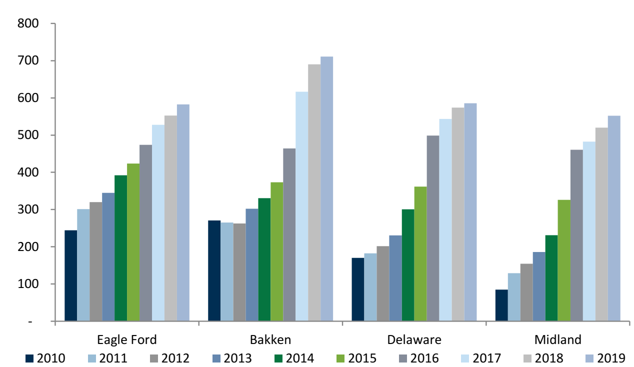
Source: IHS, Goldman Sachs Global Investment Research

Length-adjusted productivity improvements seem to have stalled as productivity comes at the expense of longer wells

Over the past 18-24 months, we have seen lateral length-adjusted productivity improvements flatten off, broadly in sync with a flattening of proppant intensity (in lb/m). However, increasing well lengths, especially in the Permian basin, have enabled overall IP rates to continue growing. All plays saw significant increases in proppant usage per length in previous years, driving greater EURs (Estimated Ultimate Recovery). But proppant usage per m flattened, and productivity improvements stalled through late 2017-18. This suggests that more frac stages and proppant (as well as high grading) were the major drivers of productivity improvements.

Exhibit 51: Wells have seen 2-8x increases in output since 2010...

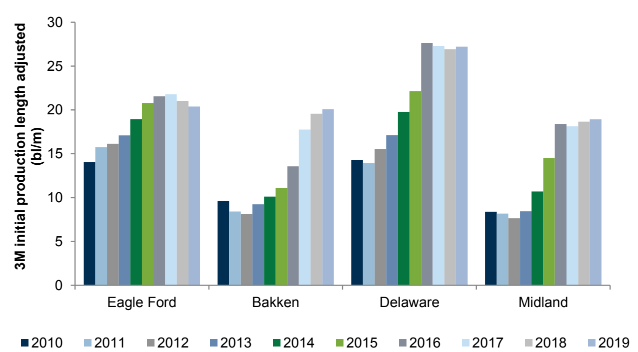
Average 3-month production in barrels/day for the Big 4 US shale basins by year of well start-up (blpm)



Source: IHS, Goldman Sachs Global Investment Research

Exhibit 52: ...but length-adjusted productivity improvements (adjusted for lateral length) seems to have stalled since 2017 and in some cases reversed

Length-adjusted 3-month production (blpm)



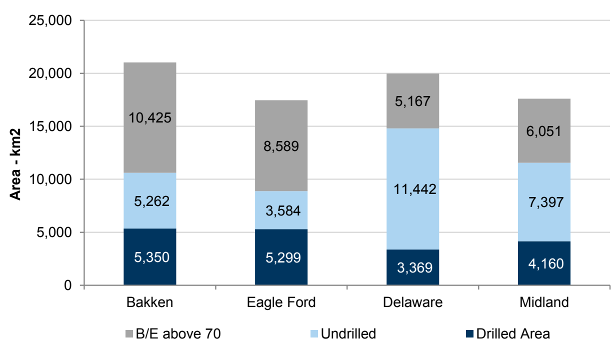
Source: IHS, Goldman Sachs Global Investment Research

Our proprietary geospatial analysis shows a declining backlog of profitable well locations in US shale

We estimate that the Big 4 shale plays have a reserve life of c.30-35 years, down from almost 80 years in 2016. This is driven by rapid growth in production, especially in the Delaware and Midland basins, as well as our view that resources are reducing progressively in the Bakken and Eagle Ford basins. By 2023, we believe shale could have a resource life of under 20 years, increasing the focus on resource depth.

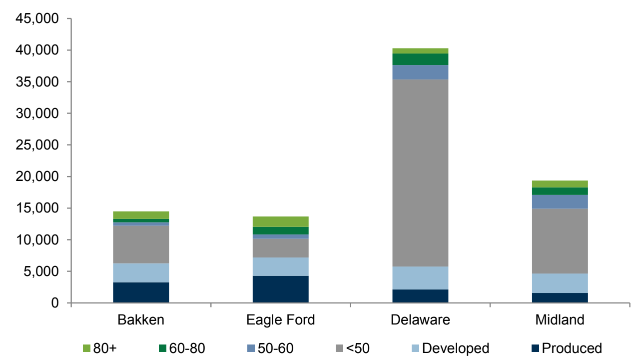
With resource depth/reserve life coming into focus, we have (in cooperation with GS DataWorks) mapped the productivity of every well drilled since 2015 in the Big 4 major US shale basins. Mapping wells that produce at different rates, and grouping them together based on distribution density, revealed different areas of productivity, i.e. "zones". This enabled the determination of the extent of core and non-core acreage, as well as the drilling density to date. This provided a gross area breakdown from which already drilled wells (since 2010) were subtracted (scaled to account for lateral length/productivity) by zone (regardless of the production of historical wells). Further economic analysis, based on each of the five zones, determined the breakeven price for the remaining resources. An example of this analysis is shown in exhibit 54.

Exhibit 53: More than half the area (with breakeven below US$70/bl) of Eagle Ford and Bakken has already been drilled
Reserve life and production from the Big 4 plays according to 2019 Top Projects data



Source: Goldman Sachs Global Investment Research, Goldman Sachs Data Works

Exhibit 54: Delaware and Midland have the largest proportion of low breakeven (< US$50/bl) undeveloped resources
Liquid resources in the Big 4 basins classified by breakeven (mn boe)



Source: Goldman Sachs Global Investment Research, Goldman Sachs Data Works

Our geospatial mapping shows uneven productivity of the acreage of all plays. When combining undrilled acreage and our type curve analysis, we see that Bakken and Eagle Ford have drilled between 50% and 60% of their economic acreage that has a breakeven below US$70/bl. We think this is starting to show in the well decline profiles, with decline rates at an accelerated pace. Accounting for longer and more productive wells in the future, we believe it is possible that these areas could be practically fully drilled in 2021-23. Meanwhile, our analysis suggests the Permian basin has both the greatest remaining undrilled areal extent and potentially multiple levels/benches of vertical zones which can contribute to production.

While de-carbonization is drastically changing the supply landscape of oil & gas, demand changes more slowly

While we see supply tightness post 2020 in the market, a direct result of underinvestment and tightened financial conditions in the industry caused by de-carbonisation concerns, demand is currently the variable most investors are focusing on in terms of the long-term oil & gas market landscape. We believe that while **de-carbonisation is changing the oil & gas supply dynamics, the demand for both hydrocarbons remains robust under the vast majority of de-carbonisation scenarios** in the medium term (to 2030 for oil & 2040 for gas). In other words, **de-carbonisation is changing the supply dynamics of the industry much faster than it changes demand** resulting in a tight overall market in the 2020s. Absent a material recession, we expect demand for both hydrocarbons to remain robust for at least the next decade.

Oil demand remains robust under most de-carbonization scenarios (considering passenger vehicle electrification, plastics recycling and GDP)

The impact of increasing electric vehicles penetration in road transport and increased growth of plastics recycling form two of the main concerns surrounding global oil demand growth longer term (in addition to the health of the economy through GDP growth). Transport today accounts for c.55% of global oil demand (2018) with petchems having the second-largest contribution to global oil demand, accounting for c.13%. We have conducted a sensitivity analysis to assess the potential impact of different EV penetration scenarios in road transport to 2030 at different GDP growth levels. The results are presented below, with oil demand growing (CAGR 2018-30E) under the vast majority of scenarios. Only if the EV penetration in transport reaches c.40% by 2030 does there appear to be oil demand deceleration in transport, while total oil demand remains on a growth trajectory at all other scenarios where GDP growth levels vary between 2.3% to 3.9%. In our analysis, we assume EVs are comprised 56% pure EV and 44% PHEV. This is on top of c.10% hybrids penetration assumed in 2030.

Exhibit 55: Total oil demand keeps growing to 2030 under most electrification and GDP growth scenarios

Transport oil emissions in 2030 and oil emissions change in 2018-30 (GtCO2eq) at different electrification and GDP growth scenarios

Total oil demand CAGR 2018-30 (%)								
GDP growth to 2020-30 (%)	% EV & PHEV fleet penetration by 2030							
	5%	10%	15%	20%	25%	30%	35%	40%
3.9%	1.01%	0.92%	0.83%	0.75%	0.66%	0.57%	0.48%	0.39%
3.7%	0.93%	0.85%	0.76%	0.67%	0.58%	0.49%	0.40%	0.31%
3.5%	0.86%	0.77%	0.68%	0.60%	0.51%	0.42%	0.32%	0.23%
3.3%	0.79%	0.70%	0.61%	0.52%	0.43%	0.34%	0.25%	0.16%
3.0%	0.68%	0.59%	0.50%	0.41%	0.32%	0.23%	0.13%	0.04%
2.8%	0.61%	0.52%	0.43%	0.34%	0.25%	0.15%	0.06%	-0.04%
2.5%	0.50%	0.41%	0.32%	0.23%	0.14%	0.04%	-0.05%	-0.15%
2.3%	0.43%	0.34%	0.25%	0.16%	0.07%	-0.03%	-0.12%	-0.22%

** Evs penetration includes 56% EV and 44% PHEV*

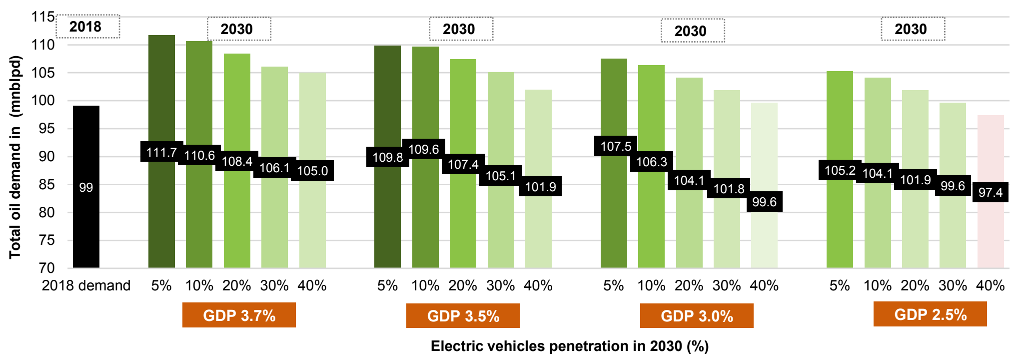
Transport emissions change 2018-30 (GtCO2eq)								
GDP growth to 2020-30 (%)	% EV & PHEV fleet penetration by 2030							
	5%	10%	15%	20%	25%	30%	35%	40%
3.9%	1.0	0.9	0.7	0.5	0.4	0.2	0.0	-0.1
3.7%	0.9	0.8	0.6	0.4	0.3	0.1	0.0	-0.2
3.5%	0.8	0.7	0.5	0.4	0.2	0.0	-0.1	-0.3
3.3%	0.7	0.6	0.4	0.3	0.1	-0.1	-0.2	-0.4
3.0%	0.6	0.5	0.3	0.1	0.0	-0.2	-0.3	-0.5
2.8%	0.5	0.4	0.2	0.1	-0.1	-0.3	-0.4	-0.6
2.5%	0.4	0.3	0.1	-0.1	-0.2	-0.4	-0.6	-0.7
2.3%	0.3	0.2	0.0	-0.1	-0.3	-0.5	-0.6	-0.8

** Evs penetration includes 56% EV and 44% PHEV*
*** Current total emissions from transport at c7.9 GtCO2eq*

Source: Goldman Sachs Global Investment Research

Exhibit 56: Global oil demand continues to grow under all EV penetration scenarios considered (assuming GDP >2% and moderate growth in petchems)

Total global oil demand under different GDP and EV penetration scenarios for 2030 (mln bpd)



Source: Goldman Sachs Global Investment Research

A similar scenario analysis was performed to assess the potential impact of plastics recycling on oil demand for petrochemicals, the second-largest contributor to oil demand. Our GS colleagues discussed the potential benefits and impact of plastics recycling in the report 'The plastics paradox', with currently c.20% of single-use plastics being recycled. The results of the analysis indicate, similarly to electric vehicle penetration, that under the vast majority of potential scenarios oil demand for petrochemicals continues to grow to 2030, unless GDP growth falls below 2.3%. The sensitivity of plastics recycling to total oil demand is even lower, with global demand for oil growing under all plastics recycling rate growth scenarios considered.

Exhibit 57: Oil demand for petrochemicals shows growth to 2030 under the vast majority of plastics recycling growth scenarios, assuming a GDP of >2.3%

Sensitivity analysis for assumed plastics recycling growth and GDP for oil petchems demand (LHS) and total oil demand (RHS) CAGR 2018-30E

Oil demand CAGR 2018-30 in petrochemicals (%)

GDP growth to 2020-30 (%)	Single-use plastics recycling in 2030: 20%	30%	40%	50%	60%	70%	80%
3.9%	2.74%	2.59%	2.45%	2.29%	2.14%	1.97%	1.81%
3.7%	2.62%	2.47%	2.33%	2.17%	2.02%	1.86%	1.70%
3.5%	2.50%	2.35%	2.21%	2.06%	1.91%	1.75%	1.59%
3.3%	2.38%	2.23%	2.09%	1.94%	1.79%	1.64%	1.48%
3.0%	2.20%	2.06%	1.92%	1.77%	1.63%	1.47%	1.31%
2.8%	2.09%	1.94%	1.81%	1.66%	1.52%	1.36%	1.21%
2.5%	1.91%	1.77%	1.64%	1.49%	1.35%	1.20%	1.05%
2.3%	1.80%	1.66%	1.53%	1.38%	1.24%	1.10%	0.94%

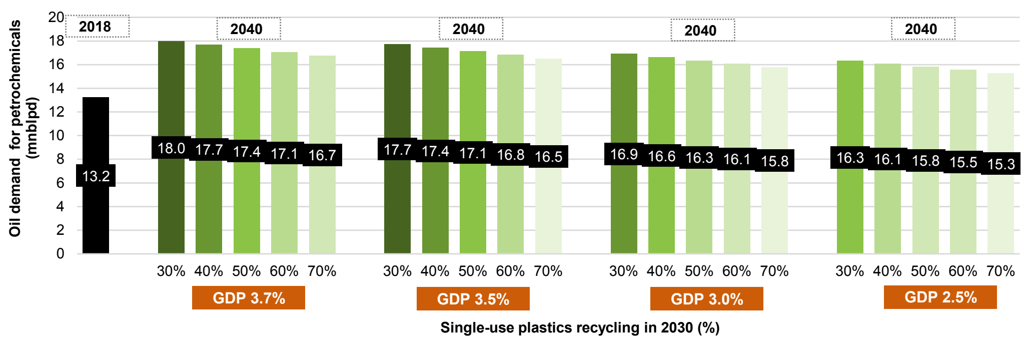
Total oil demand CAGR 2018-30 (%)

GDP growth to 2020-30 (%)	Single-use plastics recycling in 2030: 20%	30%	40%	50%	60%	70%	80%
3.9%	0.99%	0.97%	0.94%	0.92%	0.90%	0.87%	0.85%
3.7%	0.92%	0.89%	0.87%	0.85%	0.82%	0.80%	0.77%
3.5%	0.84%	0.82%	0.80%	0.77%	0.75%	0.73%	0.70%
3.3%	0.77%	0.75%	0.72%	0.70%	0.68%	0.65%	0.63%
3.0%	0.66%	0.64%	0.62%	0.59%	0.57%	0.55%	0.53%
2.8%	0.59%	0.57%	0.55%	0.52%	0.50%	0.48%	0.46%
2.5%	0.48%	0.46%	0.44%	0.42%	0.40%	0.38%	0.35%
2.3%	0.41%	0.39%	0.37%	0.35%	0.33%	0.31%	0.29%

Source: Goldman Sachs Global Investment Research

Exhibit 58: Oil demand for petrochemicals is expected to grow under all single-use plastics recycling scenarios considered, assuming GDP exceeds 2.3%

Oil demand for petrochemicals under different GDP and single-use plastics recycling scenarios in 2030 (mln bpd)



Source: Goldman Sachs Global Investment Research

Natural gas remains the hydrocarbon with the most constructive longer-term outlook as it plays a vital role in the transition away from more carbon-intensive coal in power generation, industry and heating

We believe that natural gas is the hydrocarbon with the most constructive demand outlook owing to the importance of the shift of heavily coal-dependent economies to cleaner fuels such as gas and renewables. As we have outlined in the previous section, the shift away from coal can explain c.80% of emissions reduction across the largest countries globally, and we believe that the shift away from coal in power generation, particularly in Asia (and other emerging markets), is likely to continue and accelerate. In the analysis presented in the table below, we have considered a number of different scenarios for potential growth of demand for natural gas in power generation. In particular, we have considered the combined effect of a potential reduction of coal in the power mix and increased penetration for renewables assuming a base case CAGR of electricity growth of 2% to 2040 (broadly in line with IEA ‘Stated Policies’ scenario) as electrification in transport and industry accelerates. The scenarios considered vary from

25% of coal fuel in the power generation mix by 2040 (from 38% in 2018) to 5% (broadly in line with IEA's sustainable development scenario), and from 40% to 65% of renewable fuel in electricity generation mix in 2040 (vs. 26% currently, including solar, wind, hydroelectric, geothermal & biomass).

The result indicates that with the exception of a rare case where coal declines from 38% currently to 25% in the electricity generation mix, and renewables share in electricity generation grows from c.25% currently to over 60%, in line with the sustainable development scenario, gas demand in power generation is likely to grow. More specifically, the scenarios under which gas declines due to aggressive uptake of renewables yet non-deceleration in coal are shown to result in a higher carbon intensity for electricity generation (based on current carbon intensities of coal, gas and renewables in power generation). The sensitivity analysis assumes that nuclear energy share in power generation remains at c.9% and excludes any impact from CCS.

Exhibit 59: Natural gas demand will grow under the vast majority of potential scenarios, with the exception of when coal declines less than current policies suggest and renewables grow at sustainable development levels

Natural gas demand in power generation under different scenarios of coal and renewables % fuel mix in power generation and associated carbon intensity of electricity generation mix (kg/kWh)

Natural gas CAGR 2018-40 in power generation (%)

Coal in electricity generation mix (%) - 2040	Renewables share in electricity generation mix (%) - 2040: 40%	45%	50%	55%	60%	65%
25%	2.4%	0.6%	0.0%	-1.6%	-4.4%	-13.2%
20%	3.3%	2.4%	1.2%	0.1%	-1.6%	-4.6%
15%	4.0%	3.2%	2.2%	1.4%	0.1%	-1.7%
10%	4.6%	3.9%	3.1%	2.4%	1.4%	0.0%
5%	5.1%	4.5%	3.8%	3.2%	2.4%	1.3%

** Assumming electricity generation grows by 2% CAGR 2018-40*

*** Renewables include solar, wind, hydro, geothermal & biomass*

Carbon intensity of electricity generation (kg/kWh)

Coal in electricity generation mix (%) - 2040	Renewables share in electricity generation mix (%) - 2040: 40%	45%	50%	55%	60%	65%
25%	0.35	0.31	0.30	0.28	0.26	0.24
20%	0.32	0.30	0.28	0.26	0.24	0.21
15%	0.30	0.28	0.25	0.23	0.21	0.19
10%	0.28	0.25	0.23	0.21	0.19	0.17
5%	0.25	0.23	0.20	0.19	0.16	0.14

** Carbon intensity for electricity generation for coal, natural gas and oil taken to be the current electricity generation carbon intensity for each fuel (excl. efficiency gains and CCUS)*

Source: Goldman Sachs Global Investment Research

Exhibit 60: A shift of power generation away from coal causes the most notable decrease in emissions associated with electricity generation under the scenarios considered

Emissions from electricity generation in 2040 and change in emissions in 2018-40 (GtCO2eq) for different coal and renewables share in electricity generation mix in 2040 (%)

Emissions from electricity generation (Gt CO2eq)

Coal in electricity generation mix (%) - 2040	Renewables share in electricity generation mix (%) - 2040: 40%	45%	50%	55%	60%	65%
25%	14.2	12.8	12.4	11.6	10.7	9.7
20%	13.2	12.3	11.3	10.6	9.7	8.8
15%	12.2	11.3	10.3	9.6	8.7	7.8
10%	11.3	10.3	9.3	8.6	7.7	6.8
5%	10.2	9.3	8.3	7.6	6.7	5.8

Change in electricity emissions 2018-40 (GtCO2eq)

Coal in electricity generation mix (%) - 2040	Renewables share in electricity generation mix (%) - 2040: 40%	45%	50%	55%	60%	65%
25%	1.6	0.1	-0.3	-1.1	-2.0	-3.0
20%	0.6	-0.4	-1.4	-2.1	-3.0	-3.9
15%	-0.4	-1.4	-2.4	-3.1	-4.0	-4.9
10%	-1.4	-2.3	-3.3	-4.1	-4.9	-5.9
5%	-2.4	-3.3	-4.3	-5.1	-5.9	-6.9

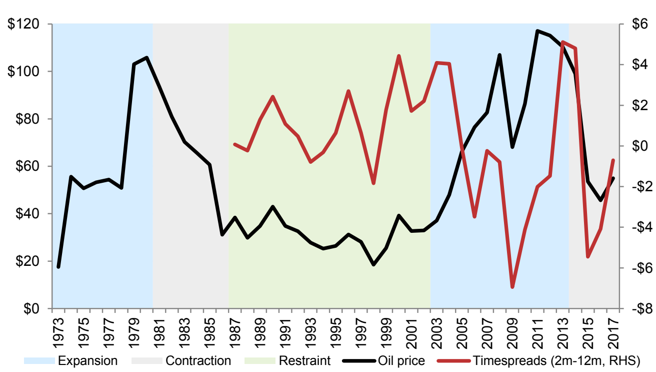
Source: Goldman Sachs Global Investment Research

A new 'Age of Restraint': De-carbonization leads to a tight oil market in structural backwardation

We believe that the industry is currently **entering the new 'Age of Restraint',** as we highlighted in our industry overview report. **Abundant OPEC spare capacity kept the curve in backwardation in the 1990s,** the previous 'Age of Restraint', as it created a sense of long-term abundance, while providing enough short-cycle production to counteract supply shocks, but not enough to move the physical market into a surplus. We view **this 'Age of Restraint' as similar in nature**, **with de-carbonisation now playing a similar role in incentivizing investments in long-cycle capacity**, while shale is setting the price in the short term through periods of expansion vs. hibernation and OPEC gaining market share. We view this **backwardated market as structural in nature.**

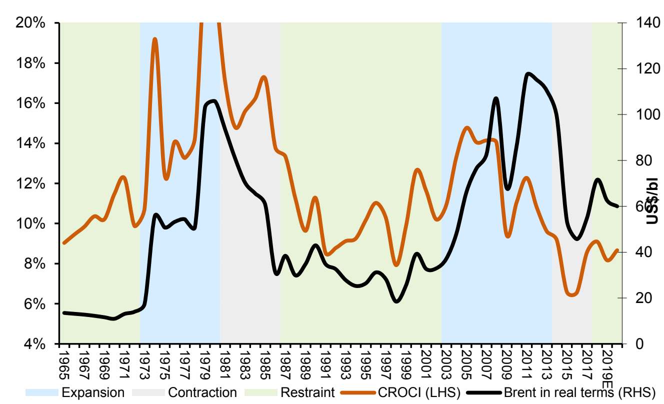
Oil prices have doubled from the trough in 2016. Similar oil price moves in 2004 to 2007 led to a doubling of hydrocarbon investments, ultimately leading to higher non-OPEC supply half a decade later, alongside cost inflation and industry fragmentation. However, in our view, a **broken financial transmission mechanism invalidates the historical relationship between oil prices, investments and future oil production**. As such, the **tight oil market that we forecast in the 2020s**, based on underinvestment and project FID delays as well as a deceleration in US shale growth, is **likely to be structural in nature**. The primary cause of this broken transmission mechanism is substantial tightening in capital availability for new hydrocarbon developments as the market becomes increasingly focused on the transition towards low carbon.

Exhibit 61: The Restraint phase is characterised by a backwardated forward curve, providing incentive for short-cycle production, and high barriers to entry for long-cycle investments
Oil prices (real terms, LHS) and timespreads (RHS), US$/bl



Source: FactSet, Goldman Sachs Global Investment Research

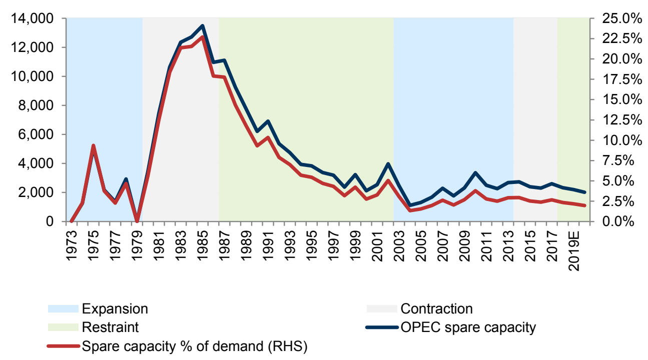
Exhibit 62: ...the underinvestment and consolidated market structure resulted in Big Oils returns improving throughout the Restraint phase
CROCI for BP, RDS, XOM over time (LHS) vs. Brent (US$/bl, real terms, RHS)



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

Exhibit 63: In the 1990s, OPEC spare capacity played a key role in keeping the market in 'Restraint'...

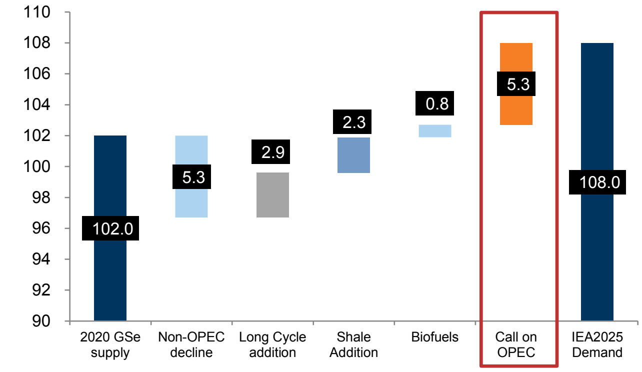
OPEC spare capacity (kbd, LHS) and as % of demand (RHS) in the various phases of the cycle



Source: IEA, BP, Goldman Sachs Global Investment Research

Exhibit 64: ...and we expect the 2020s to be similar, with a c.1mn blpd annual call on OPEC from 2021 on the back of a material slowdown of non-OPEC growth

Key drivers of oil supply growth over 2020-25E (mn blpd)



Source: IEA WEO 2018, Goldman Sachs Global Investment Research

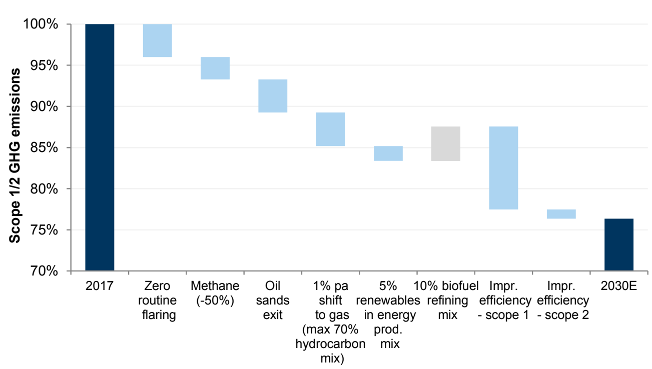
Big Oils have a key role to play in de-carbonization as they transition to Big Energy

Big Oils have many tools to become broader, cleaner energy providers: Gas value chains (incl. LNG), clean power & retail, biofuels, petrochemicals, sequestration and reforestation

Big Oils have shown tremendous ability to adapt to technological change in their 100+ years of history. We believe it is now strategic that they drive a low-carbon transition consistent with the global ambition to contain global warming within 2° C. We believe Big Oils have many tools to achieve this transition towards Big Energy and become broader, cleaner energy providers: a deeper presence in the global gas and power chains, including retail, EV charging and renewables; biofuels; petrochemicals; improved upstream and industrial operations; and carbon capture. In our deep-dive analysis, 'Re-Imagining Big Oils', we discussed the options available and argue that the strategic objective can be delivered with improving corporate returns and renewed value for scale and integration. This transition will require deep cultural and corporate changes and may leave the higher carbon parts of the value chain financially stranded and underinvested, such as oil production (particularly oil sands and older fields), as outlined in the previous sections of this report, and refining, likely leading to higher oil prices and refining margins in the coming decade.

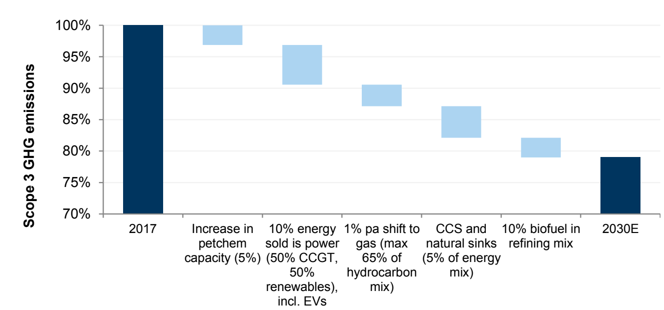
We estimate that this transition, if fully embraced and executed, has the potential to lead to a 20%+ reduction in greenhouse gas emissions (GHG) by 2030 in Big Oils' direct operations but also on a 'well to wheel' basis, consistent with a 2° C scenario. Further, we estimate that Big Oils can see improving returns in their path to becoming Big Energy, as the improved market structure that now characterises the oil & gas industry (increased consolidation and higher barriers to entry) will likely foster improved returns in the traditional oil & gas business. These higher returns from the traditional oil & gas business should in turn provide Big Oils with further funding to re-imagine their business, showing renewed value for scale and integration.

Exhibit 65: We estimate that Big Oils can deliver an equivalent 20%+ reduction in GHG by 2030 in their direct operations...
Big Oils scope 1/2 GHG emissions intensity 2018-30 bridge



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 66: ...and on a 'well to wheel' basis, transforming themselves into 'Big Energy'
Big Oils scope 3 GHG emissions 2018-30 bridge



Source: Company data, Goldman Sachs Global Investment Research

Overall, we see European Big Oils already spending c.50% of their capex on the low-carbon transition and path to Big Energy, when accounting for all low-carbon activities; gas, power & retail, petrochemicals, biofuels, renewables, natural sinks and carbon capture.

Exhibit 67: Big Oils are already spending c.50% of their capex in low-carbon activities including gas, power & retail, petrochemicals, biofuels, renewables and sequestration

	Low carbon transition capital expenditure				
	US$bn	%	US$bn	US$bn	%
	GSe capex on renewables forecast pa (2019-30)	Annual renewables Gse capex % of 2019 Gse capex	Company capex guidance on low carbon & clean energies	GSe capex expected on low carbon transition (incl. gas, power, retail, petchems, biofuels, clean energies)	Company total capex on low carbon transition as % of GSe 2019-21E capex
RDShell	0.44	1.8%	$1-2 bn to 2020, $2-3bn pa for 2021-25	$10-14 bn pa 2019-20, $13-17 bn pa 2021-25	53%
TOTAL	0.71	5.3%	$1-2 bn pa to 2020	$7 bn pa to 2021	49%
BP	0.49	3.2%	$0.5bn pa	$7 pa to 2021	45%
Equinor	0.79	7.7%	15-20% capex by 2030	$4.5 bn pa to 2021	42%
ENI	0.60	6.8%	€1.4bn (2019-22)	.€4.1-4.2 bn pa to 2021	49%
Repsol	0.19	5.1%	€2.5bn (2018-20)	€2.0bn pa to 2021	51%
OMV	0.01	0.2%	N/A	€1.0 bn pa to 2021	46%
Galp	0.01	1.5%	5% capex by 2020, 10-15% capex in renewables new business 2020+	€0.4 bn to 2021	39%
				Median	**47%**

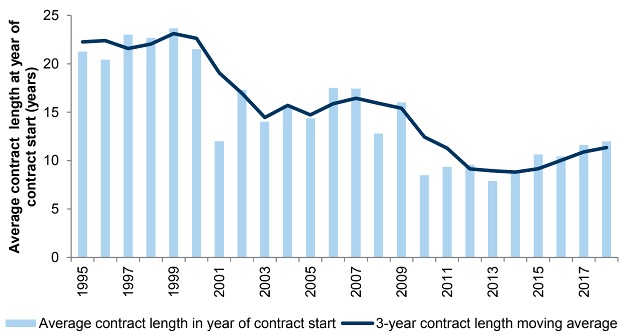
Source: Company data, Goldman Sachs Global Investment Research

LNG and power the imprint of Big Oils' de-carbonization strategy

LNG has been a cornerstone of Big Oils' businesses for decades. However, the market has structurally changed over the past decade. Historically, Big Oils would take the project and commodity price (oil price) risk of the projects, but the volume risk and the basis risk (gas prices vs. oil prices) would be incurred by the utility customers. Since 2000, the average length of LNG offtake contracts signed has almost halved to c.10 years and so has the average contract volume, with a larger share of the volumes sold on the spot market, as utilities can no longer pass through the volume and basis risk to the final customer. This 'de-regulation' of the LNG market is changing the industry dynamics, with the emergence of large portfolio players (Big Oils) with global scale and the ability to act as 'market makers' in an illiquid market with volume and basis risk. This is creating clear economies of scale and higher barriers to entry. As Asian utilities continue to de-risk through signing shorter and smaller contracts, only a handful of companies including Big Oils and a few NOCs, in our view, will be in a position to undertake major new LNG developments.

Exhibit 68: The average contract length for signed LNG contracts commencing each year has almost halved since 2000

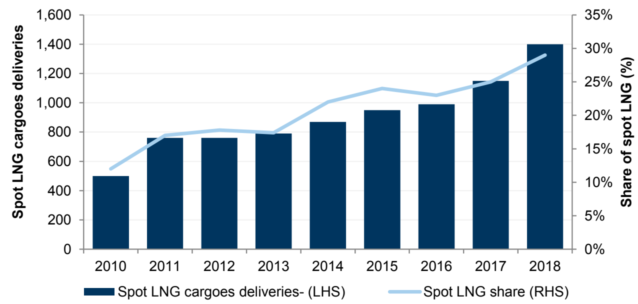
Average contract length at year of contract start and 3-year moving average



Source: Kepler, Goldman Sachs Global Investment Research

Exhibit 69: Spot LNG cargo deliveries have started to gain momentum at the expense of contracted LNG volumes over the past five years

Spot LNG cargo delivery (LHS) vs. spot LNG market share (RHS)



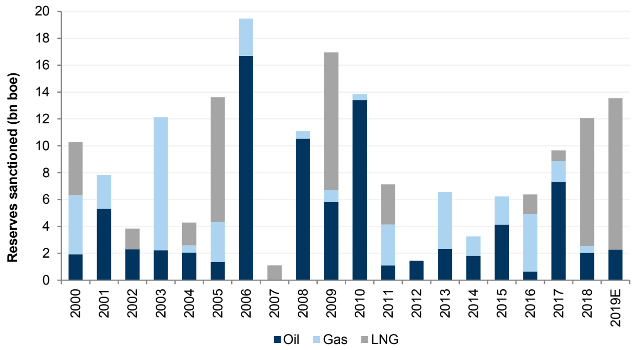
Source: Royal Dutch Shell, Data compiled by Goldman Sachs Global Investment Research

Big Oils have emerged as the key LNG market makers in a vacuum of traditional long-term contracts, allowing a number of new developments to move ahead

Among Big Oils, RDShell (followed by TOTAL and BP) has built a leadership position in global LNG volumes, both produced (equity), sourced (long-term supply) and traded (spot), as shown in exhibit 71. They have built in LNG an equivalent of the 'pyramid' in oil, where their equity oil production is levered into a larger refining throughput and even larger trading and retail volumes, with an accelerating contribution of third-party LNG volumes in their portfolio. Both RDShell and TOTAL have laid out ambitious expansion strategies in the global LNG market, with increasing market share over the past decade.

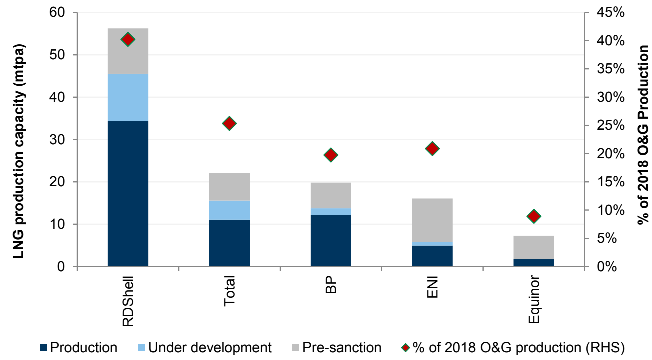
We believe that we are currently entering the **next wave of LNG projects**, dominated by Big Oils, with LNG sanctions likely to continue to accelerate in 2019-20. LNG is the hydrocarbon with the most constructive long-term demand outlook, primarily driven by the ongoing policy shift in China and its blue-sky policy. In exhibit 70, we show the reserves sanctioned by the 'Seven Sisters', according to our Top Projects analysis, split by type of product (oil, gas and LNG), with LNG dominating project sanctions by the majors in 2018 and expected to continue to lead to a healthy pace of FIDs in 2019-20, further cementing Big Oils' shift towards Big Energy.

Exhibit 70: We are entering the next wave of LNG projects sanctions...
Top Projects reserves sanctioned by the 'Seven Sisters' (RDShell, TOTAL, BP, ENI, Equinor, ExxonMobil, Chevron)



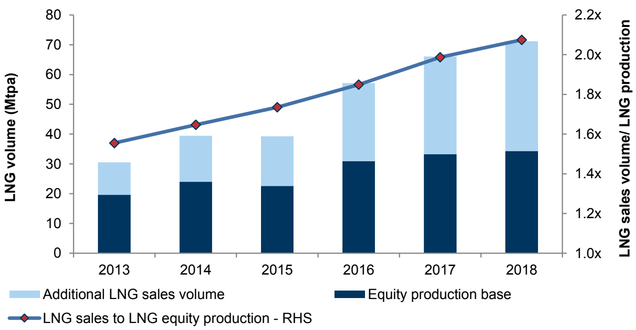
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 71: ...driven by Big Oils, as they transition to Big Energy
LNG production capacity (split by producing, pre-sanctioned and under development) and as a % of total 2018 oil & gas production for Big Oils



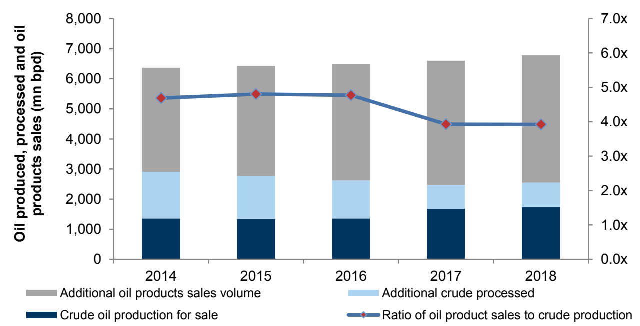
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 72: RDShell's LNG volumes have more than doubled over the past five years, with a larger contribution from third-party volumes...
RDShell LNG volumes (mtpa) - LHS split by equity production (%) - RHS



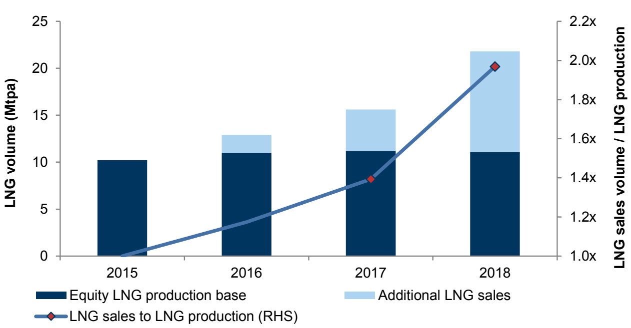
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 73: ...adopting a similar model to its integrated oil operations, with oil products volumes sold 4x larger than the company's equity production
RDShell's oil volume produced, processed and oil products sold (kbpd)



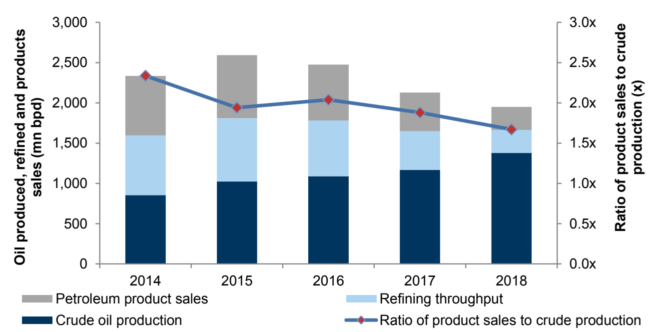
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 74: TOTAL has also been increasing its LNG volumes, a balanced portfolio of equity and third-party production...
TOTAL LNG managed volumes (mtpa)-RHS split by equity production (%)-RHS



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 75: ...a similar model to the oil products vertical integration of the company, with oil product sales currently more than double the company's equity production
TOTAL's oil volume produced, refined and oil products sold (kbpd)



Source: Company data, Goldman Sachs Global Investment Research

Appendix: De-carbonization cost curve in detail

Exhibit 76: De-carbonization conservation cost curve with the carbon abatement price range (US$/tnCO2eq) and abatement potential (GtCO2eq) split by industry

Conservation carbon abatement routes	Industry	Carbon abatement price - base case	Carbon abatement price - low case	Carbon abatement price - high case	Carbon abatement potential
Power generation - switch from coal to gas		(US$/tnCO2 eq)	(US$/tnCO2 eq)	(US$/tnCO2 eq)	(GtCO2eq)
Switch coal to gas - North America (ex-US)	Power generation	-11	-13	-8	0.04
Switch coal to gas - US	Power generation	3	2	3	0.45
Switch from coal to gas -CIS	Power generation	3	2	3	0.18
Switch from coal to gas -Middle East	Power generation	31	23	39	0.01
Switch from coal to gas -Asia Pacific (low gas price)	Power generation	31	23	39	0.23
Switch from coal to gas -Latin America	Power generation	31	23	39	0.04
Switch from coal to gas -Europe	Power generation	31	23	39	0.41
Switch from coal to gas -Africa	Power generation	45	33	56	0.13
Switch from coal to gas -Other Europe	Power generation	45	33	56	0.03
Switch from coal to gas -Asia Pacific (high gas price)	Power generation	59	44	74	3.57
Power generation - switch to renewables					
Solar low cost cost scenario, high gas price	Power generation	-100	-121	-80	0.22
Solar medium cost cost scenario, high gas price	Power generation	-76	-91	-61	0.22
Solar low cost cost scenario, medium gas price	Power generation	-62	-74	-50	0.22
Onshore wind low cost scenario, high gas price	Power generation	-47	-56	-37	0.12
Solar medium cost cost scenario, medium gas price	Power generation	-38	-45	-30	0.22
Onshore wind medium cost scenario, high gas price	Power generation	-16	-19	-12	0.12
Solar+battery low cost scenario, high gas price	Power generation	-11	-13	-9	0.19
Onshore wind low cost scenario, medium gas price	Power generation	-8	-10	-7	0.12
Solar low cost cost scenario, low gas price	Power generation	-4	-5	-3	0.43
Solar high cost cost scenario, high gas price	Power generation	0	0	0	0.22
Offshore wind low cost scenario, high gas price	Power generation	7	5	8	0.14
Onshore wind high cost scenario, low gas price	Power generation	18	15	22	0.12
Solar medium cost cost scenario, low gas price	Power generation	20	16	24	0.43
Onshore wind medium cost scenario, medium gas price	Power generation	23	18	28	0.12
Solar+battery low cost scenario, medium gas price	Power generation	27	22	33	0.19
Solar high cost cost scenario, medium gas price	Power generation	39	31	47	0.22
Wind+battery low cost scenario, high gas price	Power generation	42	34	51	0.09
Offshore wind low cost scenario, medium gas price	Power generation	45	36	54	0.14
Onshore wind low cost scenario, low gas price	Power generation	49	40	59	0.25
Onshore wind high cost scenario, medium gas price	Power generation	57	45	68	0.12
Offshore wind high cost scenario, high gas price	Power generation	60	48	72	0.14
Onshore wind medium cost scenario, low gas price	Power generation	81	65	97	0.25
Wind+battery low cost scenario, medium gas price	Power generation	81	65	97	0.09
Solar+battery low cost scenario, low gas price	Power generation	85	68	102	0.37
Solar high cost cost scenario, low gas price	Power generation	97	77	116	0.43
Offshore wind high cost scenario, medium gas price	Power generation	99	79	119	0.14
Offshore wind low cost scenario, low gas price	Power generation	103	82	124	0.28
Onshore wind high cost scenario, low gas price	Power generation	114	74	155	0.25
Wind+battery low cost scenario, low gas price	Power generation	139	90	187	0.19
Offshore wind high cost scenario, low gas price	Power generation	157	102	211	0.28
Solar+battery high cost scenario, high gas price	Power generation	197	128	266	0.19
Wind+battery high cost scenario, high gas price	Power generation	215	140	290	0.09
Solar+battery high cost scenario, medium gas price	Power generation	235	153	318	0.19
Wind+battery high cost scenario, medium gas price	Power generation	253	165	342	0.09
Solar+battery high cost scenario, low gas price	Power generation	293	191	396	0.37
Wind+battery high cost scenario, low gas price	Power generation	311	202	420	0.19
Transport					
LNG retrofit in shipping	Transport	66	28	118	0.27
City Buses to electric buses	Transport	215	123	307	0.33
Marine biofuels	Transport	217	174	261	0.10
Biofuels on road transport	Transport	268	179	357	0.29
Truck to electric, short-haul	Transport	322	230	414	1.04
Truck to electric, long-haul	Transport	376	284	476	0.99
Diesel vehicle to EV, urban	Transport	403	38	748	0.52
Gasoline vehicle to EV, urban	Transport	545	299	779	0.86
Aviation biofuels	Transport	673	594	752	0.55
Gasoline vehicle to EV, rural	Transport	1,012	779	1,311	0.81
Diesel vehicle to EV, rural	Transport	1,093	748	1,534	0.50

Source: Goldman Sachs Global Investment Research

Exhibit 77: De-carbonization conservation cost curve with the carbon abatement price range (US$/tnCO2eq) and abatement potential (GtCO2eq) split by industry

Conservation carbon abatement routes	Industry	Carbon abatement price - base case	Carbon abatement price - low case	Carbon abatement price - high case	Carbon abatement potential
Industry & industrial waste					
Secondary production through scrap/recycling in aluminium	Industry & waste	-117	-141	-94	0.12
Efficiency gains & plastics recycling	Industry & waste	-78	-63	-94	0.11
Energy & process efficiency through recycling and BAT in pulp & paper	Industry & waste	-23	-28	-19	0.11
Other petrochemical process gains	Industry & waste	12	8	15	0.43
Ammonia efficiency gains	Industry & waste	35	28	42	0.14
Iron & steel efficiency gains	Industry & waste	45	36	54	0.14
Efficiency industrial gains other low cost	Industry & waste	48	34	62	1.68
Inert anodes development for aluminium process	Industry & waste	66	46	86	0.02
Other material & energy efficiency improvements in cement (ie. BAT)	Industry & waste	78	62	94	0.72
Charcoal biomass as fuel and feedstock for iron & steel	Industry & waste	85	68	102	0.41
Efficiency industrial gains other medium cost	Industry & waste	95	67	124	1.68
DIR-EAF with zero carbon electricity in iron & steel	Industry & waste	113	90	135	0.37
Fuel switch to biomass & waste in cement	Industry & waste	127	102	152	0.30
Switch to biogas or biomass as a feedstock in ethylene	Industry & waste	130	104	156	0.07
Reducing clinker to cement ratio in cement	Industry & waste	149	119	179	0.09
Switch to biogas or biomass as a feedstock in ammonia process	Industry & waste	173	138	207	0.10
Efficiency industrial gains other high cost	Industry & waste	250	175	325	1.68
Switch to electrolysis-derived hydrogen as feedstock in ammonia	Industry & waste	290	174	407	0.05
Hydrogen or biogas DIR-EAF in iron & steel	Industry & waste	348	209	488	0.32
Buildings					
LED and increased efficiency - commercial	Buildings	-77	-96	-58	0.19
LED and increased efficiency, residential	Buildings	-67	-83	-50	0.16
Insulation (cavity and wall) - commercial buildings	Buildings	-58	-72	-43	0.11
Insulation (cavity wall) for new residential	Buildings	-50	-63	-38	0.12
HVAC smart systems/efficiency gains - commercial	Buildings	-48	-60	-36	0.04
HVAC Systems/thermostat & smart meters for residential new	Buildings	-42	-52	-31	0.05
HVAC Systems/thermostat & smart meters residential retrofit	Buildings	-32	-40	-24	0.02
Insulation (cavity wall) - residential retrofit	Buildings	-20	-15	-25	0.06
Heat pumps - commercial buildings	Buildings	76	57	95	0.27
Heat pumps (air to air), residential, new	Buildings	90	67	112	0.29
Heat pumps - water heating - commercial	Buildings	140	105	174	0.08
Renewable heat (solar thermal, PV) - water heating - commercial	Buildings	149	112	186	0.04
BACS systems/efficiency gains/BAT appliances residential	Buildings	159	120	199	0.54
Heat pumps - water heating (ground source heat pump) for residential	Buildings	164	123	205	0.32
Renewable heat (solar thermal, PV) - water heating, residential	Buildings	175	131	219	0.14
Heat pumps (air to air) residencial retrofit	Buildings	178	133	222	0.14
BACS systems - commercial	Buildings	183	138	229	0.26
Renewable heat (biomass) - commercial buildings	Buildings	224	168	280	0.02
Renewable heat (biomass), residental new	Buildings	263	197	329	0.02
Renewable heat (biomass) - residential retrofit	Buildings	283	212	353	0.01
Agriculture, Forestry and Other Land uses (AFOLU)					
Fire & disaster improved mannagement practices	Agriculture, forestry & other land uses	10	6	14	1.00
Reduced soil erosion, salinization and compaction	Agriculture, forestry & other land uses	35	21	49	1.70
Improved forest management practices	Agriculture, forestry & other land uses	37	22	52	1.00
Improved cropland management practices	Agriculture, forestry & other land uses	42	25	59	1.35
Improved grazing land management practices	Agriculture, forestry & other land uses	58	35	81	1.49
Improved livestock management practices	Agriculture, forestry & other land uses	120	72	168	1.09

Source: Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Michele Della Vigna, CFA and Zoe Stavrinou, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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

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Disclosures

Coverage group(s) of stocks by primary analyst(s)

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A-share Energy: China Oilfield Services (A), China Petroleum & Chemical (A), PetroChina (A).

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America-Integrated Oils: Canadian Natural Resources Ltd., Cenovus Energy Inc., Chevron Corp., ConocoPhillips, Exxon Mobil Corp., Husky Energy Inc., Imperial Oil Ltd., Kosmos Energy Ltd., MEG Energy, Suncor Energy Inc..

America-Refining & Marketing: Calumet Specialty Products Partners, CVR Energy Inc., Delek US Holdings, HollyFrontier Corp., Marathon Petroleum Corp., Par Pacific Holdings, PBF Energy Inc., Phillips 66, Valero Energy Corp..

Asia Chemicals: China Steel Chemical, Far Eastern New Century Corp., Formosa Chemicals & Fibre, Formosa Petrochemical Corp., Formosa Plastics, Hanwha Chemical, IRPC PCL, Kumho Petro Chemical Co., LG Chem, Lotte Chemical, Nan Ya Plastics, Petronas Chemicals Group, PTT Global Chemical, Siam Cement PCL, Taiwan Synthetic Rubber Corp..

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Australia-Energy: Beach Energy, Caltex Australia Ltd., Oil Search, Origin Energy, Santos Ltd., Viva Energy Group, Woodside Petroleum.

Australia-Utilities: AGL Energy, APA Group, AusNet Services, Contact Energy, Genesis Energy Ltd., Mercury NZ Ltd., Meridian Energy Ltd., Spark Infrastructure.

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India/ASEAN Oil & Gas: First Resources, Gas Authority of India, Golden Agri-Resources Ltd., Gujarat State Petronet, Indraprastha Gas Ltd., Oil & Natural Gas Corp., Oil India, Perusahaan Gas, Petronet LNG, PTT Exploration and Production PCL, PTT Public Co., Wilmar International.

Latin America-Airlines: Azul SA, Azul SA, Copa Holdings, GOL Linhas Aereas Inteligentes SA, GOL Linhas Aereas Inteligentes SA, LATAM Airlines Group, LATAM Airlines Group, Volaris, Volaris.

Latin America-Construction: Cemex, Cemex SAB.

Latin America-Diversified Industrials: Localiza Rent a Car SA, Weg SA.

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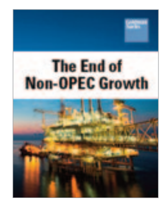

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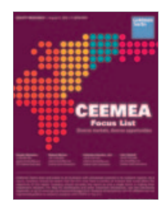

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