RystadEnergy

Scenarios for Energy Transition

A pragmatic approach to transition for the US Oil & Gas industry

US Senate Budget Committee Hearing

Oil Markets, Gas Markets, Clean Tech

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A pragmatic approach to the transition

The global energy industry is at a turning point. A transition is sweeping across many of its sectors. In some areas, like electric vehicles, solar PV, wind, and batteries the pace of change has been rapid and gaining momentum. In others, commercially competitive alternatives to oil and gas are yet to emerge. The net effect is that we do not know yet how fast and deep the process of the energy transition will be. But one thing we know for sure: The change already underway is relentless, and it's not going to be business-as-usual.

15 years ago, the Shale revolution led to a resurgence in American oil and gas production, helping it play a crucial role in satisfying domestic and global demand for hydrocarbons. This has helped keep supply steady and - as a result - prices in check through geopolitical upheavals, such as the Arab Spring. In recent times, Russia's invasion of Ukraine has been perhaps the most powerful illustration of how oil and gas supply routes can be disrupted within a matter of days. Again, US oil & gas has been essential at keeping the market balanced and prices in check.

In a similar fashion when oil began to displace coal as the main source of energy in the 20th century, technological breakthroughs have been slowly but surely integrating renewable and non-fossil fuel sources into the US and global energy systems. Just as coal was displaced by oil and gas, renewables and emerging clean technologies are positioned to take much of the pressure away from fossil fuels in the coming years and decades.

The energy transition is once-in-a-generation opportunity for the US. With strategic moves, such as the Inflation Reduction Act (IRA), with its targeted incentives to accelerate the formation of key cleantech industries, such as hydrogen and CCUS, the US can cement its position as an Energy Superpower, with state-of-the-art innovations providing homes and factories with clean, affordable, and reliable energy while also working towards the US' net zero goals. We believe this is the time for America to bet on the next energy evolution, driven by renewables, carbon capture, storage and utilization, hydrogen, and battery and energy storage.

Yet, oil and gas demand is not going away in the short term. The capital stock associated with energy consumption takes time to be replaced, while emerging nations aim to grow their per-capita energy consumption on the back of their urbanization and industrialization. The US is currently the largest oil & gas producer worldwide, meeting 16% of the world's oil supply and 20% of natural gas. It is also one of the cleanest and cheapest suppliers. US production is in the bottom quartile of upstream carbon intensity globally and in the bottom half in terms of breakeven costs.

Hence, if we were to divest too quickly from oil & gas, the price of both would increase. While focusing on the US, it is also essential that we think of the global markets implications.

Rystad Energy has developed three transition scenarios using proprietary modeling: A fast transition, called – Sigma / 1.6 DG, which would limit global temperature increase to 1.6 DG; a slow transition, +Sigma / 2.2 DG; and middle ground, Mean / 1.9 DG.

Any of these scenarios is still achievable. The fast deployment of renewables and EVs in the past 5 years may lead us to think we are on the fast transition. Yet, extrapolation of trends might fail to grasp supply-chain constraints, the need for regulatory tightening to achieve those targets, and the likely higher costs associated with the fast transition. Also, China's current stranglehold on some renewables' supply chain nodes could be a risk factor if a dramatic reduction in global trade were to occur. By the same token, the current lack of competitive alternatives to oil in key demand sectors like petrochemical, heavy duty road transport, aviation, may lead us to think that oil is on the slow transition, while technological breakthrough could quickly upend these assumptions. Currently, we think that the Mean scenario is perhaps the one with higher chances of coming to fruition for oil. In that case, US shale will remain a key energy source for the next 10-15 years, maintaining today's levels of crude production, and increasing natural gas. In the slow transition, Shale production would need to increase quite dramatically to match global demand. Yet, if a fast transition comes about, then Shale production would rapidly decrease in response to low market prices.

In conclusion, the transition is highly uncertain and the outlook for US oil & gas could be dramatically different post-2030 depending on the pace of technological development and uptake. Thus, now is the time for the US to take a pragmatic approach to energy policy, which leverages the flexibility of Shale oil & gas, while championing renewables, the likely winners in the future energy order. By doing so, the US can maintain its place as the leader of the energy world.

A brief history of oil demand, and its uncertain future

Oil began to displace coal as the most important source of primary energy during the second world war and global demand reached a peak of 64 million barrels per day (bpd) by 1980 , on the back of the powerful post-war boom spearheaded by the United States. Yet, with the second oil crisis and the consequent surge in oil prices, OECD countries started to substitute oil for gas and nuclear in power generation and invested heavily in fuel efficiency in the early 1980s. This process brought about half a decade of declining and then stagnant growth. It took almost ten years for global oil demand to reach its previous high-point in 1989.

However, by the start of the 1990s, Emerging Markets' increasing industrialization and urbanization were again lifting oil demand up. With China joining the WTO in 2001, the stage was then set for a relentless growth in oil demand for the next two decades, on the back of globalization. Not even the great financial crisis in 2008 did manage to dent this growth trajectory. It finally took the first pandemic in a century, COVID-19, to see this 30-year trend temporarily broken. Yet, by the end of 2022, the pandemic gap had already closed, and demand was back to 100 million bpd, its previous all-time high.

Therefore, history teaches us that global oil demand has shown a remarkable tendency to grow for the past six decades, bar a major oil crisis and a pandemic., both of which had only transitory effects. So, how can we credibly make the case that the next 30 years could be different?

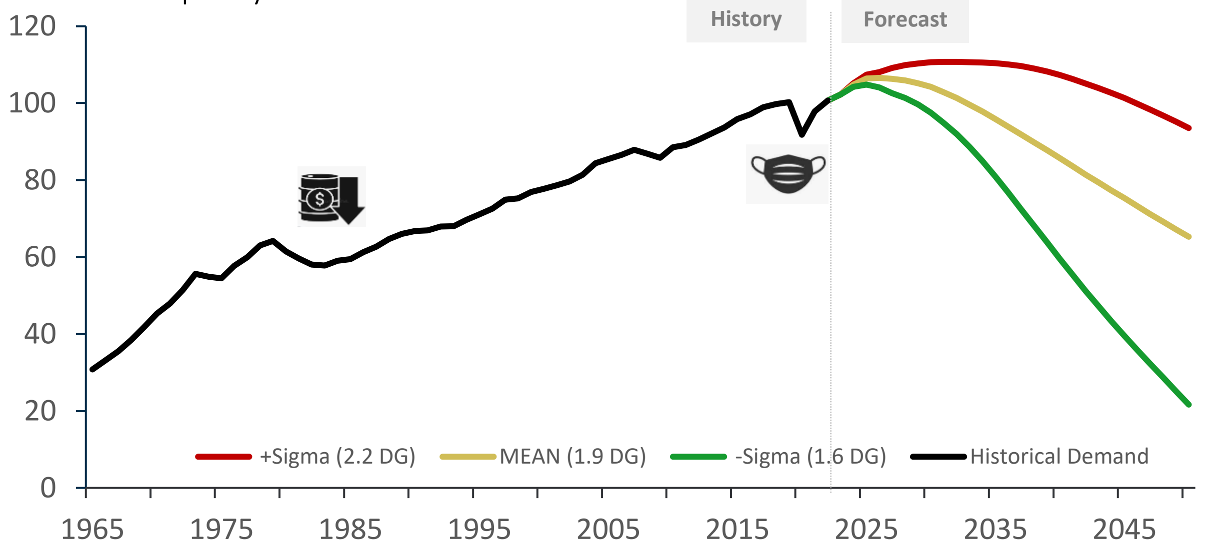
We believe it is down to the energy transition. A combination of ground-breaking technologies, some of which are already mature like the electric vehicles (EVs) in passenger road transport, others still to be proven commercially competitive such chemical recycling in the petchem sector, sustainable aviation fuel, ammonia in the maritime sector, along with a likely tightening in regulations in the form of ICE bans, curbs to some plastic consumption, carbon footprint targets in hard-to-abate industries, has the *potential* to bring about a long-term transition away from oil as a primary energy source.

The speed, depth, geographical distribution, and persistence of this epochal change is far from known and cannot be forecasted using standard models. It can only be imagined through the lenses of a scenario analysis, which allows to understand what assumptions must be met in order to credibly fulfill these trajectories.

Rystad Energy developed three oil transition scenarios: a fast one, called –Sigma, a slow one, +Sigma, and a middle of the range one, Mean. None of these are business as usual and all of them can still be achieved, albeit they require very different sets of assumptions.

Long-term global oil demand scenarios and historical demand

Million barrels per day



Source: Rystad Energy research and analysis

Global population growth to peak in the 2080s

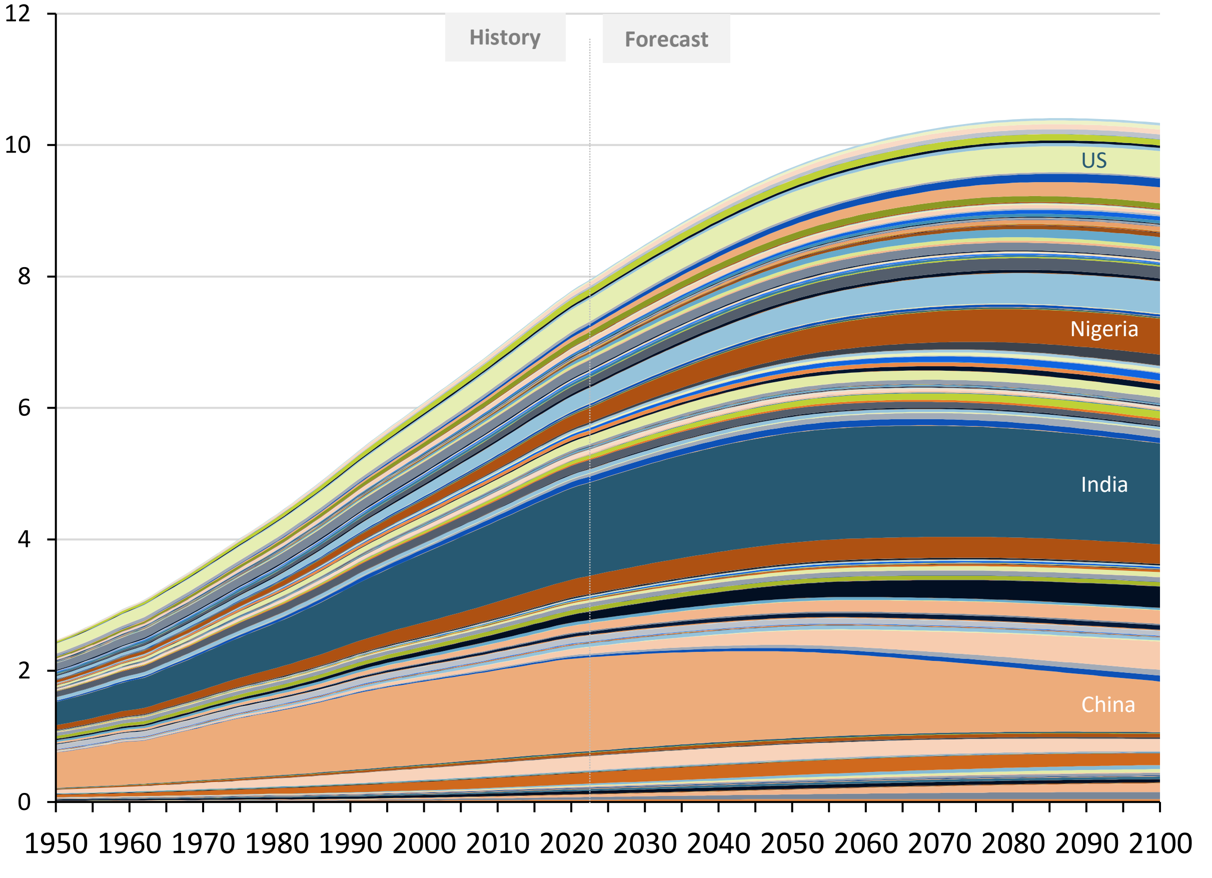
Population changes are inextricably linked to energy demand. For zero growth, sustainable population, the fertility rate allows the population to replenish itself from one generation to the next.

For developed economies, the replenishing fertility rate is on average 2.1. For less developed economies, this rate is highly dependent on the mortality rate. We see trends in developed countries of average birth rate decline below this level.

In the Rystad Base Case for population growth, which is aligned with the UN, we see total population growth peak around 2080.

When we assess demand for energy across the globe, population is one of the key drivers. In many instances, a rise in population is correlated with an increase in energy demand as a result of socio-economic advances and better quality of life. Globally, the main drivers for population levels are mortality and fertility rates.

Global population forecasts
Billion



Source: Rystad Energy, United Nations (UN)

GDP drives energy demand – US still largest economy, China runner up by end of century

Rystad Energy estimates put global GDP on track for $280 trillion by the end of the century, up from about $100 trillion today.

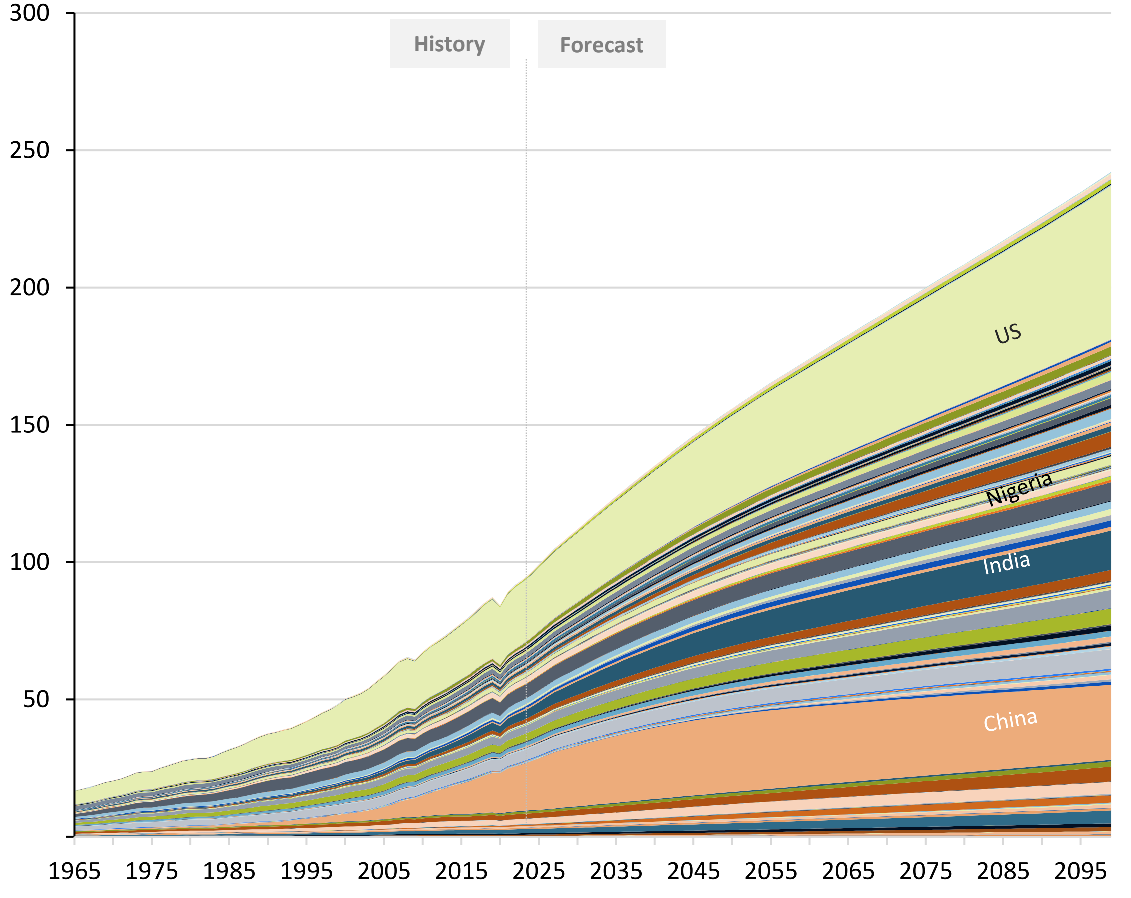
GDP and GDP per capita drive future energy use across all sectors, as more people can afford energy services and benefit from a higher standard of living as economies develop.

Rystad Energy GDP model forecasts the US will remain the leading economy globally as we move towards the end of the century. The US has been the world's largest economy since 1890 and even with its remarkable historical growth, this trend is set to continue upwards base on analysis and figures currently available.

China and India will see strong economic growth as well.

However, a decrease in the population of almost 400 million in China compared to levels today, will lead to a stagnation of GDP growth in the latter part of the century.

Global GDP by country
USD trillion (Real 2019)



Source: Rystad Energy research and analysis

Energy demand per capita dips after per capita demand saturates

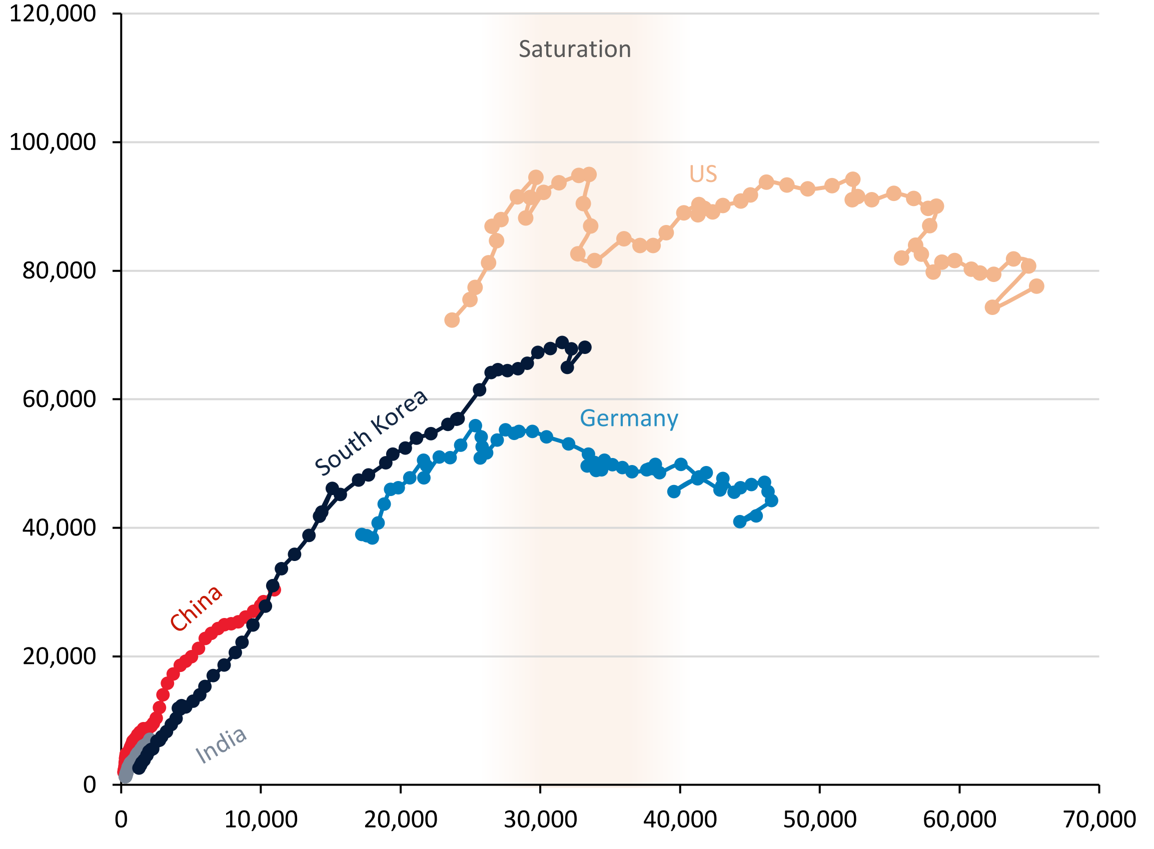
There is a strong correlation between energy demand and economic development. As countries progress trough development decades, industrialization and higher personal income levels contribute to both higher GDP and energy consumption – usually.

Historically, we have seen many countries approach a saturation level for energy consumption when GDP per capita reached $25,000 to $40,000 (at real 2019 levels).

At this point, the economy is mature, and most of the population has ownership over personal mobility solutions (like cars, bikes, etc.) and home appliances.

As countries reach higher development decades, energy consumption per capita tends to decline as energy efficiency improves.

Energy consumption and GDP growth per capital by selected countries*
Primary energy consumption (kWh) per capita, GDP per capita (2019 USD)



*China, India, South Korea, Germany and the US
Source: Rystad Energy research and analysis, IMF data, BP

Three scenarios for the oil transition

The **+Sigma (2.2°C)** scenario is a reasonable upside probabilistic range from our Mean scenario. Oil demand peaks in **2031** at **111 million bpd** and declines to 94 million bpd in 2050. These oil consumption levels are compatible with a global average temperature rise of 2.2°C by 2100 versus pre-industrial levels from the 1850s.

Key Assumptions:

- EV adoption happens slowly and, in non-OECD countries, with more consumer-side headwinds, such as lack of charging infrastructure and robust used ICE vehicle market, supporting oil demand for longer
- Plastic recycling rate increases according to historical levels and does not reach the same rate as glass or iron
- Aviation jet displacement is limited, as is maritime gasoil
- Stationary sectors continue historical linear declining trend without acceleration

The **Mean (1.9°C)** scenario is a probable long-term oil demand trajectory.

Oil demand peaks at **107 million bpd in 2027** and declines progressively to 65 million bpd in 2050. These oil consumption levels are compatible with a global average temperature rise of 1.9°C by 2100 versus pre-industrial levels from the 1850s.

Key Assumptions:

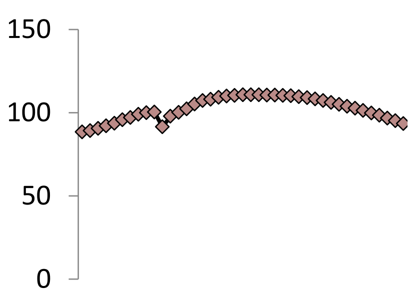
- EV adoption develops according to risked down current EV manufacturers' targets
- Plastic recycling and bans on single plastic use play a large role in reducing plastic demand and, as a result, petchem feedstock by 2050
- Bio-jet displaces an increasing percentage of jet fuel from the 2030s
- Maritime sector witnesses increasing oil displacements via LNG and ammonia
- Trucks sector begins electrification in 2030s, which accelerates in the 2040s
- Bus sector will be largely electrified by the end of the 2020s

The **–Sigma (1.6°C)** scenario is a potential downside probabilistic range from our Base Case: Mean scenario.
Oil demand peaks at **105 million bpd in 2025** and then falls precipitously to 22 million bpd in 2050. These oil consumption levels are compatible with a global average temperature rise of 1.6°C by 2100 versus pre-industrial levels from the 1850s.

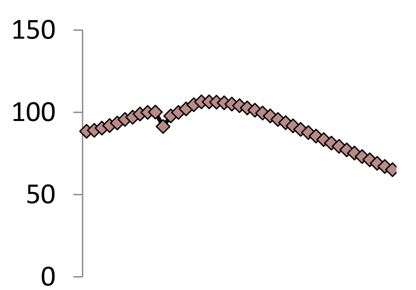
Key Assumptions:

- EV adoption proceeds according to unadjusted EV manufacturers' targets, which are ambitious
- All EV consumer constraints (charging infrastructure, power supply, etc.) are solved, and governments will adopt policies to curtail short-distance transport
- Plastic recycling converges to 90% by 2050 for some plastics types. In addition, green hydrogen accounts for around 70% of feedstock for certain plastic types
- Oil substitution notably accelerates in stationary sectors versus recent trajectories due to energy carrier substitution and efficiency gains

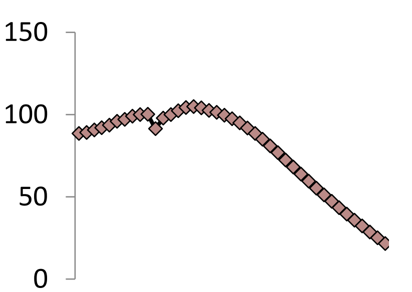
+Sigma (2.2°C)



Mean (1.9°C)



-Sigma (1.6°C)



Source: Rystad Energy research and analysis

Oil demand in passenger cars drops in the Mean scenario …

In our Mean (1.9°C) scenario, oil demand for passenger vehicles peaks at almost 30 million bpd in 2025. It rapidly drops to 8 million bpd in 2050.

The fast decline in oil demand for vehicles is mainly due to the electrification of the fleet, which is already proceeding at a fast pace, especially in Europe and China. In particular, we forecast that by 2030, EVs will have conquered more than half of the global market share. This impressive sales growth will start visibly affecting the fleet composition in the 2030s, driving down oil demand.

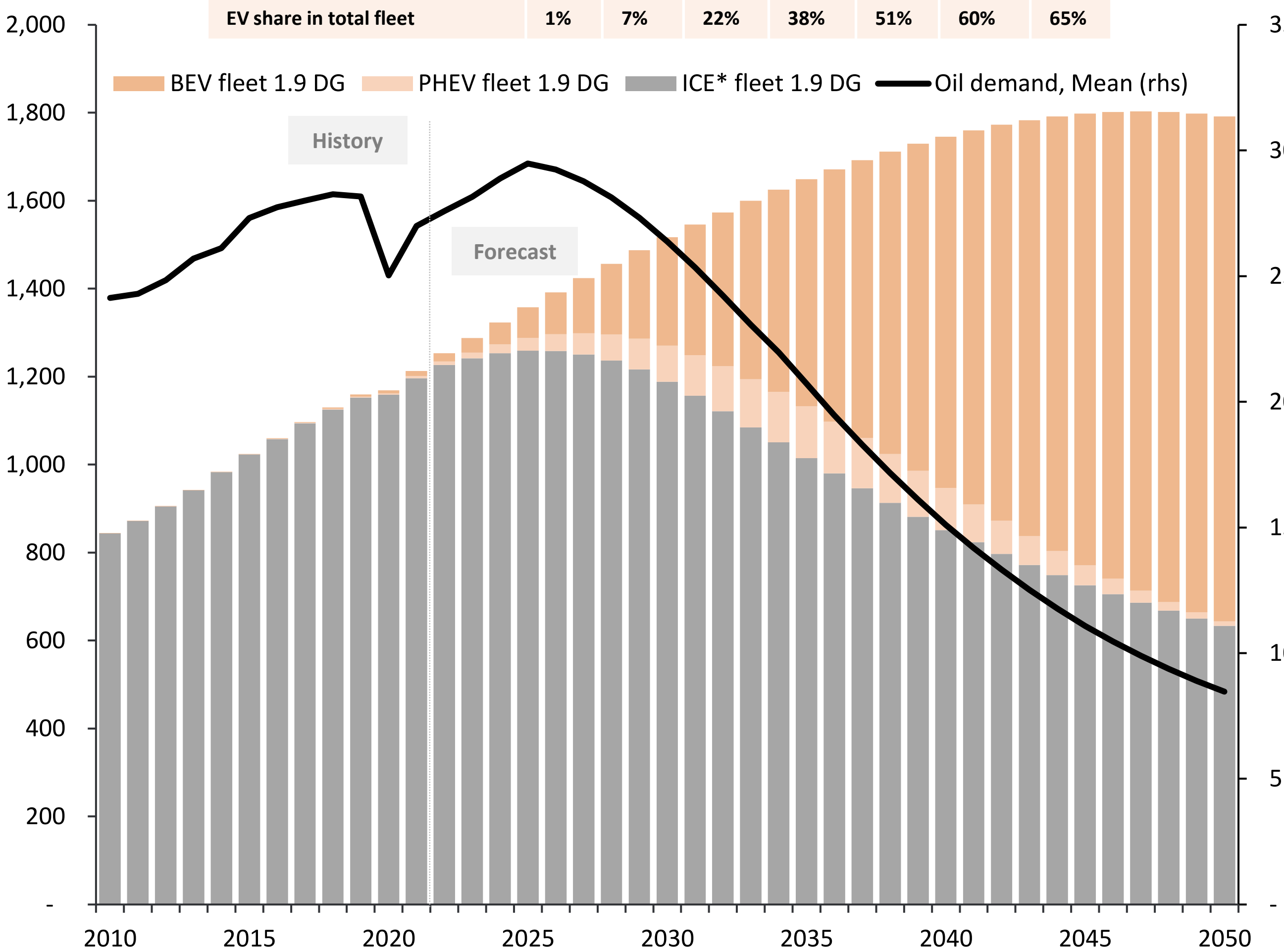
Europe and China will be at the forefront of the EV revolution, but after the US and other regions catch up from the 2030s.

Gasoline demand will be further undermined by a likely reduction in the distance driven by passenger cars. Going forward, we expect the mobility demand to be increasingly more satisfied by alternative means of transport. For instance, as the urbanization process continues, we expect public transport to become more available and to drive down the commuting demand currently satisfied by vehicles. In addition, where an efficient railway system is developed, high-speed trains will become more convenient for covering longer distances.

Global passenger vehicle fleet
Million vehicles

Global passenger vehicle oil demand
Million barrels per day

	2020	2025	2030	2035	2040	2045	2050
EV share in total sales	**5%**	**30%**	**57%**	**74%**	**84%**	**87%**	**90%**
EV share in total fleet	**1%**	**7%**	**22%**	**38%**	**51%**	**60%**	**65%**



Source: Rystad Energy research and analysis, OilMarketCube

… while it is still at today's level by 2040 in the +Sigma …

In our +Sigma (2.2°C) scenario, vehicle oil demand at 30 million bpd in 2028 and plateaus before declining to 20 million bpd in 2050.

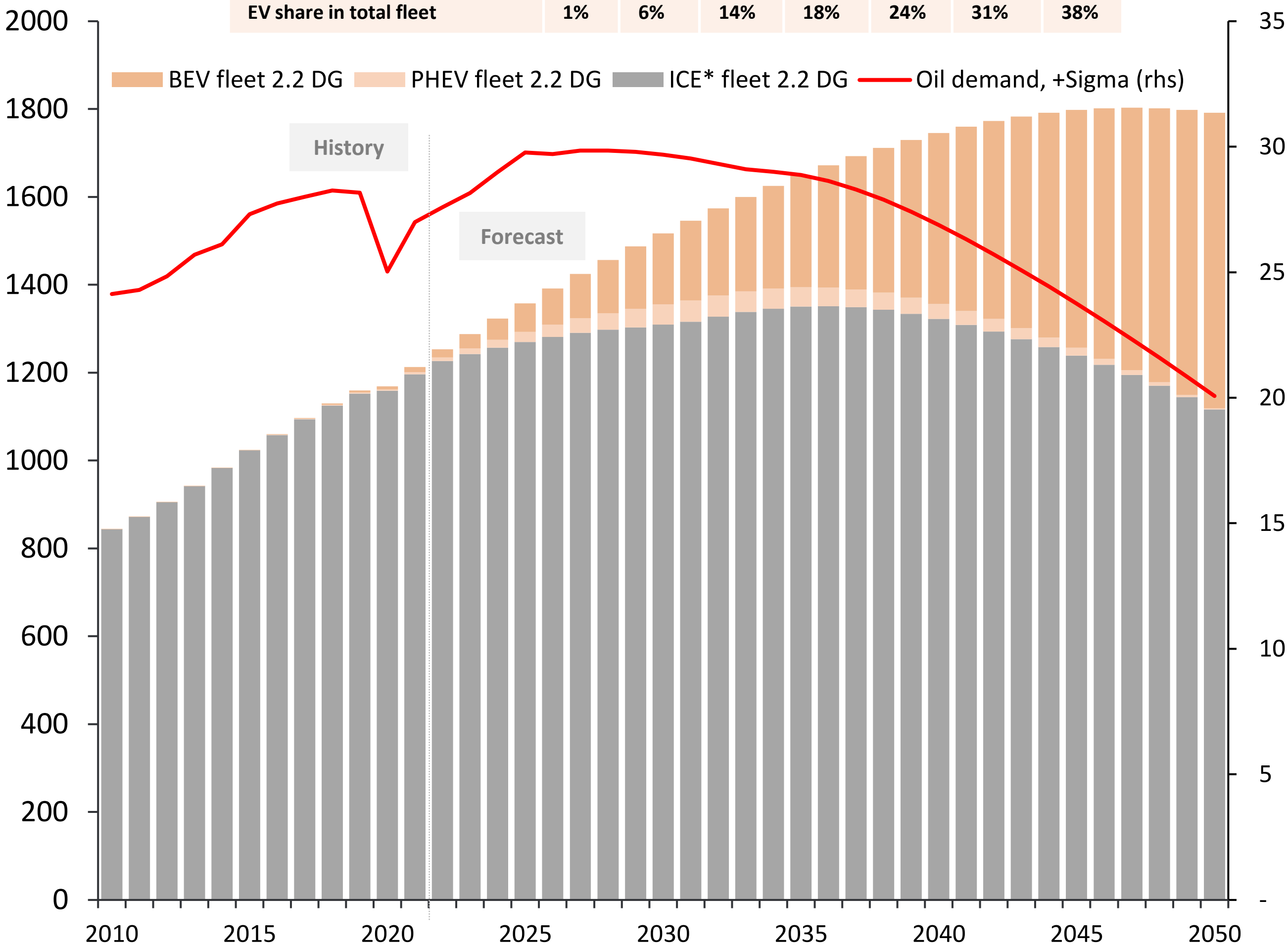
In this scenario, structural hiccups in EV development, problems in deploying the charging infrastructure, and inadequate incentives delay EV penetration, which ends up expanding the lifetime of ICEs. In the 2.2°C scenario, EV sales will reach 70% penetration only in 2050, entailing a much slower change in the fleet composition.

This scenario could materialize in the absence of adequate incentives and economic conditions, however, we deem it unlikely, given how quickly the EV market is expanding in the West (EU in particular) and China.

Global passenger vehicle fleet
Million vehicles

Global passenger vehicle oil demand
Million barrels per day

	2020	2025	2030	2035	2040	2045	2050
EV share in total sales	**5%**	**23%**	**28%**	**38%**	**51%**	**60%**	**73%**
EV share in total fleet	**1%**	**6%**	**14%**	**18%**	**24%**	**31%**	**38%**



Source: Rystad Energy research and analysis, OilMarketCube

… and almost disappears by 2050 in the –Sigma scenario.

Our -Sigma (1.6°C) scenario sees oil demand for vehicles peaking at 29 million bpd in 2025 before drastically falling to 2 million bpd in 2050.

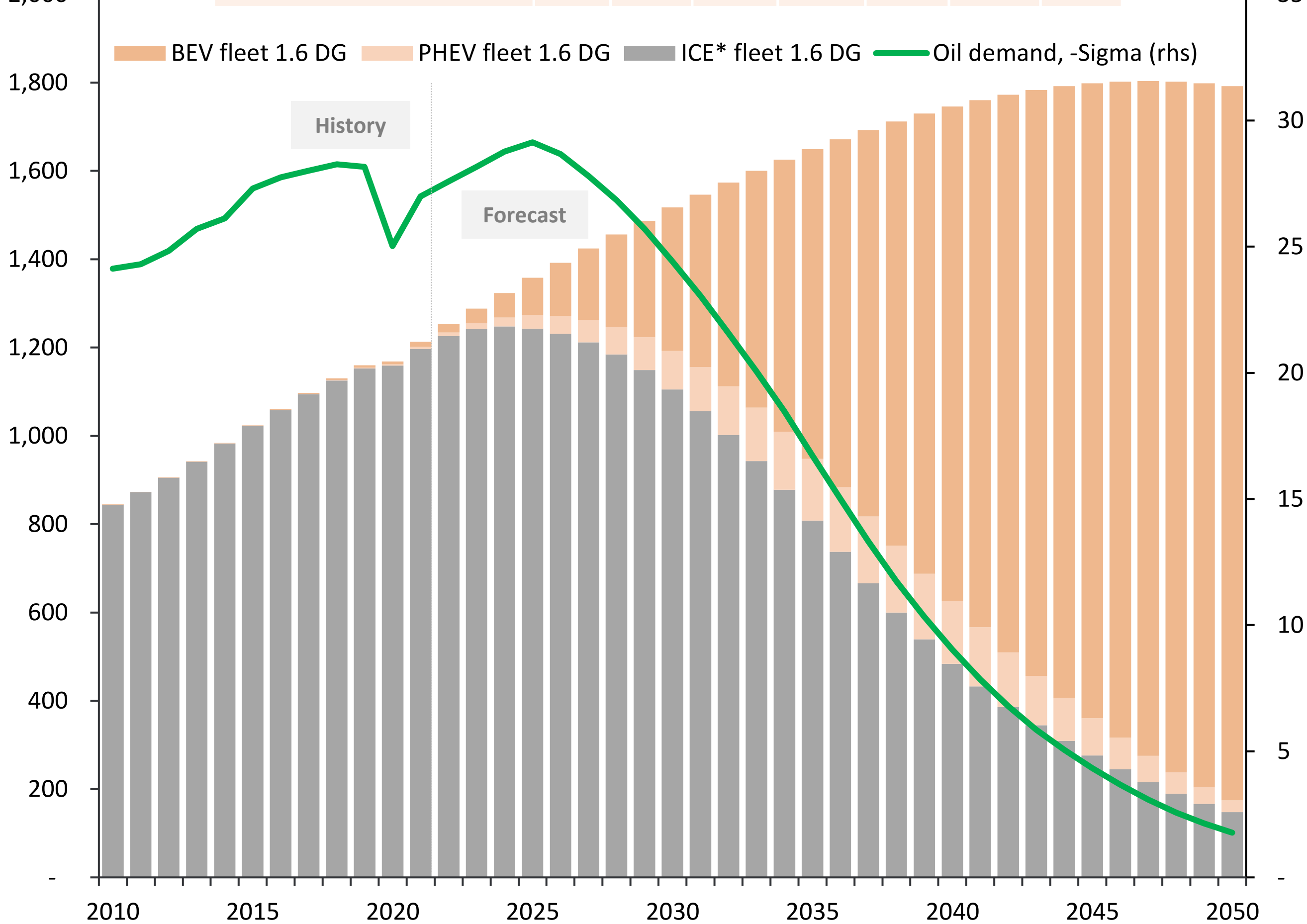
This scenario assumes that EVs will reach 70% of global market share before the emnd of this decade, quickly displacing ICEs. In a 1.6°C world, the transition does not face any structural obstacles, and EVs become perfect substitutes for ICEs. This allows half of the global fleet to be electric by 2050.

Similarly to the mean (1.8°C) scenario, we assume passengers will become more conscious and adopt more sustainable choices to satisfy their demand for mobility using alternative means of transport. This contributes to further drive oil demand down in the long-run.

Global passenger vehicle fleet
Million vehicles

Global passenger vehicle oil demand
Million barrels per day

	2020	2025	2030	2035	2040	2045	2050
EV share in total sales	**5%**	**41%**	**72%**	**87%**	**94%**	**96%**	**98%**
EV share in total fleet	**1%**	**8%**	**27%**	**51%**	**72%**	**85%**	**92%**



Source: Rystad Energy research and analysis, OilMarketCube

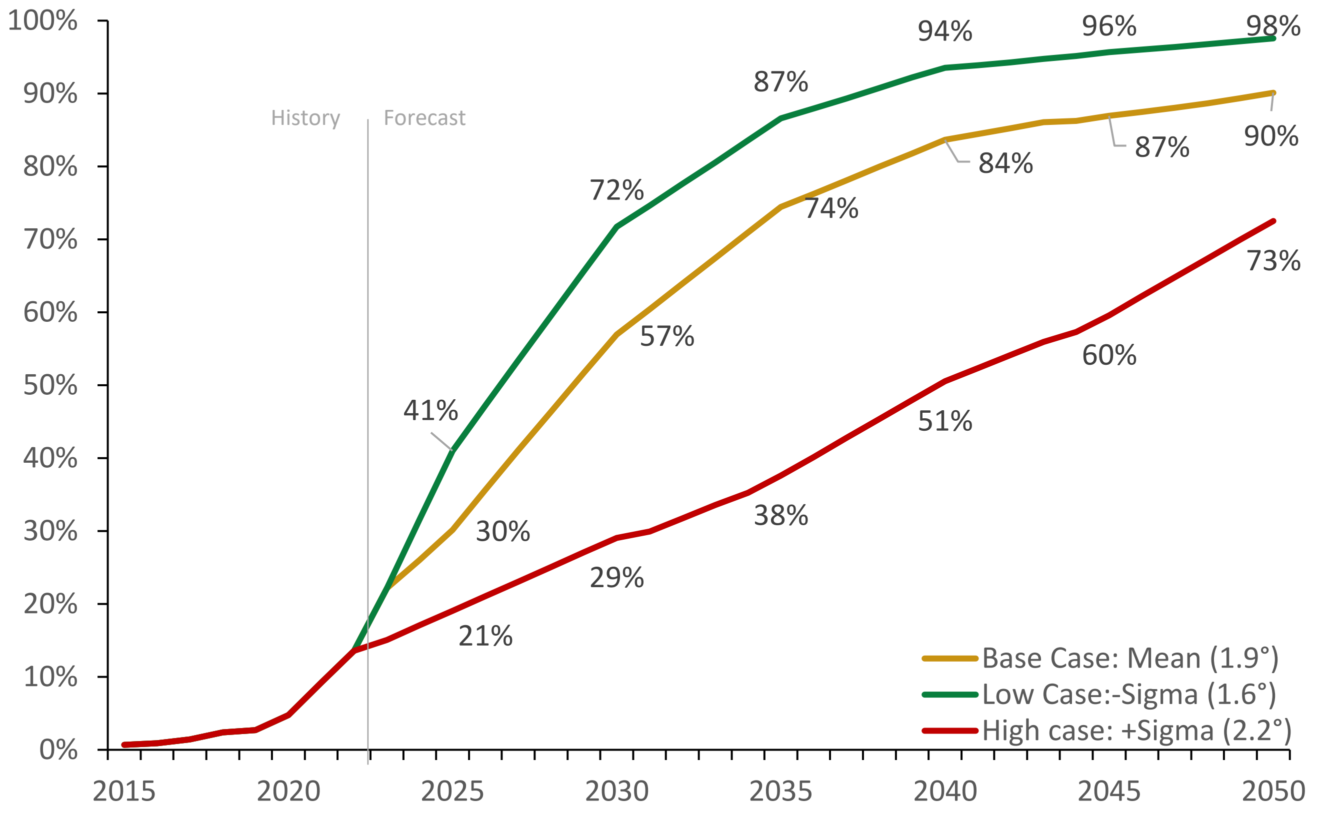
EV penetration is the most crucial assumption for oil demand in cars

Since 2019, the penetration of EV in the global car sales has experienced an exponential growth. It was around 2% in 2019, 5% in 2020, 8% in 2021 and approached 15% in 2022.

Can we assume that the EV penetration will keep on doubling every year till saturation? There are reason to doubt such an assunption. First, EVs have so far been sold primarily in China and Europe where penetration rates are well above the global average. In many regions of the world, EV penetration is below global average and, in some cases, close to zero. This may depend on cosnumer preferences, cost differential of EV vs ICEs, availability of EVs, or a combination of the above afctors. Second, the availability of a charging infrastructure is likely to slow down adoption rates in places where such an infrastructure is absent or lacking, which is in most of the Emerging Markets. Third, the supply of energy metals for battery packs could be under strain in the –Sigma scenario and also in the Mean. Forth, the ICE cars price tag may drop and EV one increase as a result of the supply and demand dynamics, making EV less competitive.

Yet, it is a fact that OEMs are increasingly investing in the development of EV powertrains and have decreased - and in some cases stopped - the development of ICE cars. If we factor in the likely bans on ICE sales in some regions by the 2040s, we see how the Mean scenario may becpme possible. Still the lack of a decent charging infrastructure globally may indeed forcethe EV penetration rate down to the linear growth of the +Sigma scenario

EV share in total passenger vehicle sales by scenario
Percent



Source: Rystad Energy research and analysis

Efficiency gains essential to reduce oil demand in trucks in Mean scenario …

In our Mean scenario, oil demand for trucks will continue to increase throughout this decade and peak at 20 million bpd in 2030.

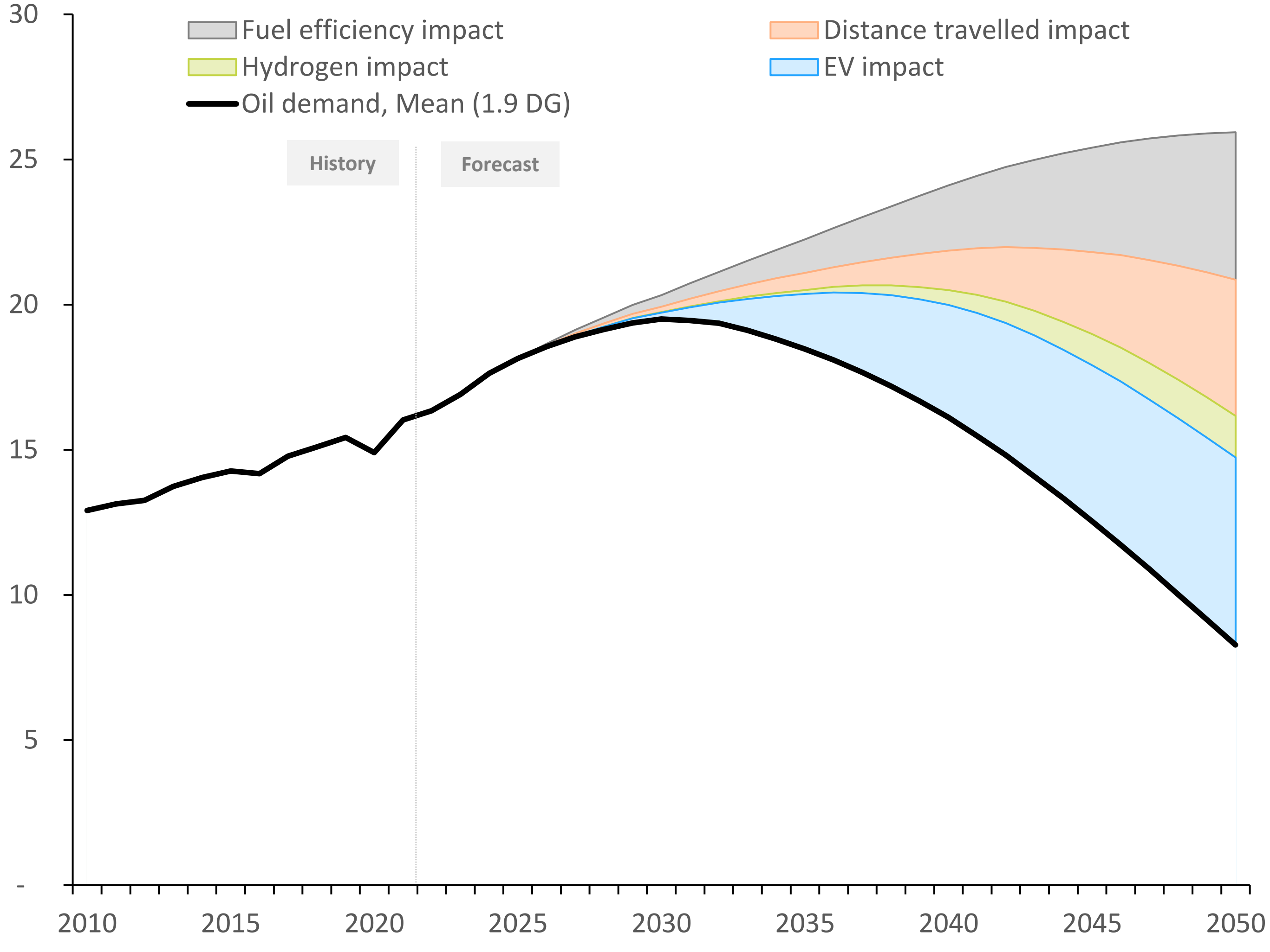
From the 2030s, we expect the EV technology will have become mature enough to quickly penetrate the hauling sector, benefiting from the technological spillovers from passenger vehicles. EV sales will expand, especially in the LCV segment. We expect new models will become available to allow for the electrification of the MCV and HCV fleet from the 2040s. With the available infrastructure, logistics companies would be incentivized to upgrade fleets as EV trucks can reduce operating costs and require less maintenance.

In our Mean case, we forecast hydrogen-powered fuel cell electric trucks to become economically viable and start replacing ICE trucks from the mid-2030s. We factor in two main challenges, which explain the relatively slow adoption of this technology: the large-scale supply of green hydrogen and the refueling infrastructure to be developed for heavy vehicles.

Unless strong policies are introduced in the following years, we expect ICE trucks will continue to be sold, although at decreasing rates. Hence, in the long-run, to meet governmental-stated environmental targets, fuel efficiency will need to continue to grow.

To meet the 1.9°C target, however, innovation will have to also have to come from the industry itself, besides manufacturers. The utilization of each truck unit needs to increase, which can be done by introducing multi-hub centers. This would drastically reduce the average yearly distance traveled, and ultimately oil demand.

Global trucks oil demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

… and indispensable to meet +Sigma if electrification lags behind

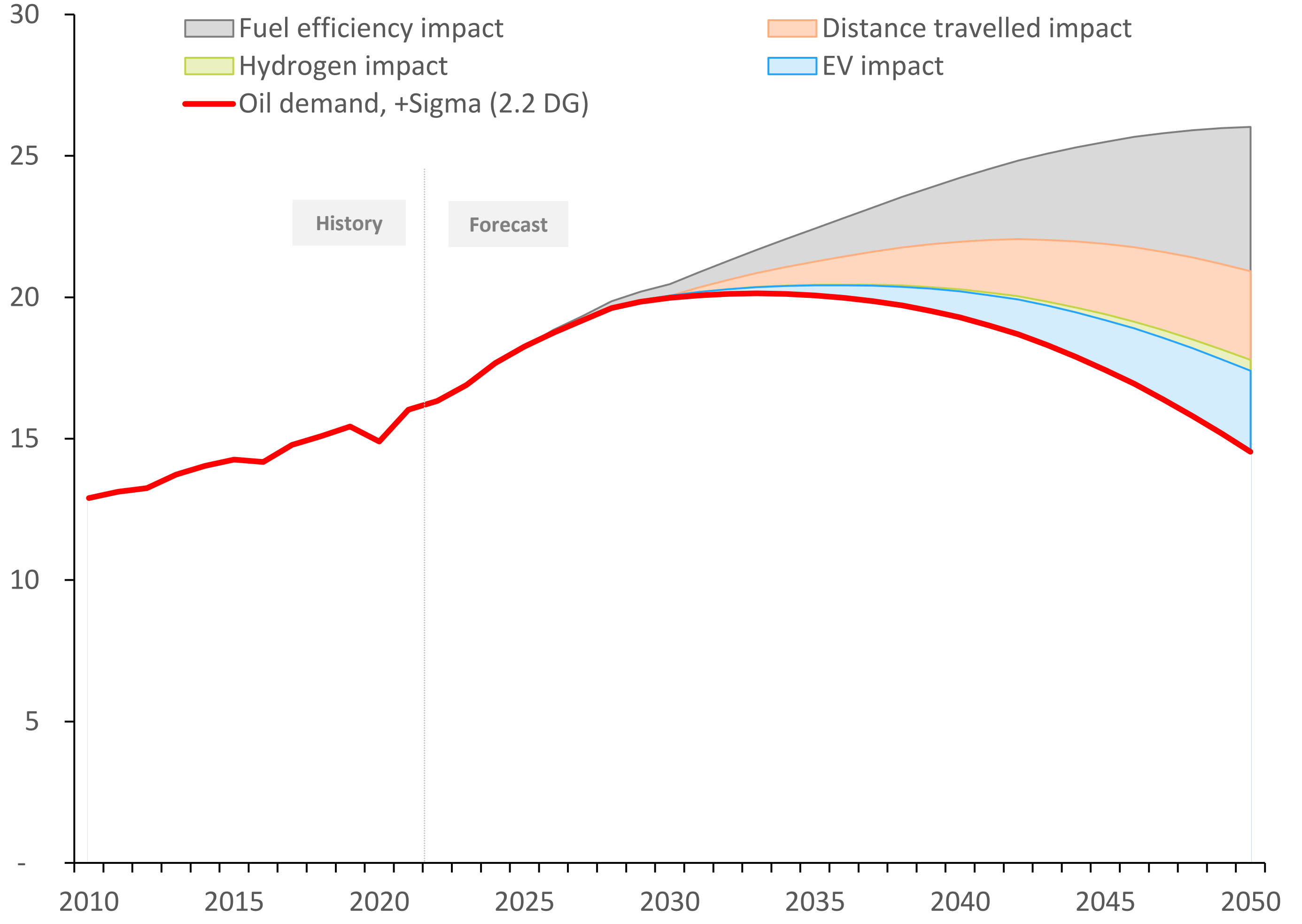
In the +Sigma (2.2°C) scenario, oil demand in the trucking sector peaks in 2033 at 20 million bpd, Thereafter it plateaus, before starting to visibly decline from the 2040s.

In this scenario, the electrification of the commercial transport sector faces both economic and structural challenges, especially when it comes to MCVs and HCVs, preventing a structural fleet substitution. ICEs continue to satisfy most of the global service demand.

Therefore, in this scenario, efficiency gains in the industry are the main contributors to the displacement of oil demand in the long-term.

Where the electrification process is slower than expected, efficiency improvements become indispensable to contain the expansion of oil demand in a sector that is bound to grow, driven by economic growth.

Global trucks oil demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

Deep electrification in trucks required to achieve –Sigma

In our –Sigma (1.6°C) scenario, oil demand for trucks peaks in 2029, before rapidly falling to 3 million bpd in 2050.

In this scenario, the electrification of the fleet is the primary driver behind the oil demand decline.

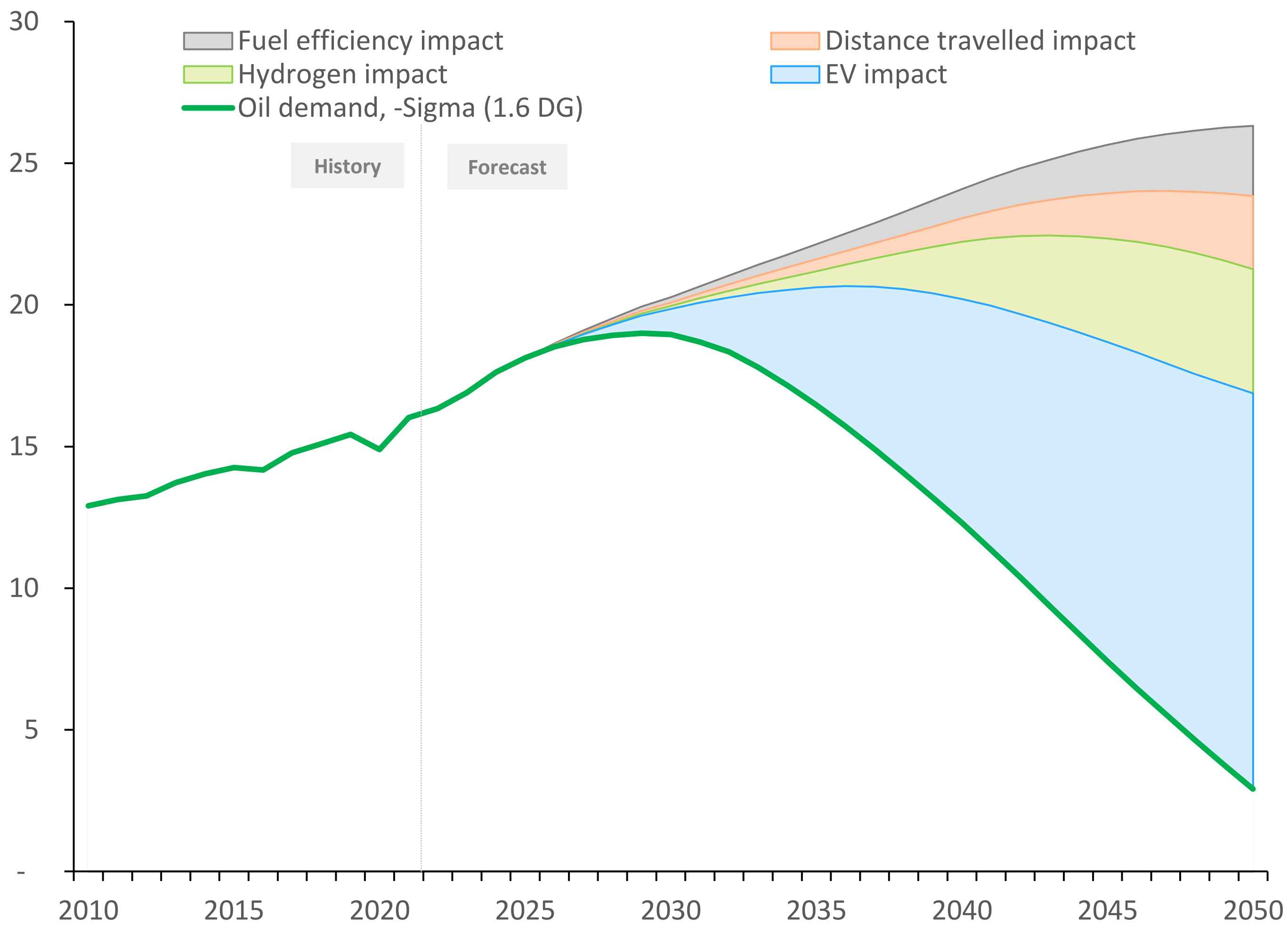
To meet the 1.6°C target, a rapid technological shift is needed, as efficiency gains (both in the existing technologies and of the commercial transport sector itself) would not be enough to meet the CO2 emission abatement requirements.

Therefore, meeting this scenario entails substituting the conventional ICE fleet with BEVs and hydrogen-powered fuel cell electric trucks.

Not only does this require large investments to facilitate the replacement of the existing fleet and the installment of the required infrastructure, but also the exclusive focus of R&D on the new technologies at the expense of fuel efficiency improvement.

We deem this to be a very ambitious scenario, as the electrification process is not developing quickly enough yet to satisfy the growing service demand.

Global trucks oil demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

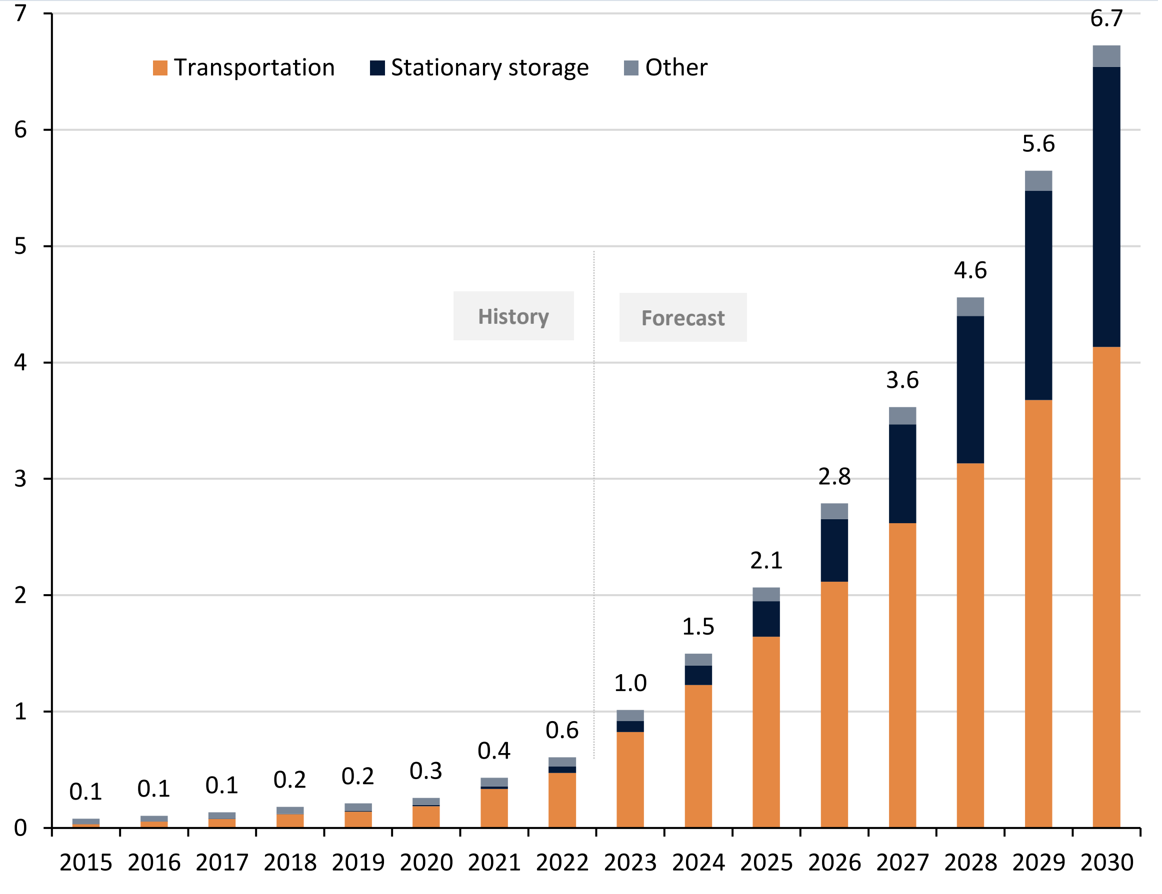
Battery demand to hit 6.7 TWh in our fast transition – driven by transport

We expect that passenger vehicles will emerge as the largest battery demand segment for the coming years. More than 60% of cells will support the automotive sector. Battery pack sizes may differ but often range between 45-70 GWh per battery electric vehicle.

Furthermore, the stationary storage market will also demand batteries. As more intermittent renewable energy sources such as solar and wind are added to the power mix, the need to balance or shift the power generation to times when the power is needed most will become increasingly important and financially beneficial. Frequency control is especially profitable at present. However, this is expected to change to energy arbitrage in the coming years.

Other battery demanding sectors such as consumer electronics, power tools, two-and three wheelers, or portable energy storage only account for 25% in 2022 and will decrease in market share further until 2030 with the exponential developments in the stationary storage and automotive sector.

Battery demand high case
Terawatts (TW)

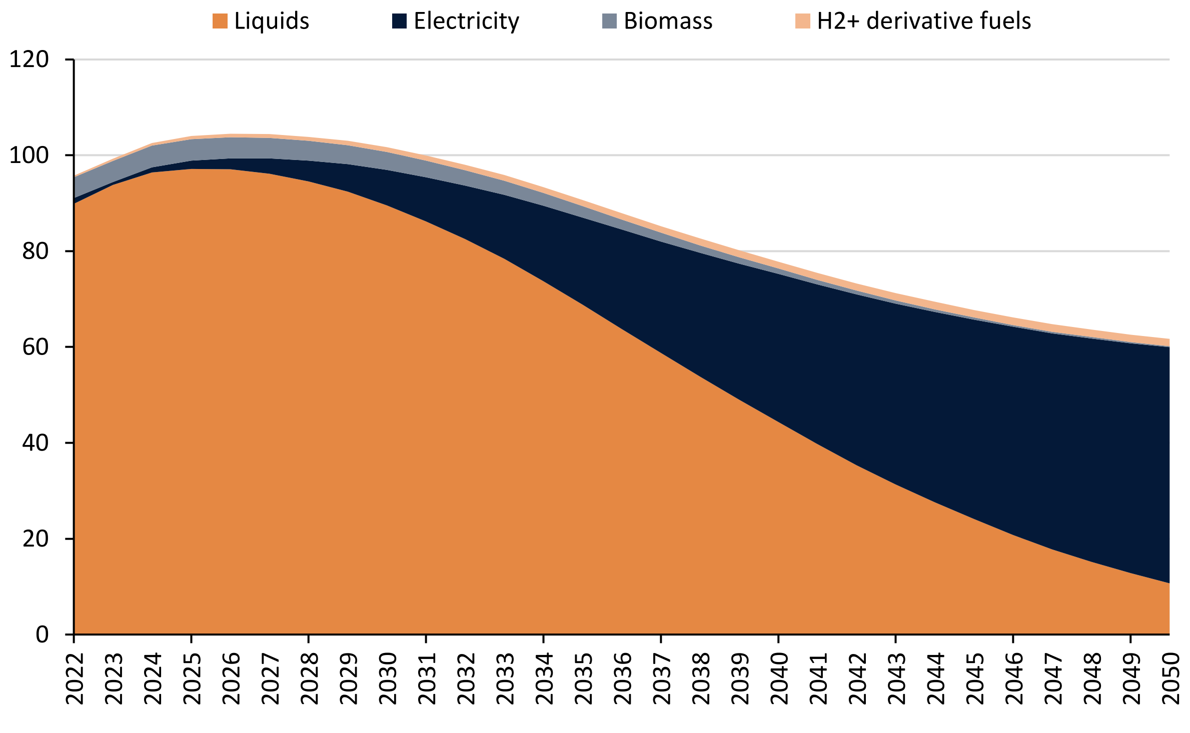


Source: Rystad Energy BatteryCube

Road transport needs to become 80% electric by 2050 to keep -Sigma on the table

As we expect current policies and EV sales trends to continue, electrification of the transport sector is set for a swift transition towards record levels of electrification. However, as with solar and wind, the supply chain for batteries per today's outlook looks unlikely to be able to sustain the demand that will engulf the sector if we are to meet the capacity required for a 1.5 DG scenario.
As such, the supply chain – characterized by dependency on critical minerals such as lithium, cobalt and nickel – may be a stronger barrier than the drivers emerging from policy and targets can surpass.
Nevertheless, the requirements posed by a 1.6 DG scenario is considerably less aggressive, and we believe this is within reach despite it too being a massive requirement. Specifically, we will need to see current liquids demand decrease from 93.8% of current supply, to 17.3% of 2050 demand.
We note that this is a much large decrease compared to current demand – 2050 liquids demand is 10% of the total fuel demand in 2022.
We expect a total decrease in energy demand from the road transport segment as a result of the increased levels of efficiency of electric powertrains as compared to internal combustion engines.
This results in a much lower total energy demand, despite the increasing total end use of road transport services.

Global energy demand from road transport – 1.6 DG scenario
Exajoules (EJ)



Source: Rystad Energy, Energy Scenario Cube

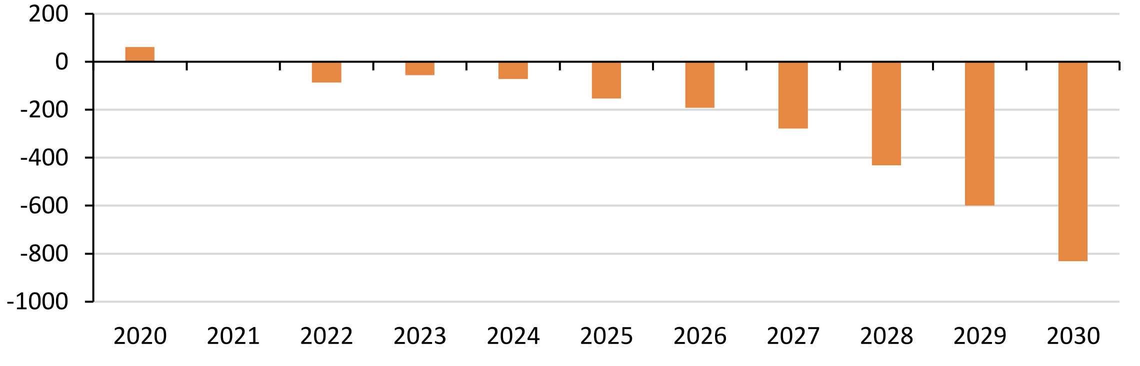
Supply chain needs massive investments to enable fast transition

To reach the ambitious 1.5 DG scenario, massive investment into lithium mining as well as cell manufacturing is required.

Rystad Energy believes that until 2030, the 1.6 DG scenario remains within reach, but we note that announced and operating mining capacity for lithium at present shows deficits in supply compared to demand, and action is needed to ensure a match.

In 2022, lithium installed capacity amounted to 992,000 tonnes of lithium carbonate equivalent. By 2030, 800,000 tonnes of additional lithium is needed to match our high case demand trajectory. However, lithium capacities are increasing over the coming years – 3.5 million tonnes by 2030 – and as innovation and learning takes off, we may yet see a shift in the trajectory of the battery supply/demand balance.

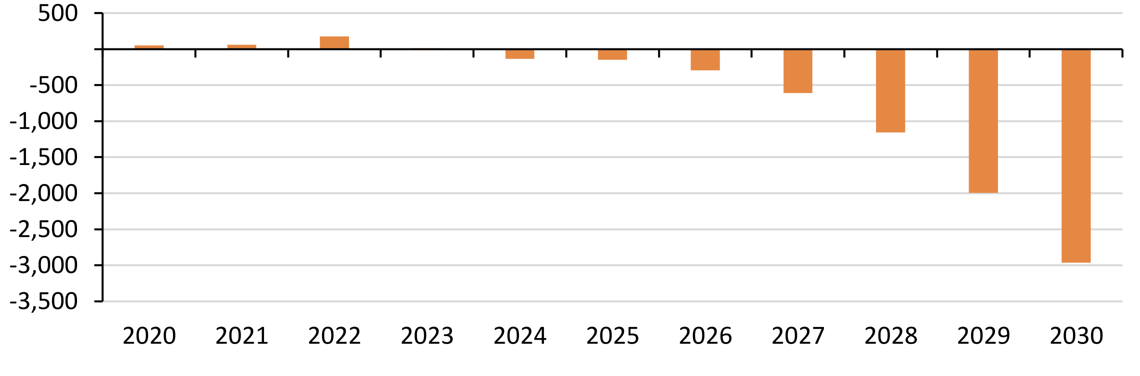
Lithium carbonate equivalents supply deficit
Thousand tonnes



The deficit is also notable on the battery cell side as cell demand is ramping up exponentially. It is necessary to look at production instead of nameplate capacity as these can vary substantially. Especially, battery cell incumbents tend to face more challenges when ramping up cell production quickly and often have high failure rates during cell production. As such, this causes the actual output to be lower than nameplate capacity.

Rystad Energy expects that until 2030 there will be a deficit of up to 3,000 GWh in our high case if no new announcements are made until then.

Battery cell supply and demand balance
Gigawatt-hours (GWh)



Source: Rystad Energy BatteryCube

Fuel substitution critical to meet aviation's Mean scenario

Unlike road fuels, jet fuel demand continues to grow in the Mean (1.9°C) scenario, driven by the expansion of the middle class and the current lack of alternative sources and services in the short- and medium term.

Jet fuel does not have commercially viable substitutes and thus will be sticky in the medium term. Still, the industry is making great progress when it comes to the development of sustainable aviation fuel (SAF*).

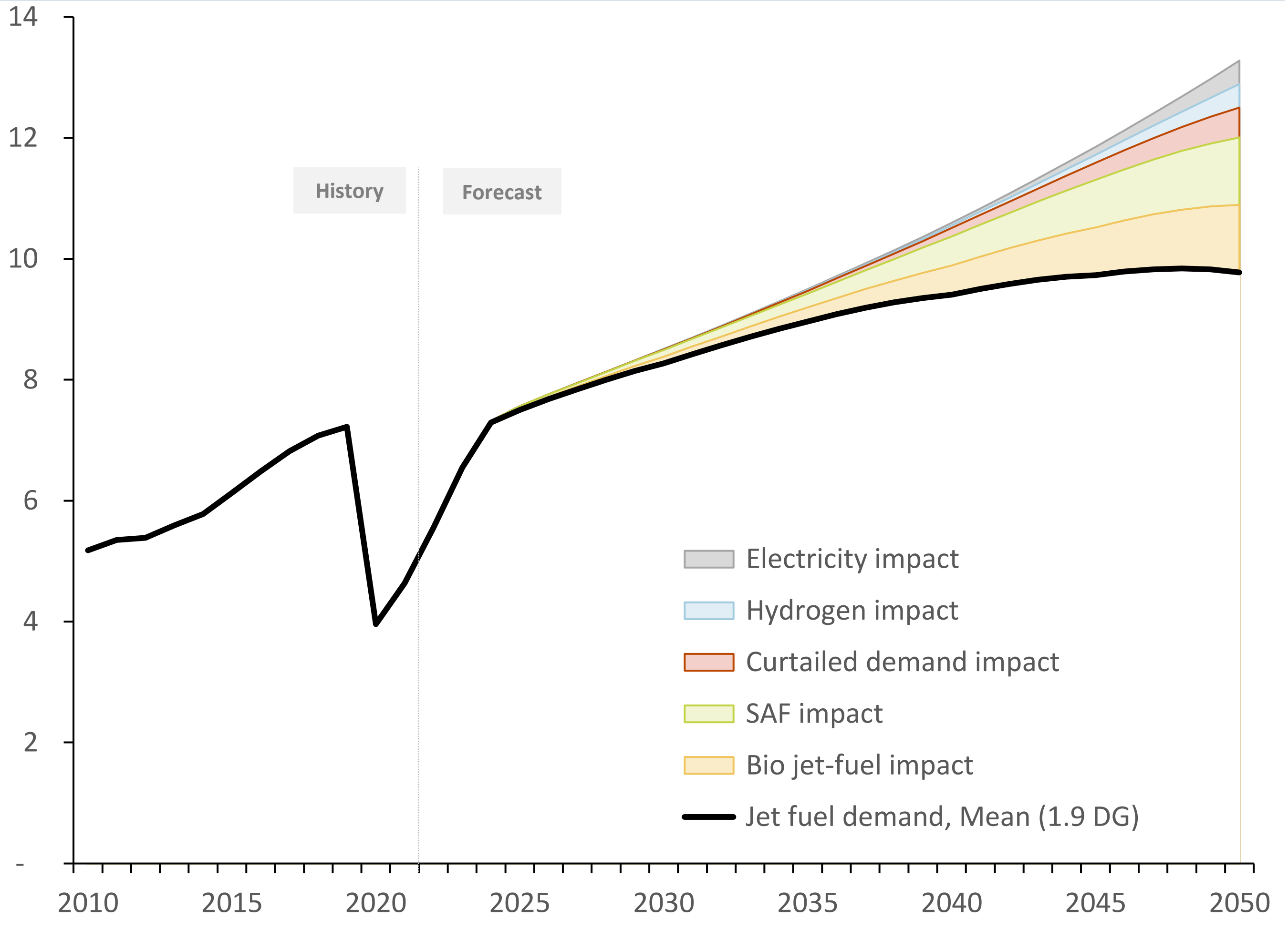
We expect that SAF and bio jet-fuel will be crucial in satisfying aviation demand in the medium and long term, especially in the short-haul segment. Indeed, the aviation industry has committed to reducing carbon emissions by 50% by 2050 versus 2005 levels. Depending on the region, we assume that at most half of this target will be achieved by introducing a 40% blend-in of sustainable fuel.

To meet the ambitious goal, the introduction of other solutions will be required. We assume that jet fuel efficiency will continue to grow over time. In addition, we expect that governments will introduce some restrictions, especially in the short-haul segment, where rail substitution is viable.

Finally, we assume that alternative technologies, such as electric and hydrogen-powered flights, will become viable and will be introduced during the 2040s, further tapering oil demand down in our Mean scenario by 2050.

*Sustainable aviation fuels (SAF) are defined as renewable or waste-derived aviation fuels that meets sustainability criteria

Global aviation liquids demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

Close to 'business-as-usual' in aviation sector leads to +Sigma

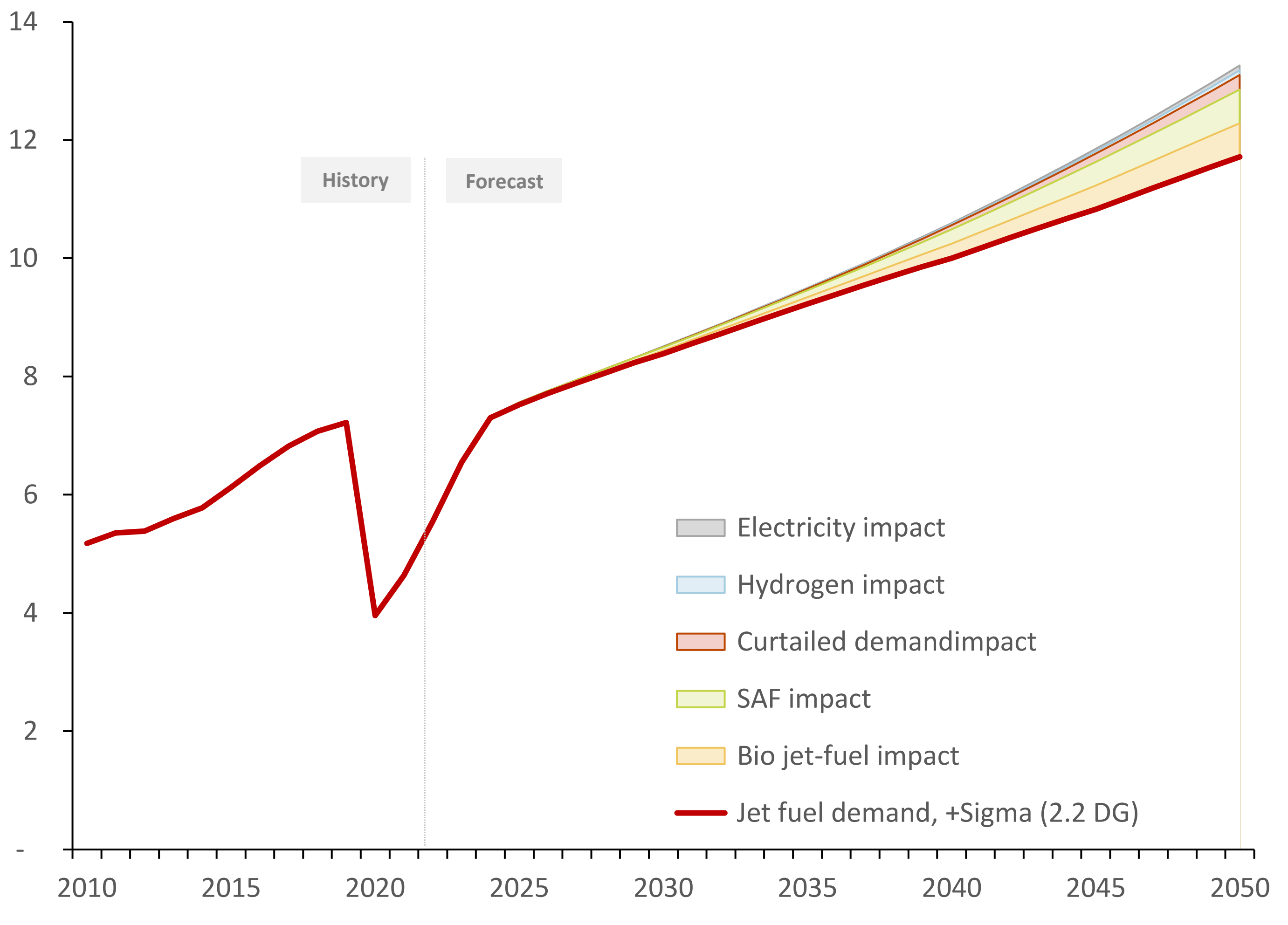
In our +Sigma (2.2°C) scenario, jet fuel demand is sticky and grows to satisfy almost the entire aviation demand.

Alternative technologies are predominant in the short-haul segment, while medium- and long-haul flights depend on traditional jet-kerosene.

In a 2.2°C world, the ambitious CO2 emission abatement targets of the aviation industry are not met, as SAF and bio jet-fuel struggle to become commercially viable, and governments are not able to implement the bold policies needed to curtail demand in the short-haul segment.

*Sustainable aviation fuels (SAF) are defined as renewable or waste-derived aviation fuels that meets sustainability criteria

Global aviation liquids demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

Flight bans, SAF/bio-jet and electrification needed to meet -Sigma

In our –Sigma (1.6°C) scenario, jet fuel demand stabilizes in the medium-term after recovering from the Covid-19 hit and starts to decline in the 2040s.

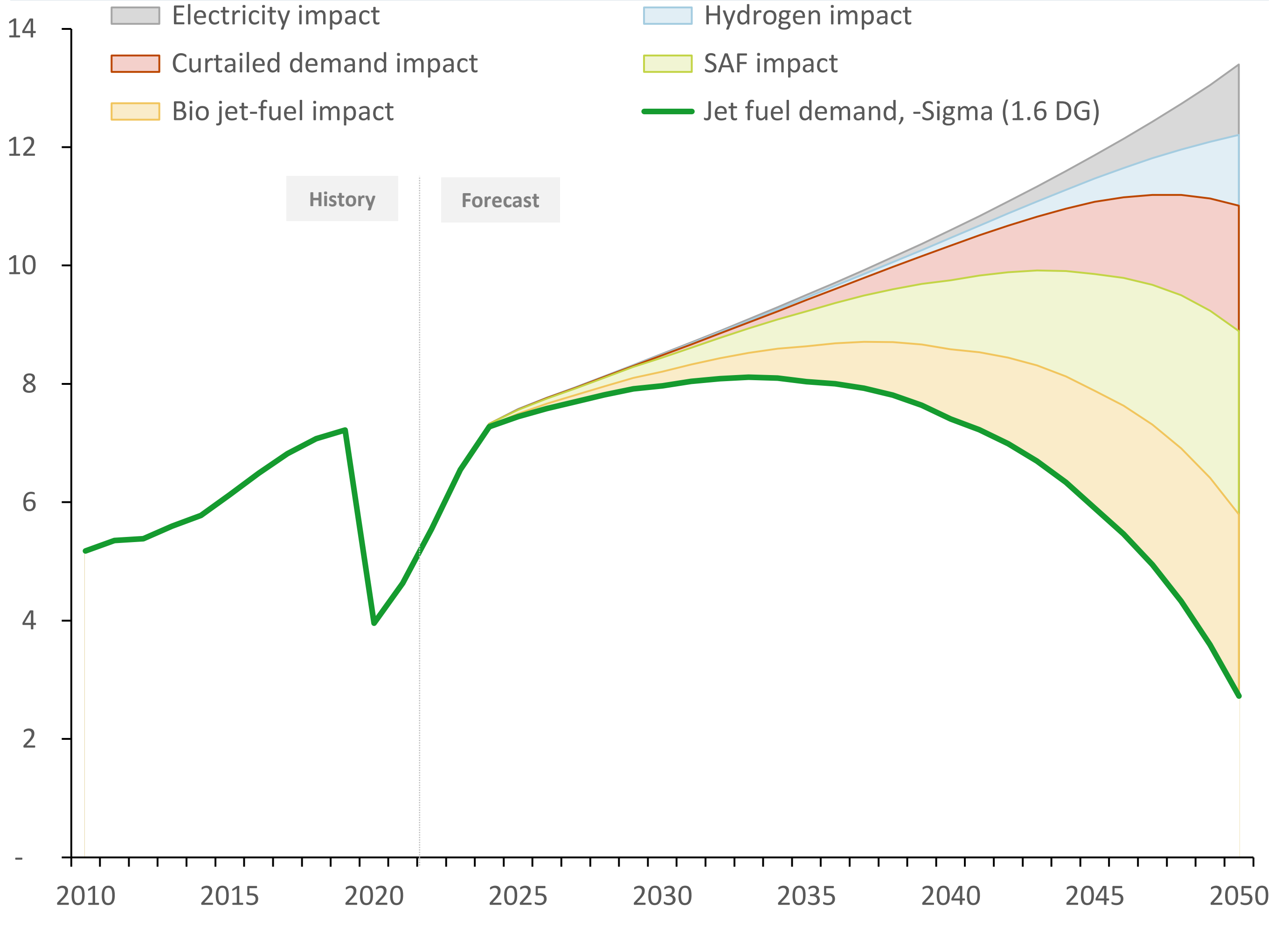
This is an ambitious scenario that relies on the strong technological development and commercial viability of alternative fuels, namely SAF and bio jet-fuel, already starting from the 2030s.

Here, we assume that short-haul flights will be heavily curtailed and either fully powered by SAF or electrified. The medium-haul segment also needs to see alternative fuel consumption scale up substantially, leaving the long-haul segment relying the most on conventional jet kerosene.

For this scenario to materialize, a technological shift needs to occur for the entire transportation system. For instance, short-haul flights need to be replaced by an efficient and capillary high-speed railway, and hydrogen aircraft need to substitute the conventional fleet from the late 2030s for additional oil demand displacement

*Sustainable aviation fuels (SAF) are defined as renewable or waste-derived aviation fuels that meets sustainability criteria

Global aviation liquids demand and energy transition impact
Million barrels per day



Source: Rystad Energy research and analysis, OilMarketCube

Oil demand for shipping remains sticky in the Mean scenario

Shipping is responsible for about 3% of global emissions, which is roughly equivalent to the total emissions from Germany, the largest economy in Europe.

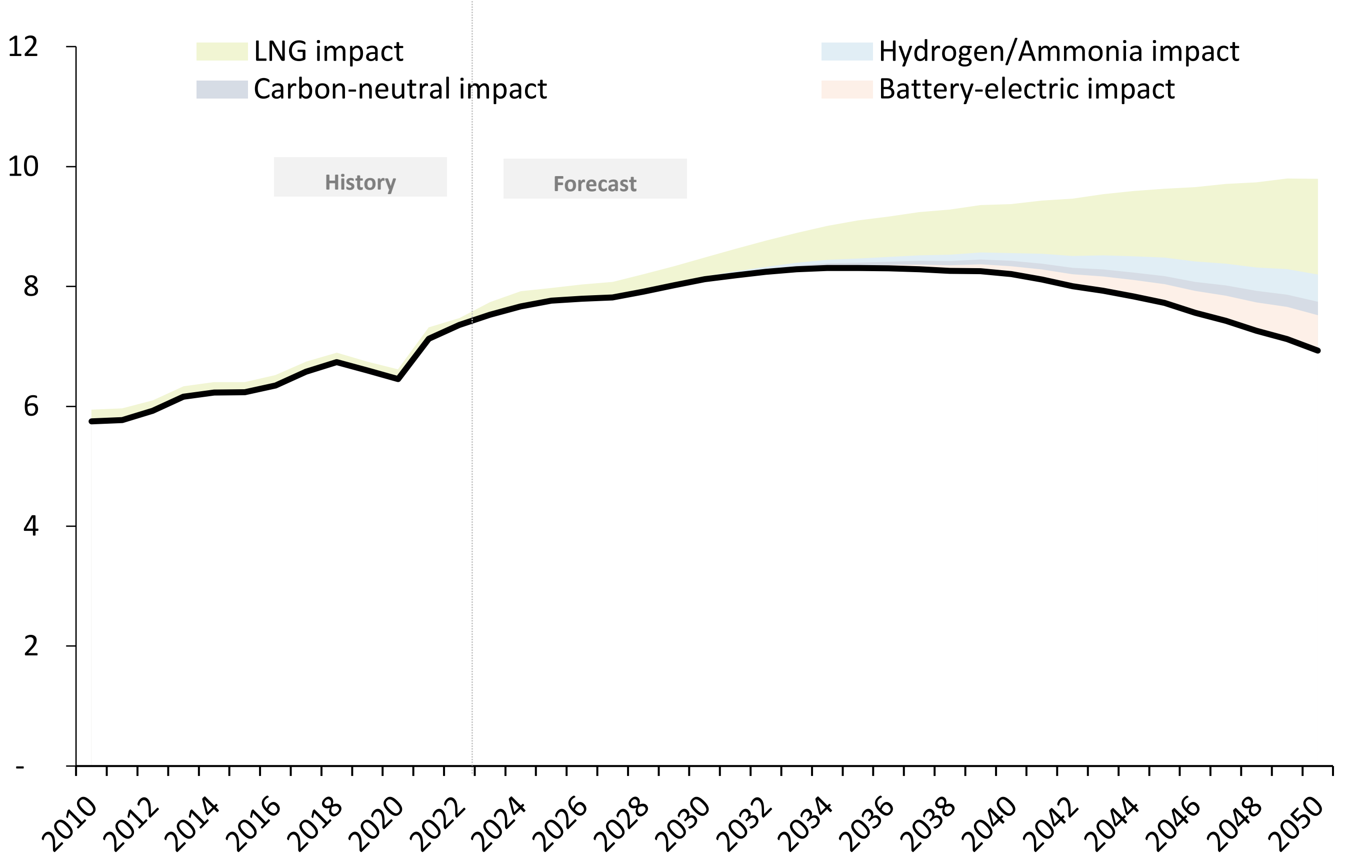
As with renewable energy, an opportunity for a faster transition towards zero and net-zero fuels is emerging on the back of the energy crisis for shipping. With LNG now seeing record high price outlooks from the energy crisis, sustainable alternatives appear a lot more attractive to shipping companies.

However, main challenge for shipping decarbonization now lies onshore – zero carbon fuel production and new bunkering infrastructure require massive investments, and a united policy approach is crucial to support the developments needed to meet climate targets.

The global retail sector is helping pull demand by adopting aggressive decarbonization targets - being shipping's largest customer, their demand for a zero-carbon supply chain is creating a large incentive for sustainable fuels. Initiatives such as the Clydebank declaration, alongside the Aspen Institutes Shipping Decarbonization Initiative, are pushing for zero carbon fuels (not net zero or carbon neutral).Most shipping companies are now including sustainable fuels as part of their strategy – we have seen many new commitments over the past year, with a few players still focusing solely on fossils – even fewer are excluding fossil fuels entirely.

As more vessels become compatible with new fuel alternatives, and record numbers of companies are ramping up commitments to zero/net-zero carbon fuels during the past 12 months, we need to see more investments in fuel production and bunkering infrastructure, and a united global regulatory approach that can leapfrog the transition from fossil fuels to sustainable alternatives, including fast tracking retrofits of fossil fuel vessels to run on sustainable fuels.

Maritime demand and energy transition impact
Million barrels per day



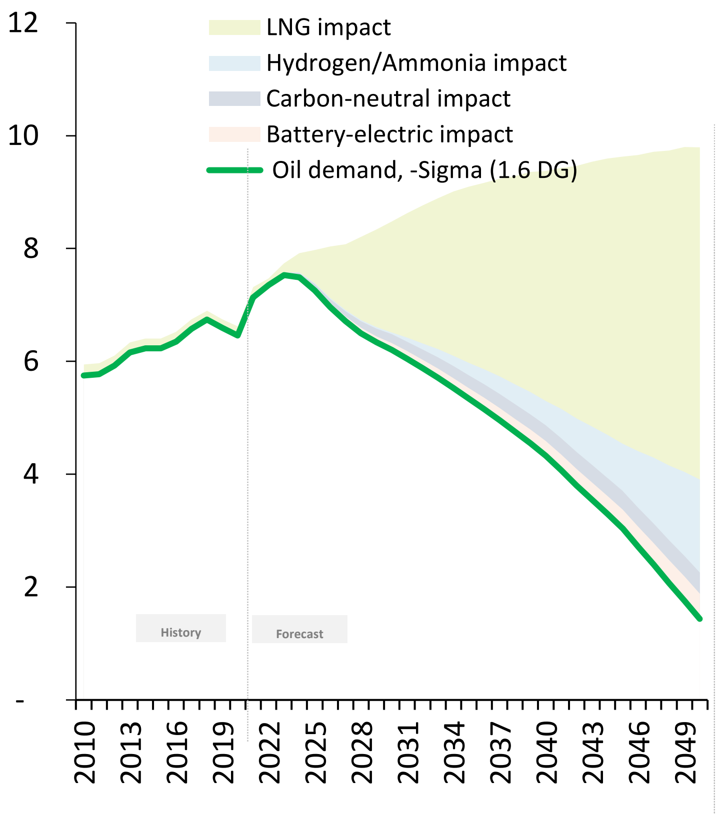
Source: Rystad Energy research and analysis, OilMarketCube

LNG, ammonia affordability/availability to shape shipping's oil transition paths

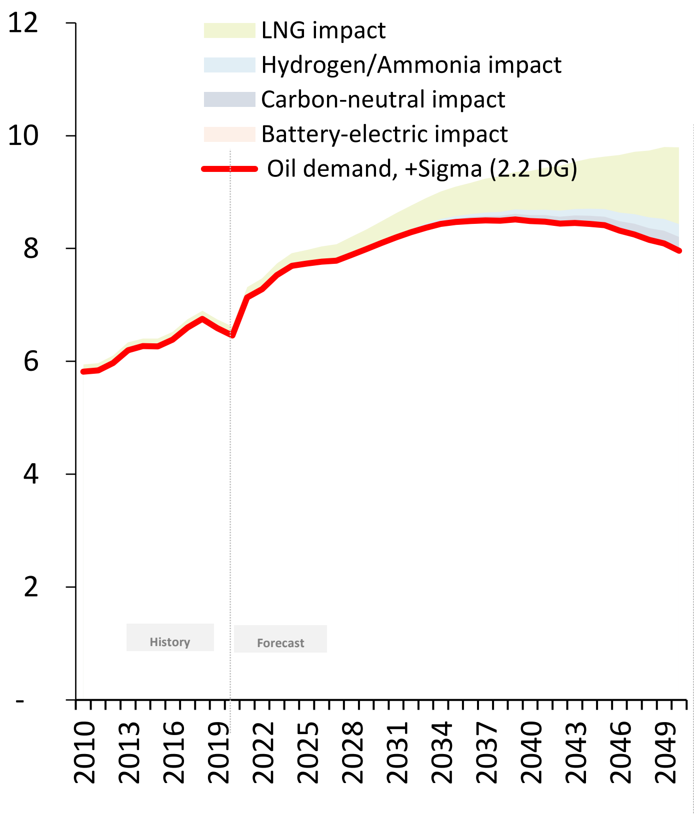
Based on our findings, we expect zero carbon fuels to make up an increasing share in the –Sigma scenario. This is supported by e.g., the Aspen Institutes Shipping Decarbonization Initiative, which sets an aim for signatories to have a zero emission (not net-zero) supply chain by 2040.
This significant initiative is signed by Amazon, Ikea, Inditex, and Unilever to name a few of the major global brands party to the initiative. Retail giants like these form the majority of global shipping demand. As such, we believe that ammonia, which is the sole viable zero carbon candidate for deep sea shipping, is in for a demand surge from shipping.
This is further substantiated by cost analysis for different fuels to assess financial viability – ammonia has the best outlook and can gain market share. Also, fleet structuring strategies are aligning with ammonia seeing a drastic ramp-up in 2022, with now over 130 ammonia ready vessels in the order books, i.e., bottom up, we see a massive increase of interest in ammonia vessels.
As with shipyards, we also see large engine manufacturers are prioritizing ammonia ahead of other solutions, with several players looking start scaling production and retrofits in the short term.

In a fast transition scenario, we see the scaling up of LNG and ammonia to quickly displace the use of fuel oil and gasoil in the maritime sector. This could result in oil demand dropping to less than 2 MBD in 2050, from 7 MBD today. Yet, in a sector with historically wafer-thin operating margins like the shipping business, we recognize that fuels adoption will be on their affordability. Hence, if LNG and ammonia fail to become structurally competitive vs. fuel oil and gasoil, maritime oil demand will continue to grow through the 2030s and land at just below 8 MBD by 2050.

Maritime demand, -Sigma scenario (1.6°C)
Million barrels per day



Maritime demand, +Sigma scenario (2.2°C)
Million barrels per day



Source: Rystad Energy Oil Market Transition Solution, Rystad Energy OilMarketCube

Plastic demand to double by 2050 …

Most plastics are produced from crude oil or natural gas. Petrochemical feedstock accounts for 14% of global oil demand and is expected to increase in the future. Demand for recycled plastics are increasing, but challenges in petrochemical recycling is limiting recycling growth. The rest of petrochemicals end their life in energy recovery facilities, landfills, or are mismanaged through littering, burning and dumpsites.

The petrochemical industry is typically viewed as hard to abate industry sector not so much due to the lack of tangible decarbonization strategies, but due to the general expectation about continuous long-term expansion in the consumption of key end products. One of the key output of petrochemical industry are various polymers and global consumption of plastics skyrocketed from ~130 million tonnes in 1990 to nearly 500 million tonnes in 2022 (based on preliminary estimates). Petrochemicals are seeing nearly linear growth pace at ~11 Mt per year throughout the last three decades with only rare events of sequential annual declines in global plastics use, which typically coincided with the periods of material economic downturns (2008) or global lockdowns (2020).

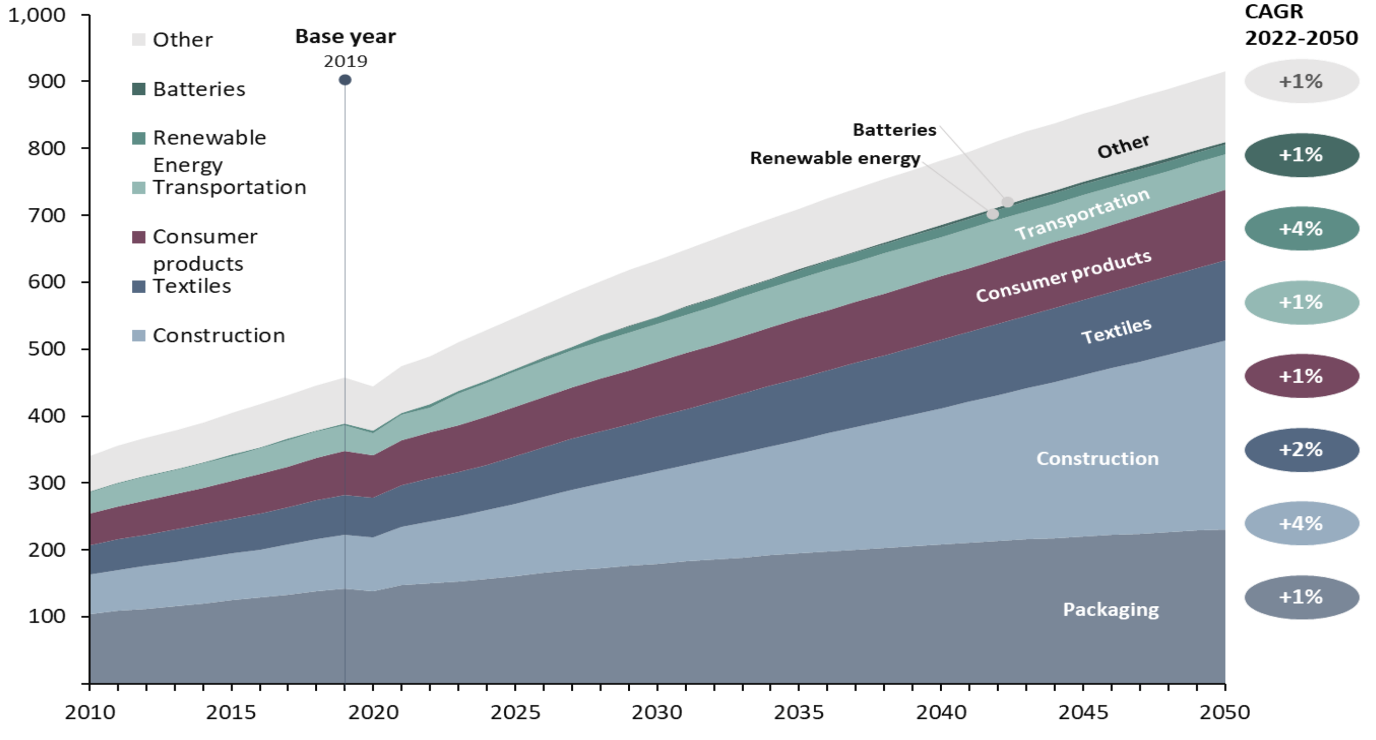
The **packaging industry** is currently the largest sector for petrochemical demand. Continued growth is expected towards 2050, however the growth is expected to slow down in developed regions due to consumer preferences towards environmentally friendly materials.

The **construction industry** is predicted to see the largest growth in plastics demand towards 2050. This is largely due to the fact that plastics are durable, light-weight and low cost. Insulation, roofing, framing and flooring is predicted to increase plastics usage. In addition, the world is predicted to see a continuous increase in population and economic growth, which largely drives the construction industry.

The **transportation sector** is likely to continue its path in light-weighting vehicles parallel to EVs penetrating the markets. This is predicted to change, more than increase the plastics demand, as new use cases are explored.

For batteries and the renewable energy, plastics will se a percentagewise huge growth in demand. This is largely driven by the substantial growth in annual added capacity, as well as a shift towards more polymers in wind turbines, solar panels and battery casing.

Plastic demand by sector, 2010-2050
Million tonnes per annum (Mtpa)



Source: Rystad Energy research and analysis

… while recycling rates remain low

The world produced 460 Mt plastics in 2019, where 29 Mt came from the recycling process. Thus, the total accumulation of plastics in the economy was 3120 Mt.

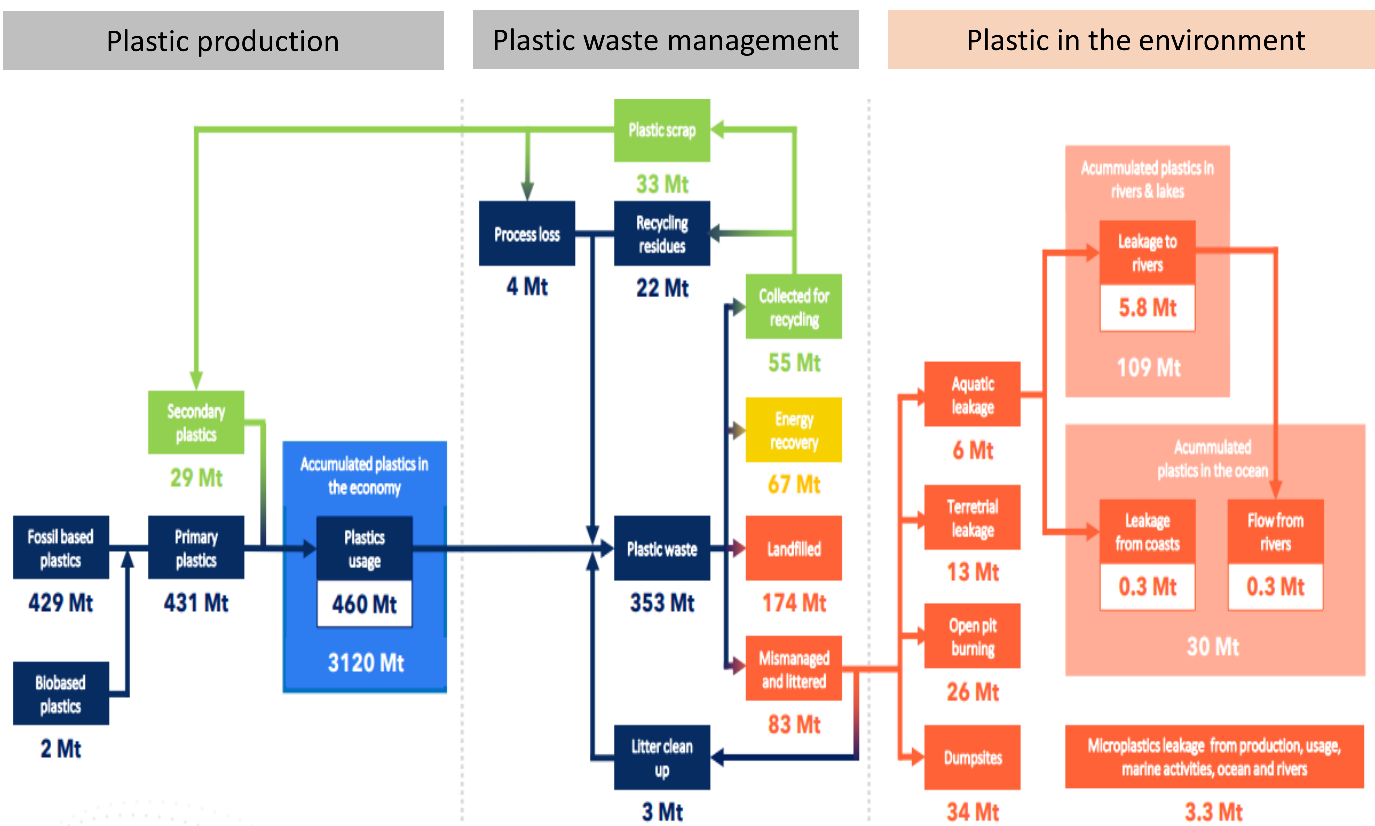
Most plastics are either landfilled or mismanaged. From the 55 Mt plastics collected for recycling, only 29 Mt become secondary plastics.

83 Mt plastics made its way into the environment in 2019. Of these 3.3 Mt were microplastics, and 6 Mt of plastics entered the worlds rivers and oceans.

Mechanical recycling: also known as back to polymer, it involves 5 steps. Collection, sorting, cleaning, reprocessing by melting, and producing new products from recycled polymers. The biggest drawback is that it is hard to remove and additives or dyes, which is some cases can reduce the end-product quality. Also, it relies on the ability to melt plastics without releasing toxins, as well as effective sorting and washing.

Chemical recycling: also known as back to monomer recycling, it is the process of sorting and breaking down the petrochemical compound to pure monomer. In theory, this method should deliver same quality as virgin products. Yet, the big drawback of this process is the fact it is highly energy intensive and therefore highly costly. So far, chemically recycled monomers are uncompetitive on price against virgin material.

Geographical distribution: All the regions in the world are expected to increase their recycling of plastics. Europe and China have a recycling rate of 12% of all plastic waste. This makes the two regions have the highest recycling rate compared to the other regions. Europe is the region which is expected to increase its recycling rate the most. Going from 12% in 2019 to 23% to 2050. Russia have a recycling rate of 5% in 2019. This make the region have the lowest recycling rate. Russia is expected to have the lowest recycling rate in 2050. With a share of only 9% of all their plastic waste going into recycling.



Source: Rystad energy research and analysis, OECD The future of petrochemicals

Petchem demand flattens in Mean scenario driven by regulation & recycling

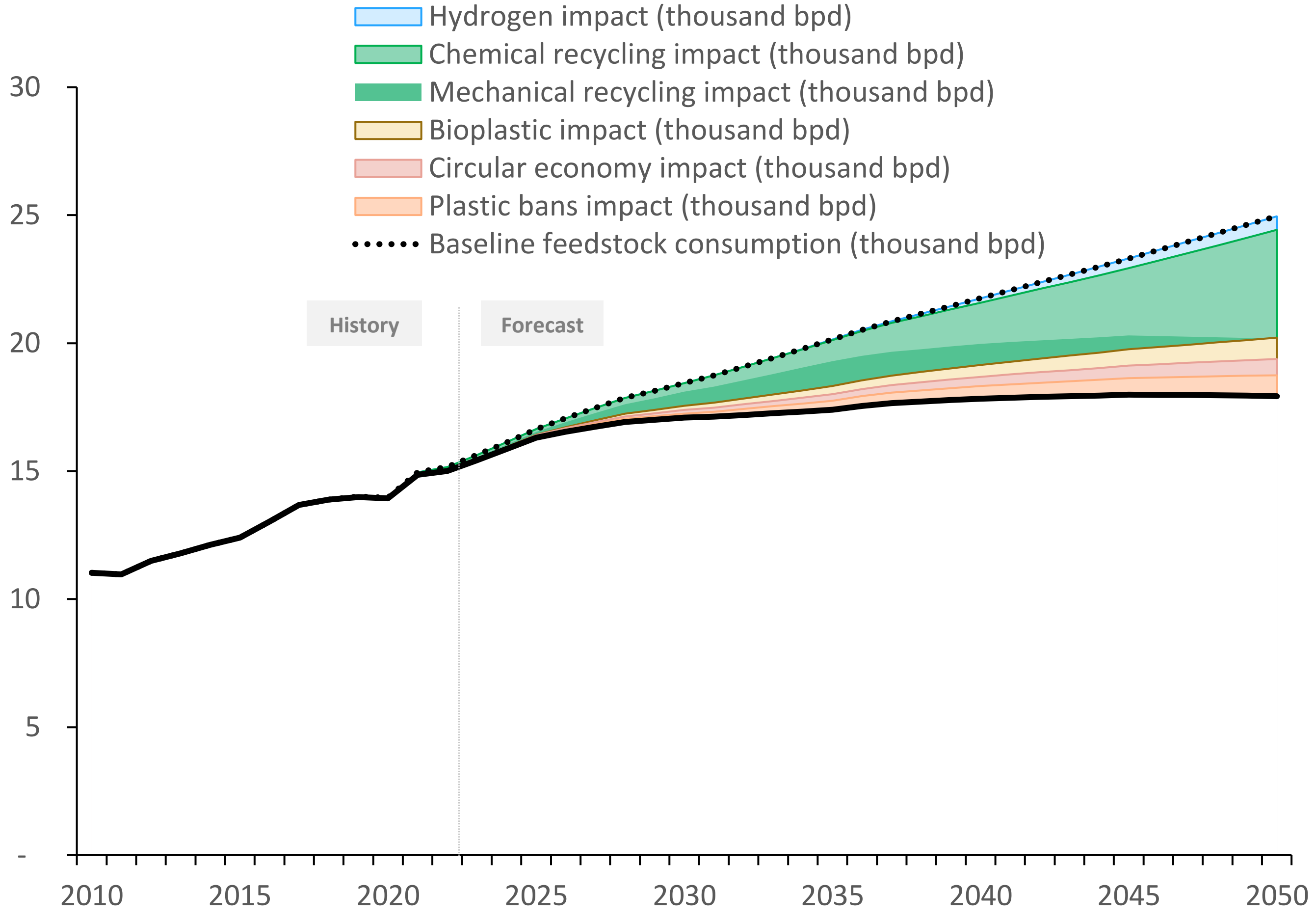
Oil demand in the petrochemical sector is set to grow in the short and medium term before stabilizing and plateauing at around 18 million bpd in our Mean (1.9°C) scenario.

In this scenario, recycling is crucial to halt the expansion of oil demand in the sector. Now, the current mechanical recycling rates are not growing quickly enough to meet the stated governmental targets. For instance, the total recycling rates in Europe and the US remain relatively small at 15% and 9%, respectively. However, they have the potential to grow to reduce feedstock demand. Therefore, mechanical recycling grows and plays the most important role until the 2040s, when chemical recycling becomes predominant as the technology becomes more mature.

By affecting the chemistry of polymers, chemical recycling processes break the plastic waste down to its constituent molecular parts, which become ready to be reconverted into new polymers or petrochemical feedstocks (pyrolysis). Chemical recycling is expected to grow exponentially, as it can overcome the limits of mechanical recycling, a process that is only possible with certain types of plastics, and only if they are made up of single polymers.

To meet the 1.9°C target, the technological development on the recycling front needs to be complemented by bold policies aimed at reducing single-use plastic and behavioral changes in favor of a more circular economy

Petrochemicals demand and energy transition impact
Million barrels per day



*Closed-loop recycling is the manufacturing process that leverages the recycling and reuse of post-consumer products to supply the material used to create a new version of the same product. Closed-loop recycling sees products retain their value indefinitely
**“Renewable methanol” is an ultra-low carbon chemical produced from sustainable biomass, often called bio-methanol, or from carbon dioxide and hydrogen produced from renewable electricity.
Source: Rystad Energy Oil Market Transition Solution, Rystad Energy OilMarketCube

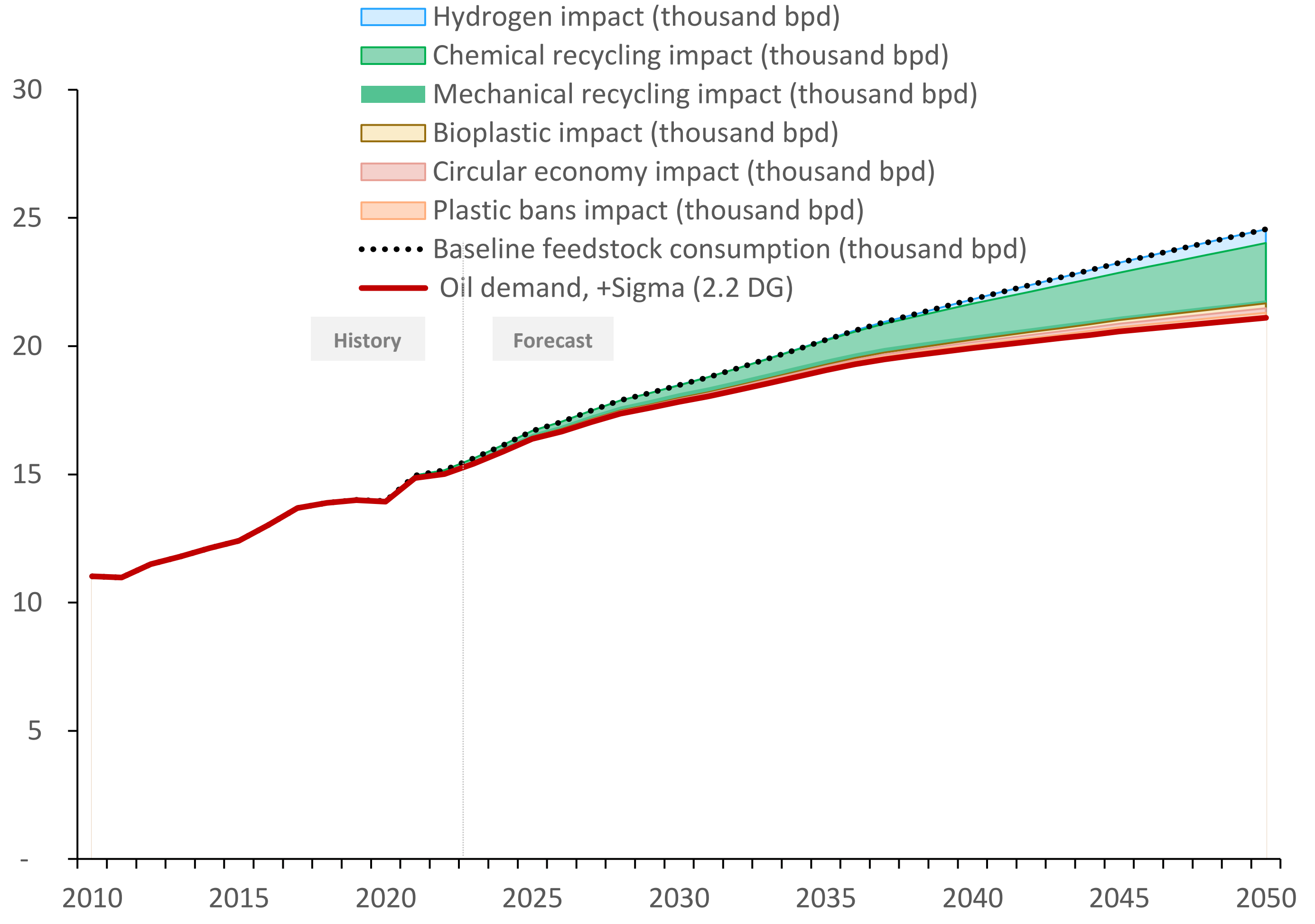
… but grows at close to business-as-usual rates in +Sigma

In our 2.2°C scenario, oil demand in the petrochemical sector continues to increase, driven by population growth and global economic expansion.

Recycling is the only process with the potential of slowing down the business as usual (BAU) growth in the petrochemical sector in a 2.2°C world. None of the other technological developments/policy changes or behavioral changes have the strength to limit plastic consumption and oil demand.

This scenario is as close to business-as-usual as it gets.

Petrochemicals demand and energy transition impact
Million barrels per day



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Source: Rystad Energy Oil Market Transition Solution, Rystad Energy OilMarketCube

Bold policies, disruptive technologies essential to meet –Sigma in petchem

Oil demand in the petrochemical sector peaks at 16 million bpd in 2029, before dropping to 4 million bpd in 2050 in the –Sigma (1.6°C) scenario.

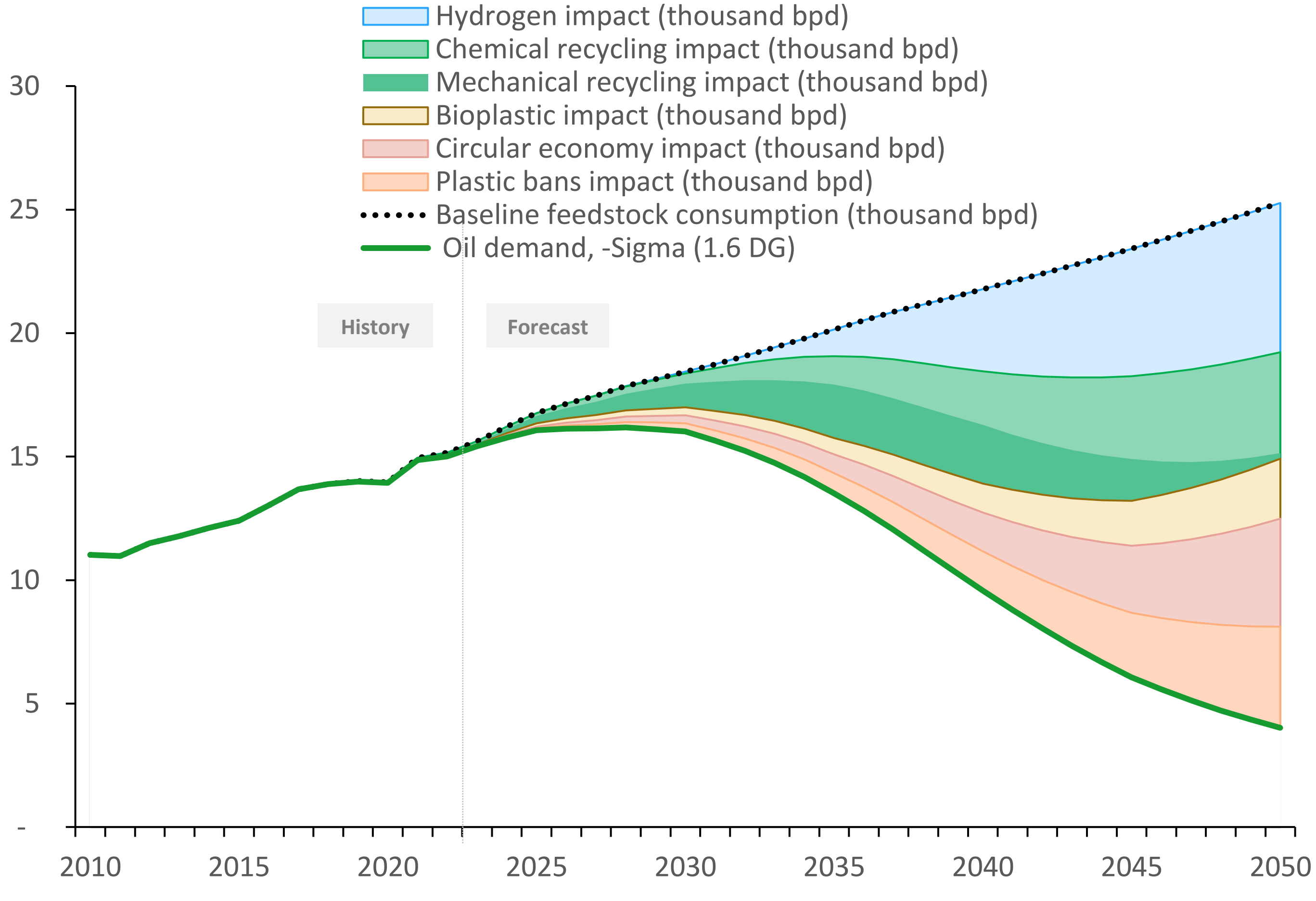
To meet the conditions of a 1.6°C world, recycling rates need to start growing exponentially, and the mechanical recycling process needs to become more efficient by both ensuring that the collected plastic waste gets recycled and displaces virgin feedstock and also by increasing the amount of plastic recycled in a closed loop*.

In this scenario, technological innovation needs to expand even further, allowing hydrogen to have a disruptive role through the production of renewable methanol**, starting from the 2030s.

Finally, unlike the 1.9°C scenario, here, the role of circular economy and plastic bans is fundamental to reducing oil demand in the medium- and long-term.

We consider this scenario unlikely, given that none of these effects has so far generated a visible disruptive impact on oil demand.

Petrochemicals demand and energy transition impact
Million barrels per day



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Source: Rystad Energy Oil Market Transition Solution, Rystad Energy OilMarketCube

US oil has at least another decade of growth ahead, with price as main factor

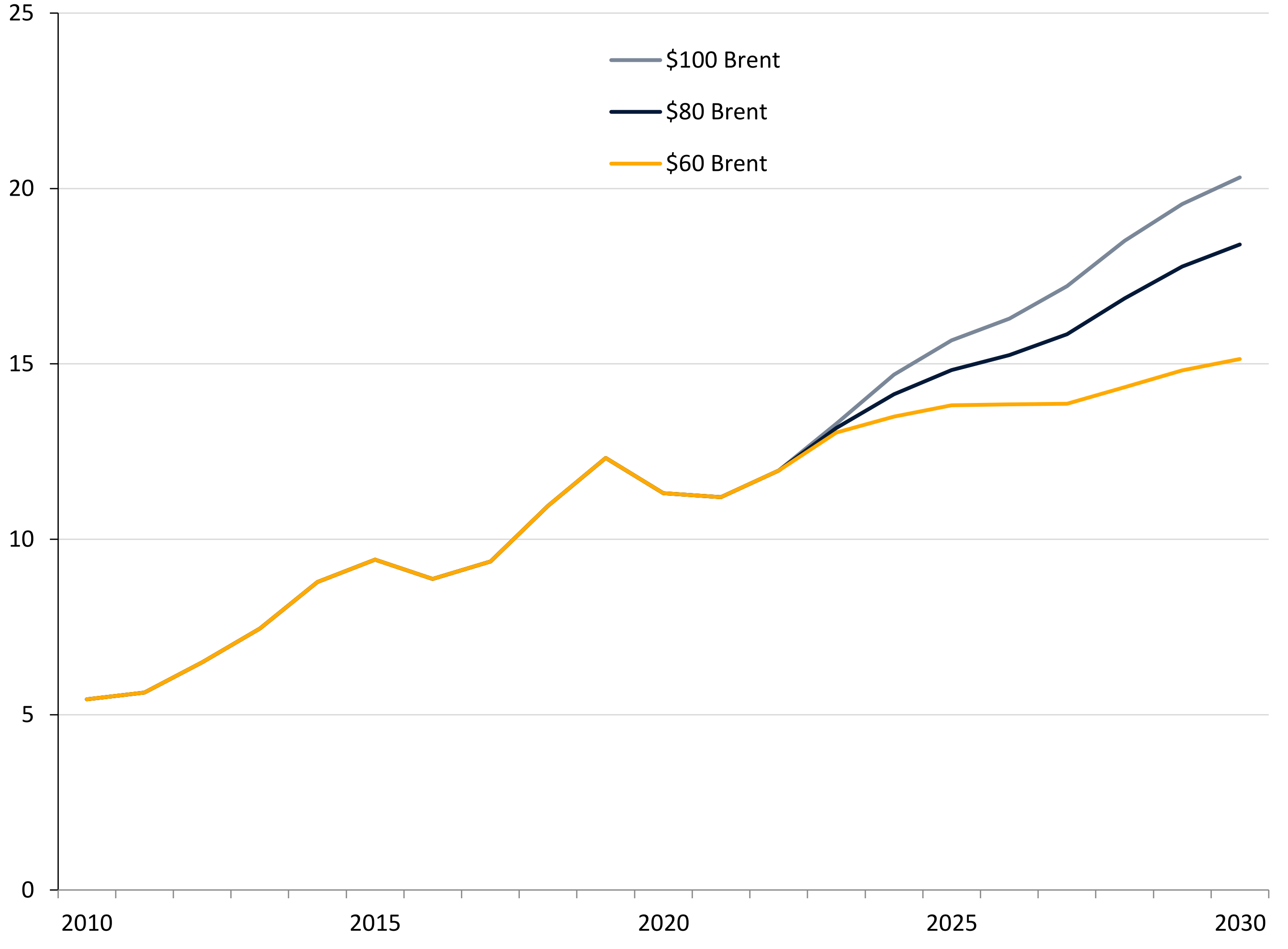
Our forecast for long-term US oil and lease condensate production suggests robust growth until the early 2030s, after which declining demand will have a stronger impact on production.

US oil production as a whole would grow to 18.7 million bpd in 2031 if Brent (and the relatively discounted WTI) were to stay at today's current prices. In a scenario where Brent is assumed at $100 per barrel, US output could flourish to 20.5 million bpd. In a scenario in which Brent is $60 per barrel, the third shale wave would be muted to a peak of 15.3 million bpd in 2031.

How much it costs to produce a barrel of oil in the US greatly varies. In the Permian Basin, production growth can be sustained at $50 Brent, whereas the price in more mature or less economic basins can be as much as $70 per barrel. The current environment of cost inflation and other above the ground barrel risks and considerations can push this number even higher. A higher price for oil in order to attract investments may thus be needed to meet customer demand in the US until the year 2025, when we expect peak oil demand.

This analysis isolates only price as a predictive factor in US oil growth. Many other drivers, such as the introduction of a carbon tax, a more stringent policy on flaring, or a ban on fracking on federal lands, would constrain operators' cash flow and deliver fewer fossil fuels burned.

US crude and condensate production outlook
Million barrels per day



Source: Rystad Energy UCube

Mean demand scenario calls for 65 million bpd from new wells by 2030

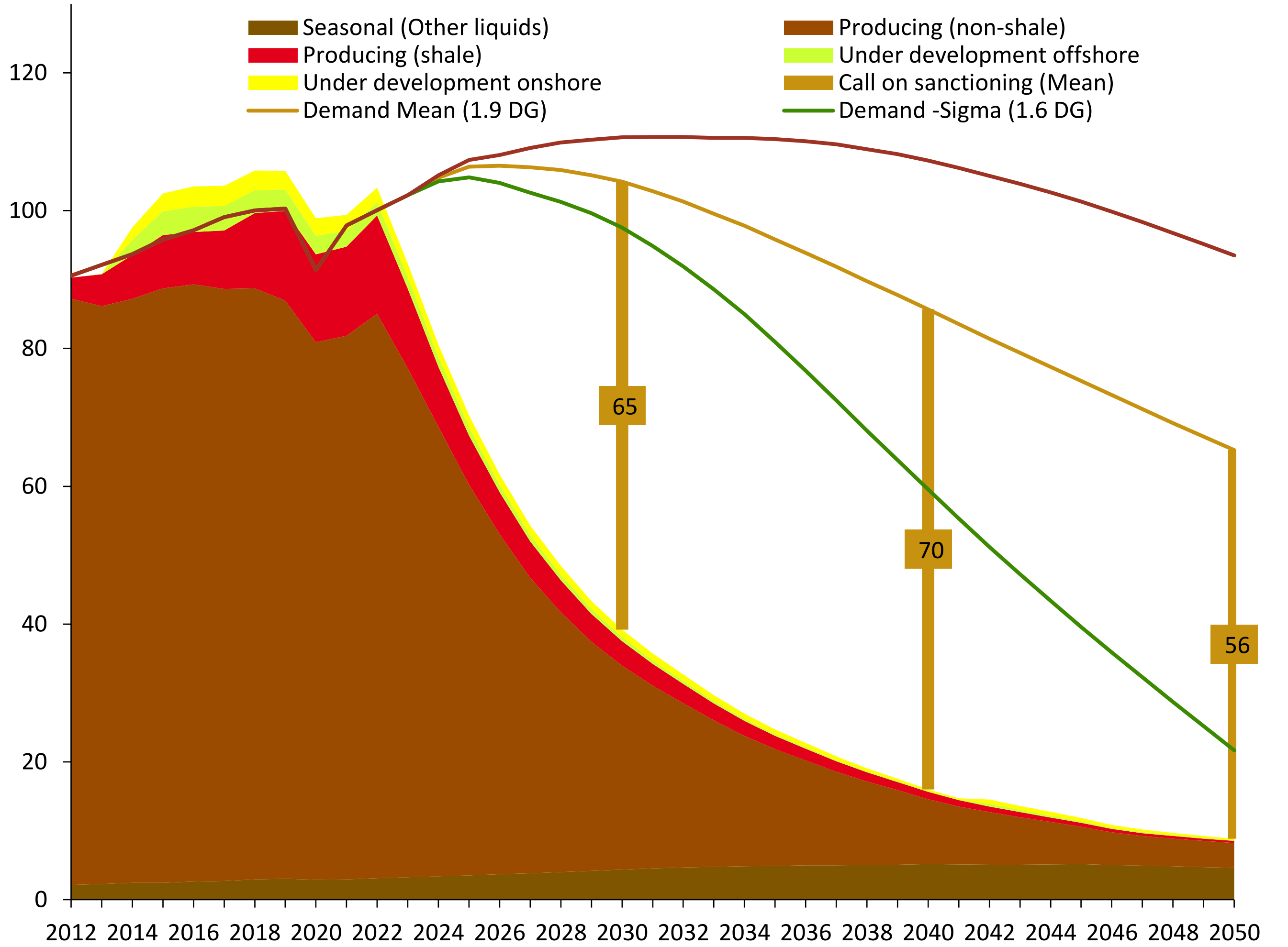
In our Mean (1.9°C) demand scenario, liquids demand peaks at 107 million bpd in 2026 and declines thereafter to 104 million bpd for 2030. For the same year, we forecast 39 million bpd of liquid supply coming from currently producing wells and conventional wells already under development. This means, as shown in the chart, 65 million bpd of supply will need to come from new wells (either from pre-FID fields or new infill wells on producing fields and assets under development). Please note that the numbers do not precisely add up due to individual rounding.

The call on sanctioning increases to 70 million bpd for 2040 as the base decline from existing wells outpaces the decline in our Mean demand scenario.

For 2050, we see a call on sanctioning of just 56 million bpd as the decline from existing (and by then very mature) wells flattens out. We revised the call on sanctioning up from 42 million bpd since of May 2022 report because we adjusted our demand projections upwards.

The spread between the call on sanctioning in the various demand scenarios naturally widens as we move out in time from today's point of view. However, along the way, sanctioning activity will be determined by actual demand developments.

Liquids supply from producing wells and developments* vs total liquids demand
Million barrels per day



* Includes conventional wells under development. Drilled but not yet completed (under development) Shale / LTO wells are not included in the base production as we classify them as pre-FID.
Source: Rystad Energy research and analysis, OilMarketCube, UCube

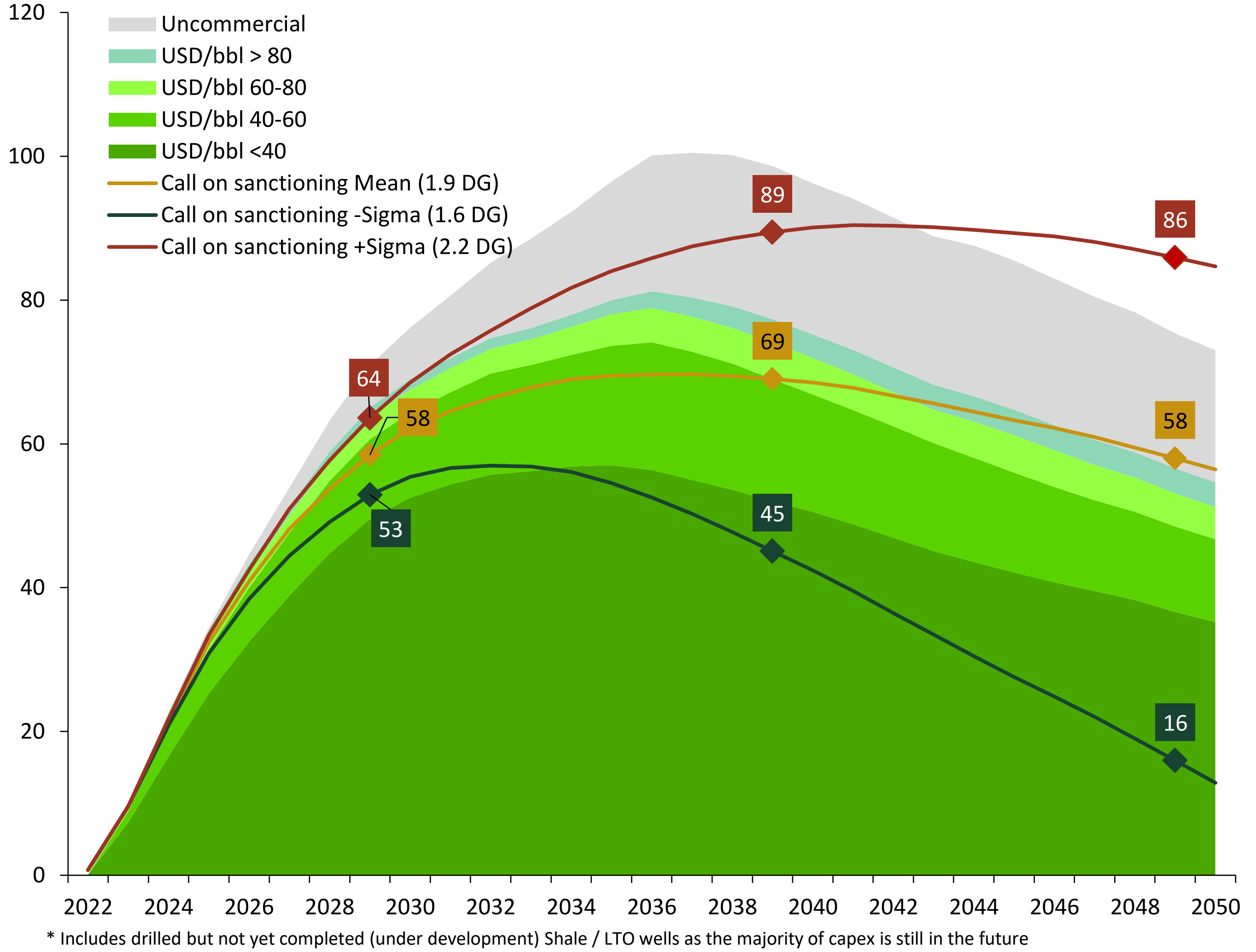
Sanctioning met by wells with different breakeven depending on scenario

Looking more into the details of our call on sanctioning, we see that sanctioning is still very much needed in all three of our demand scenarios. At the same time, our supply database suggests that the existing stock of global discoveries is sufficient to meet demand in the three scenarios, except in the +Sigma (2.2°C) case from mid-2030s, in which the discovered supply resources are deemed "uncommercial" (shown in light gray).

This slide looks at the existing stock of global drilling opportunities at discovered assets, split by breakeven price (split in shades of green), and compares the supply potential to the call-on-sanctioning in our three demand scenarios.

Future liquids demand in the Mean (1.9°C) case can be met by discoveries for which we estimate a breakeven oil price of up to $60 Brent until 2040. However, there will certainly be upcoming discoveries that will out-compete existing discoveries based on breakeven prices. As shown on the following slides, this leads to lower equilibrium breakeven oil prices than indicated on this slide. This does not mean that we will not see up and down cycles going forward. It rather suggests that we have sufficient supply potential as long as sanctioning continues. In the -Sigma (1.6°C) scenario, 2030 demand can be satisfied by discoveries with a breakeven oil price in the lower $40s Brent. The most realistic call on sanctioning, however, is likely higher than indicated on this slide as we do not account for negative impacts on producing wells in a price environment in which the -Sigma (1.6°C) scenario would create. The +Sigma (2.2°C) case calls for additional exploration activity as the current stock of commercial discoveries is insufficient.

Liquids supply from pre-FID wells* at already discovered assets and call on sanctioning
Million barrels per day



* Includes drilled but not yet completed (under development) Shale / LTO wells as the majority of capex is still in the future
Source: Rystad Energy research and analysis, OilMarketCube, UCube

Onshore infill wells, Shale/LTO to add largest amount of new supply in 2030

We can dive deeper into the cost of supply analysis by zooming in on the supply segment type, here splitting the conventional infill drilling into further granularity.

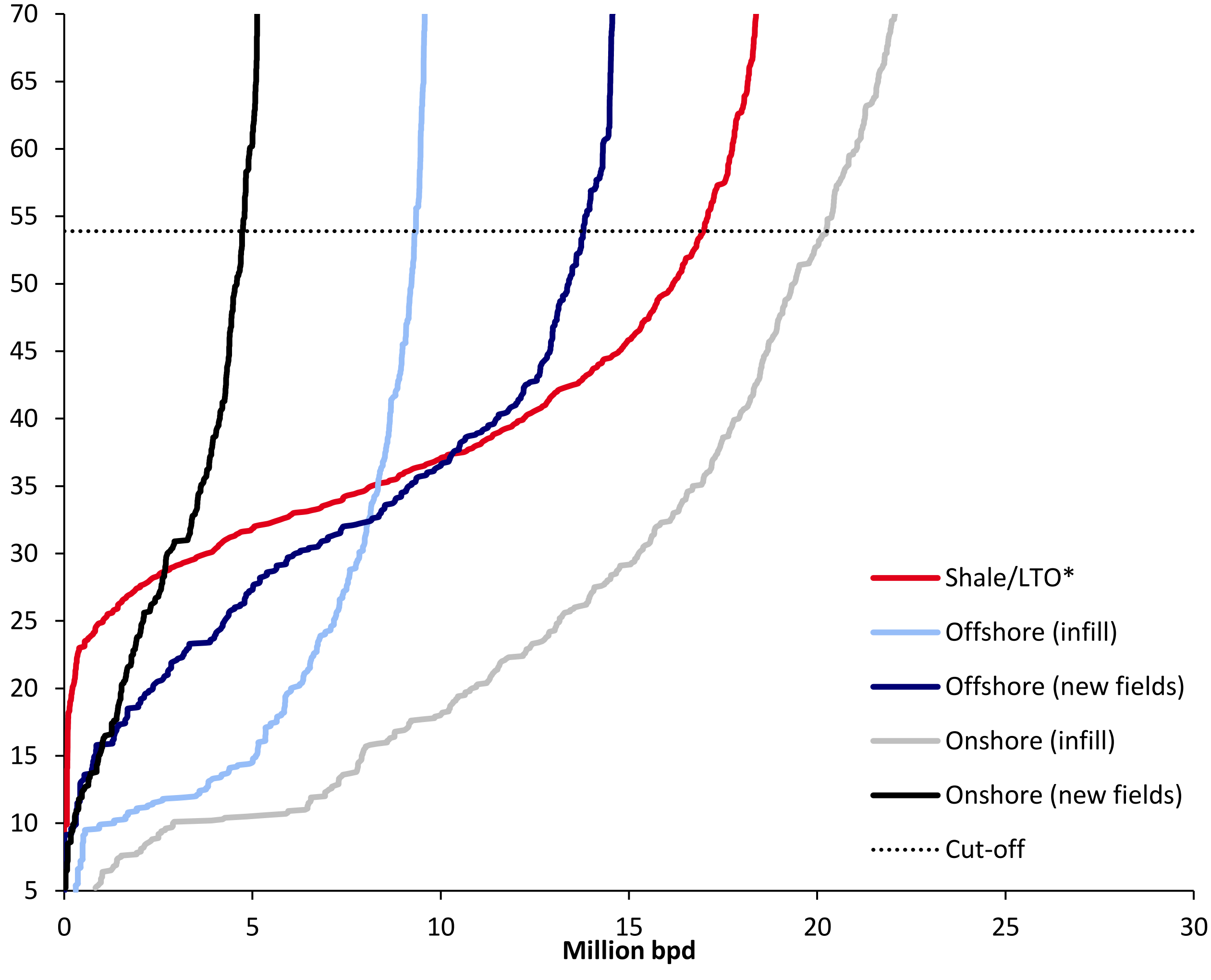
Our models suggest that by 2030 the call on sanctioning in the 1.9°C (Mean) scenario, or the amount of "new oil" needed to satisfy demand (on top of already producing wells), amounts to 65 million bpd, here further to the right on the x-axis. The dotted green curve represents the cost of supply curve for Onshore infill wells (new wells in producing fields). We see that at the $54 (Brent) breakeven price, as much as 31%, or 20 million bpd, of the entire call on sanctioning would be satisfied by Onshore infill wells.

Conventional onshore wells in not-yet-sanctioned oil fields would contribute with about 5 million bpd. The cost of supply curve for conventional onshore infill wells suggests that around half of the volume would come from infill wells that have a breakeven price of below $20, led by super-competitive opportunities mostly in the Middle East.

For shale/LTO, we see that the cost of supply curve is fairly flat between $30 to $40 Brent, with significant volumes becoming commercially attractive when prices move incrementally above $30 per barrel.

The offshore segment contributes 22 million bpd to satisfy demand for new supply in 2030, of which entirely new wells at not-yet-sanctioned fields contribute with nearly 14 million bpd, whereas offshore infill wells contribute around 9 million bpd.

Cost of liquids supply curve for pre-FID wells* for 2030 by supply segment type
USD per barrel (real), Brent-equivalent



Source: Rystad Energy research and analysis, OilMarketCube, UCube

Natural gas to play a key role in the Energy Transition

Consistent with oil, Rystad Energy has developed the latest degree gas transition scenarios. In this section, we discuss three Rystad Energy degree scenarios, RE 1.6 DG scenario (low), RE 1.9 DG scenario (base case) and RE 2.2 DG scenario (high).

In our base case, the 1.9 DG scenario, gas demand peaks in 2033 at 4,746 Bcm and declines to 3,390 Bcm in 2050. Gas is considered an important part of the transition towards a low carbon world in markets that are currently highly dependent on coal. Gas demand will continue to grow, replacing coal in Asia while renewables will take shares from gas in Europe, the Middle East and North America. Further, robust growth in renewable power generation supported by declining costs will drive an electrification of industrial and residential gas use which will intensify in the early 2030s. Gas will be the key source of power during periods of intermittent renewables, but growth in battery storage will support the case for declining use of gas from the second half of the 2030s.

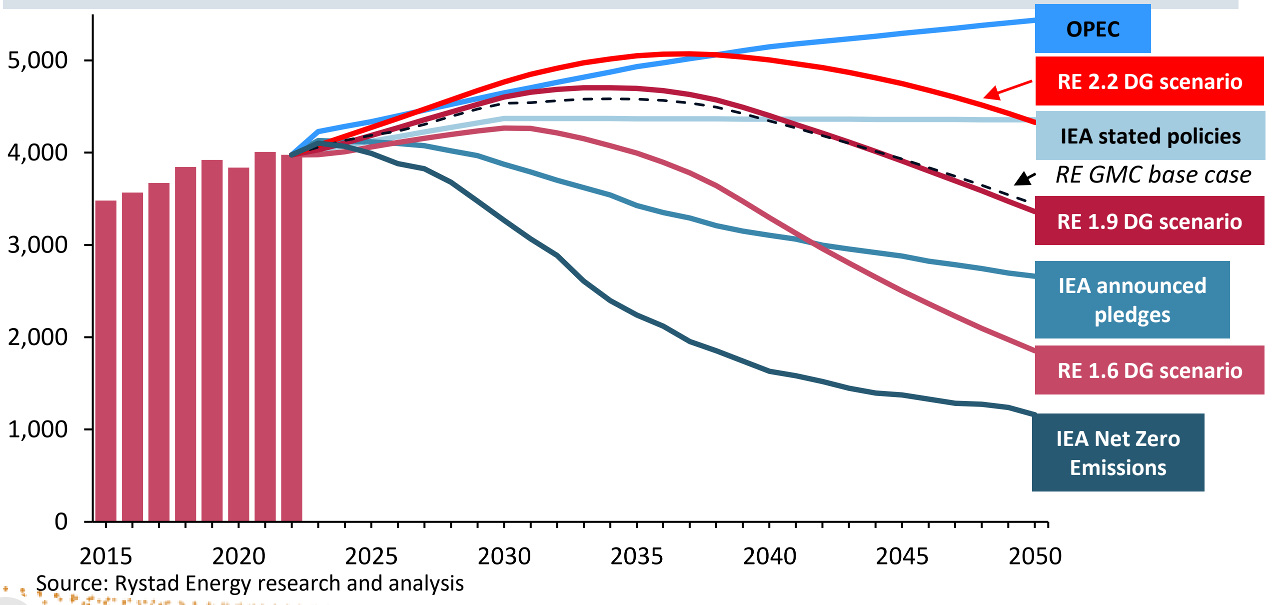
Comparing our global demand scenarios with other predictions, there is a wide range of outcomes predicted by various institutions.

Overall, the 2.2 DG scenario shows gas peaking in 2037 at 5,117 Bcm. By contrast, the 1.6 DG scenario shows gas peaking much earlier in 2030 at 4,287 Bcm.

On the supply side, in Rystad Energy's 1.9 DG, significant investments in new source of supply are required. About 1,700 Bcm of new gas supplies are needed by 2030 and 2,700 Bcm by 2040. As demand declines at a similar pace as sanctioned supply between 2040 and 2050, the need for new supplies remains flat at about 2,400 Bcm in 2050. In the 2.2 DG scenario, we see increased demand for new developments and about 3,400 Bcm of new supply required to meet long-term demand in 2050. However, In the 1.6 DG scenario, significantly lower volumes are needed to meet demand. In this scenario, only 900 Bcm of new supplies are needed by 2050.

The development of the global energy crisis will continue to dominate price drivers in Europe and Asia in the next 2-3 years. Price formation in the 1.9 DG and 2.2 DG scenarios will be driven by a global shortage of gas during which the consumer sets the prices.

Global natural gas demand by scenario
Billion cubic meters (Bcm)



Source: Rystad Energy research and analysis

Significant investment needed across all scenarios due to maturing assets

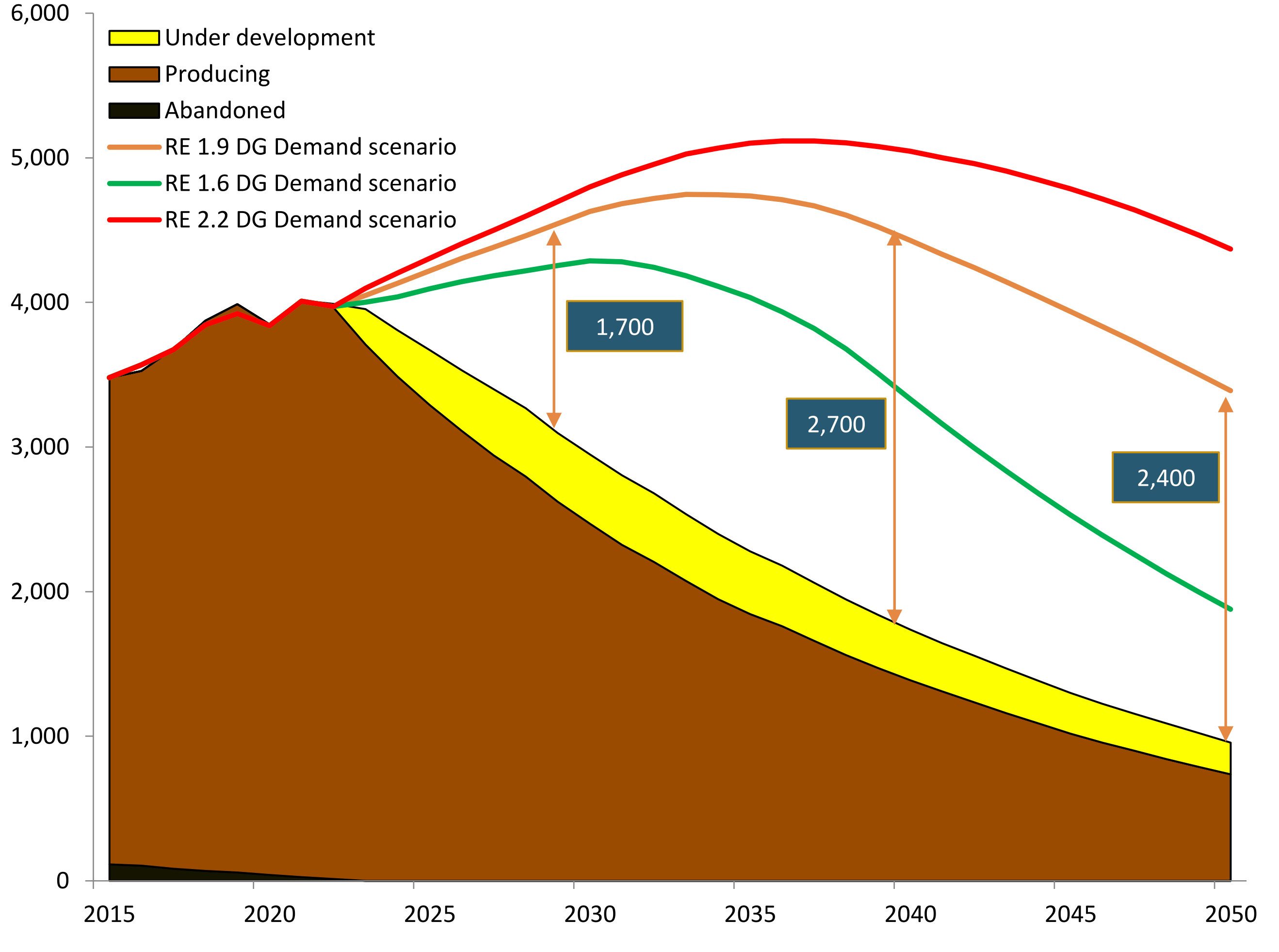
On this page we compare the different demand scenarios for natural gas with currently sanctioned natural gas production. This shows how much new production is needed in each of our demand scenarios.

Sanctioned gas production includes production from gas fields that are either producing or under development as of today. Sanctioned gas production amounts to 3,980 Bcm in 2022. The volumes from sanctioned fields will, however, decline to 2,950 Bcm in 2030 as upstream assets mature. Other sanctioned supplies will decline further to 1,735 Bcm in 2040 and 955 Bcm in 2050. This means that significant new investments are needed to meet demand in the 1.9 DG scenario, and even more in the 2.2 DG scenario.

In Rystad Energy's 1.9 DG, significant investments in new source of supply are required. About 1,700 Bcm of new gas supplies are needed by 2030 and 2,700 Bcm by 2040. As demand declines at a similar pace as sanctioned supply between 2040 and 2050, the need for new supplies remains flat at about 2,400 Bcm in 2050.

In the 2.2 DG scenario, we see increased demand for new developments and about 3,400 Bcm of new supply required to meet long-term demand in 2050. However, In the 1.6 DG scenario, significantly lower volumes are needed to meet demand. In this scenario, only 900 Bcm of new supplies are needed by 2050.

Sanctioned natural gas supply vs demand scenarios
Billion cubic meters (Bcm)

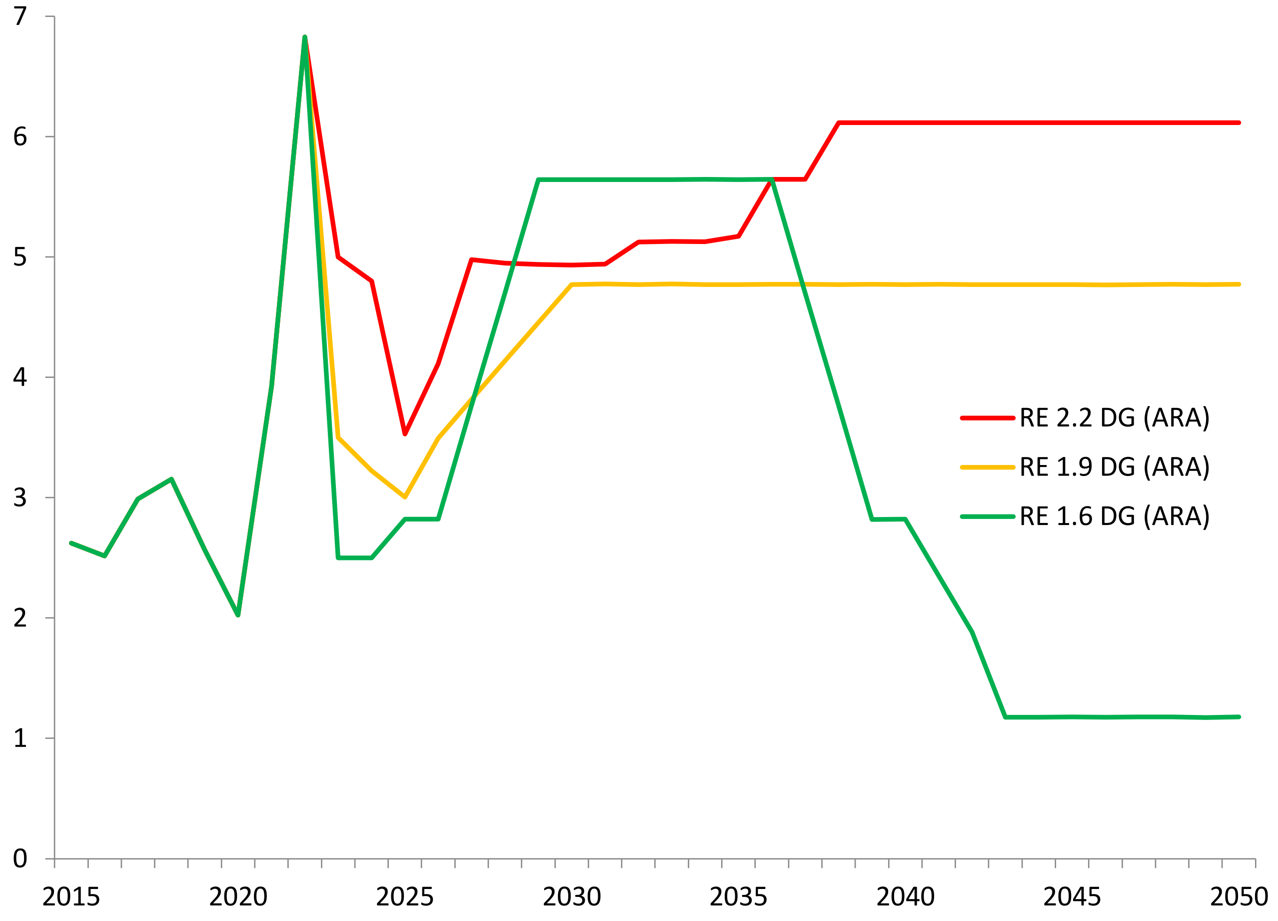


Source: Rystad Energy research and analysis

Loss of associated gas supplies to drive US gas price higher in the 2030s

In this report, we are presenting Rystad Energy's new gas prices scenarios which are linked to our degree (DG) scenarios for global warming. The 1.9 DG price scenario is the closet to our base case, while the 1.6 DG and 2.2 DG ones present the price strips in the low and high demand scenarios for natural gas.
Rystad Energy forecasts that US gas prices will slide in the mid-2020s across all demand scenarios driven by growing domestic demand and LNG exports in combination with strong supply growth. The Henry Hub is forecast to trade between $2.5-3.5/MMBtu by 2025. However, in the 2030s we expect to see Henry Hub prices increase across all scenarios due to quite different drivers. In the 1.9 DG scenario, prices are driven by continued increasing demand for gas and LNG exports out of the US which drive upstream and midstream investments higher as discussed in our base case outlook for the US. Henry Hub is expected to reach $4.8/MMBtu in the 1.9 DG scenario. The same drivers dominate the 2.2 DG scenario, but with stronger impact causing Henry Hub up to trade around $5.0-5.5/MMBtu. However, price drivers in the 1.6 DG scenarios are more impacted by a decline in oil demand and activity in oil basins which would remove significant volumes of associated gas supplies. Since gas demand remains more robust than oil in the 1.6 DG scenario, a Henry Hub price of $5.6/MMBtu is needed to secure sufficient gas supplies. Post 2040, demand will be the most important price driver. In the 1.6 DG scenario, quicker decarbonization will drive down demand for US gas and LNG, and we expect $1.0-1.5/MMBtu will be sufficient to meet demand. In the 1.9 DG scenario, demand declines at a slower pace. Still, steep decline curves for shale assets will require a price of about $4.8/MMBtu to keep activity at levels that meets demand according to our base case. In the 2.2 DG scenario, demand stays more robust with $6.1/MMBtu needed to supply sufficient volumes of gas to the domestic and international markets, primarily through LNG.

Henry Hub forecast by scenario
USD per MMBtu (real)



Source: Rystad Energy research and analysis

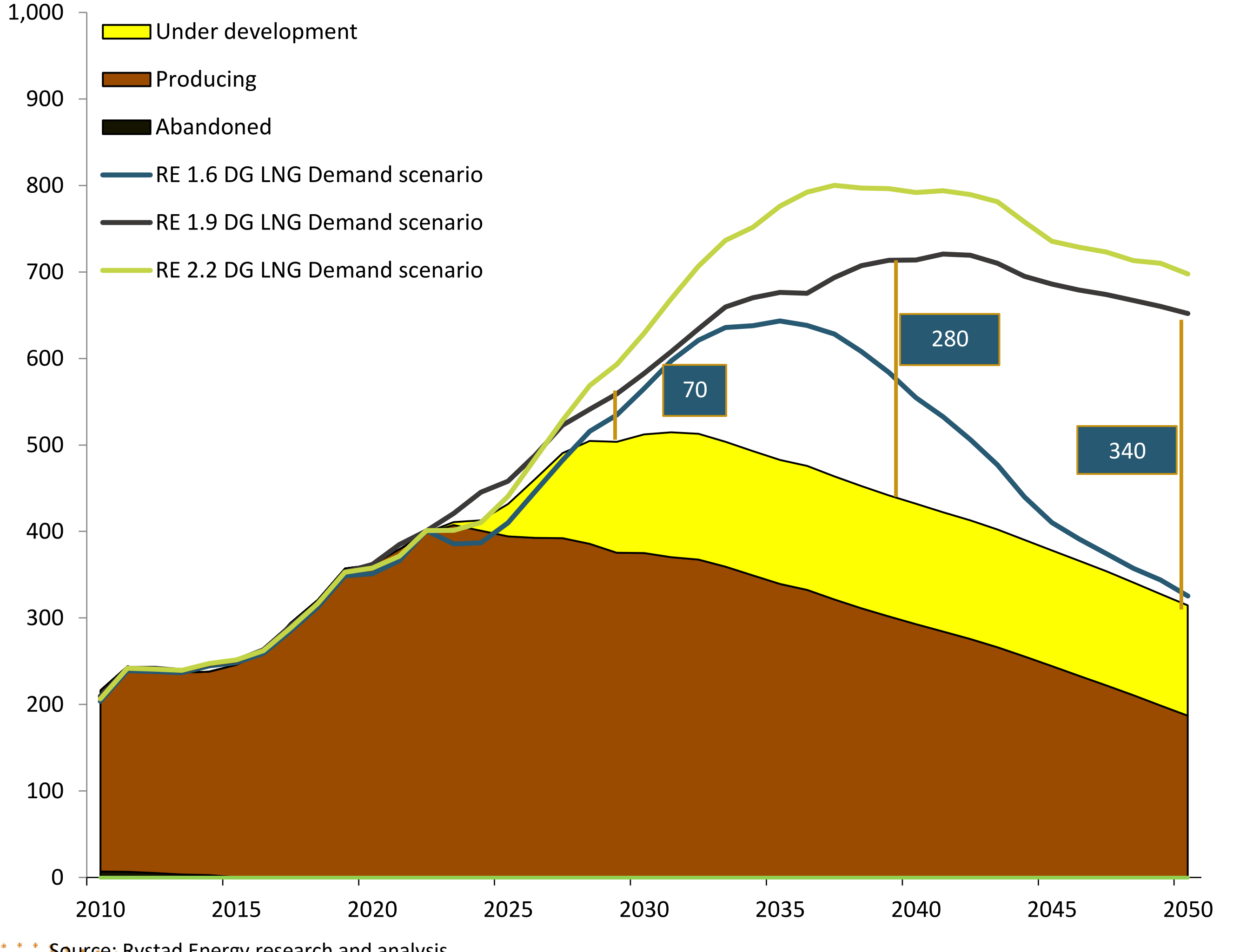
Robust LNG investments needed in 1.9 and 2.2 DG scenarios by 2050

On this page we compare the different degree-scenarios for LNG with currently sanctioned LNG production. This shows how much new LNG production is needed under each of the demand scenarios. Sanctioned LNG production includes production from LNG projects that are either operational or under construction as of today.

Sanctioned LNG production amounts to about 398 Mt in 2022 and will increase to about 514 Mt by 2031 as new LNG projects that are currently under construction come online. The volumes from sanctioned LNG projects will, however, decline to 432 Mt in 2040 and 315 Mt by 2050 as the underlying upstream assets that are feeding the liquefaction plants mature. This means that significant new investments will be needed to meet demand in both the 1.9 and 2.2 DG scenarios.

Significant investment in new sources of supply are needed to meet growing LNG demand in the medium and long-term. About 70 Mt of new LNG supplies are needed by 2030 and 280 Mt by 2040. As sanctioned supplies decline at a quicker rate compared to demand between 2040 and 2050, about 340 Mt of new LNG supplies are needed to meet demand in 2050. However, in the 1.6 DG scenario, the LNG market is over-supplied in the second half of the mid-2020s. We see a wider range between the scenarios for LNG compared to the scenarios for natural gas as LNG meets incremental gas demand across key markets in Asia and Europe, creating uncertainty in natural gas demand.

Sanctioned LNG supply vs demand scenarios
Million tonnes (Mt) LNG



Source: Rystad Energy research and analysis

Cost of US LNG to drive European and Asian spot prices in coming decades

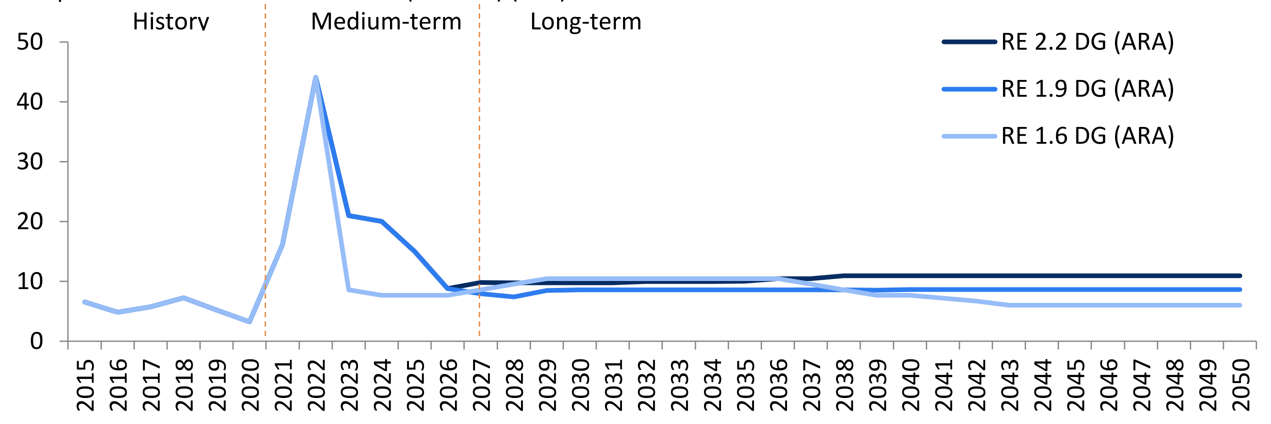
The development of the global energy crisis will continue to dominate price drivers in Europe and Asia in the next 2-3 years. Price formation in the 1.9 DG and 2.2 DG scenarios will be driven by a global shortage of gas during which the consumer sets the prices. Price levels will be at levels that trigger demand reduction and destruction in mainly the industrial and power sectors. Through 2025, this will see prices trade around $15-20/MMBtu. In the 1.6 DG scenario, a rapid reduction in gas demand drives a much quicker balance in the gas and LNG market with prices decreasing to $7-9/MMBtu over the coming years but remaining at a level that still supports new LNG investment decisions.

In the 2030s, we continue to see the need for new LNG supplies with the US the marginal supplier of new LNG volumes. Hence, the long-run marginal cost (LRMC) of US LNG will drive European and Asian spot LNG prices in this period. As noted in our discussion on US gas price formation, we expect prices to be highest in the 1.6 DG scenario in the first half of the 2030s, driven by a low oil price curbing associated gas supplies. TTF and Asian spot LNG is set to trade at levels of around $10-11/MMBtu in this period. In the 1.9 DG scenario, TFF and Asia spot LNG is forecast to trade around $8-9/MMBtu respectively, while in the 2.2 DG scenario $10-11/MMBtu will be needed in Europe and Asia to drive new LNG investments.

The Long Run Marginal Cost (LRMC) of US LNG will continue to drive the TTF and Asian spot LNG price in the 1.9 and 2.2 DG scenarios into the 2040s with new investments in supply still needed. In the 1.9 DG scenario, TFF and Asia spot LNG is forecast to trade at around $8.6-9.6/MMBtu respectively, while in the 2.2 DG scenario, $10.9-11.8/MMBtu will be required. In the 1.6 DG scenario, the short-run marginal cost of US LNG will be a central price driver of European and Asian prices, suggesting price levels as low as $3-4/MMBtu. However, intermittent renewables can drive volatility, typically during the winter requiring annualized prices as high as $6-7/MMBtu in Europe and Asia respectively.

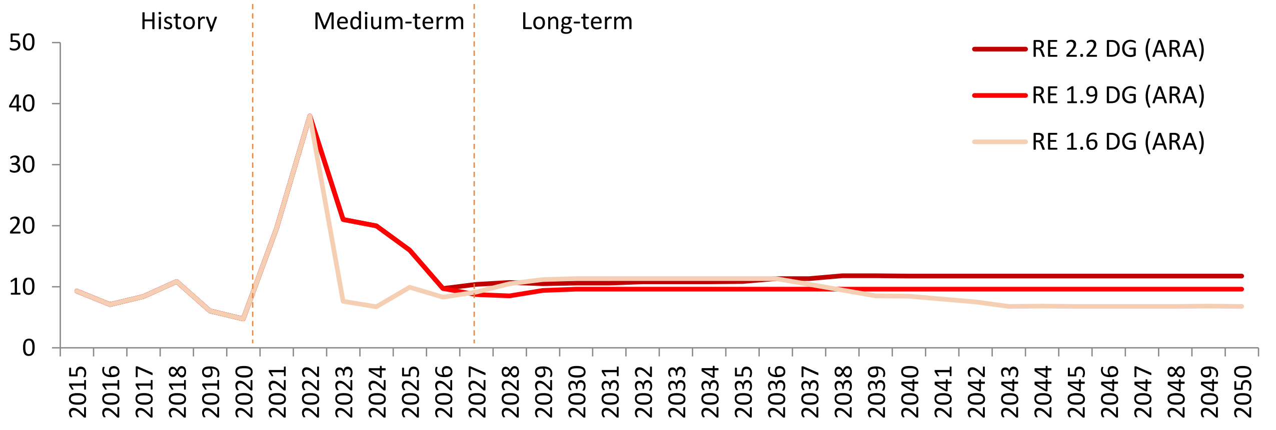
TTF price forecast by scenario

USD per million British thermal units (MMBtu) (real)



Asia spot LNG price forecast by scenario

USD per million British thermal units (MMBtu) (real)

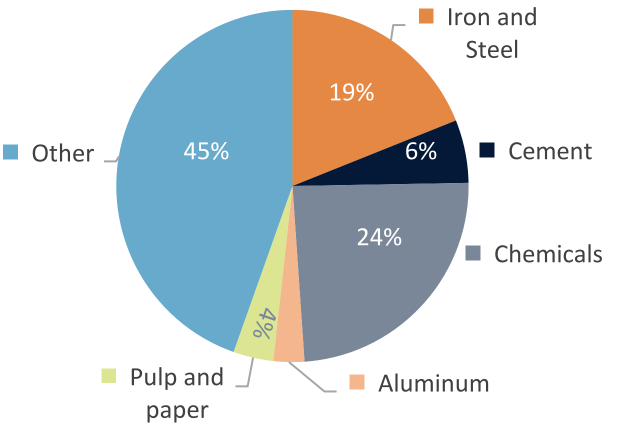


Source: Rystad Energy research and analysis

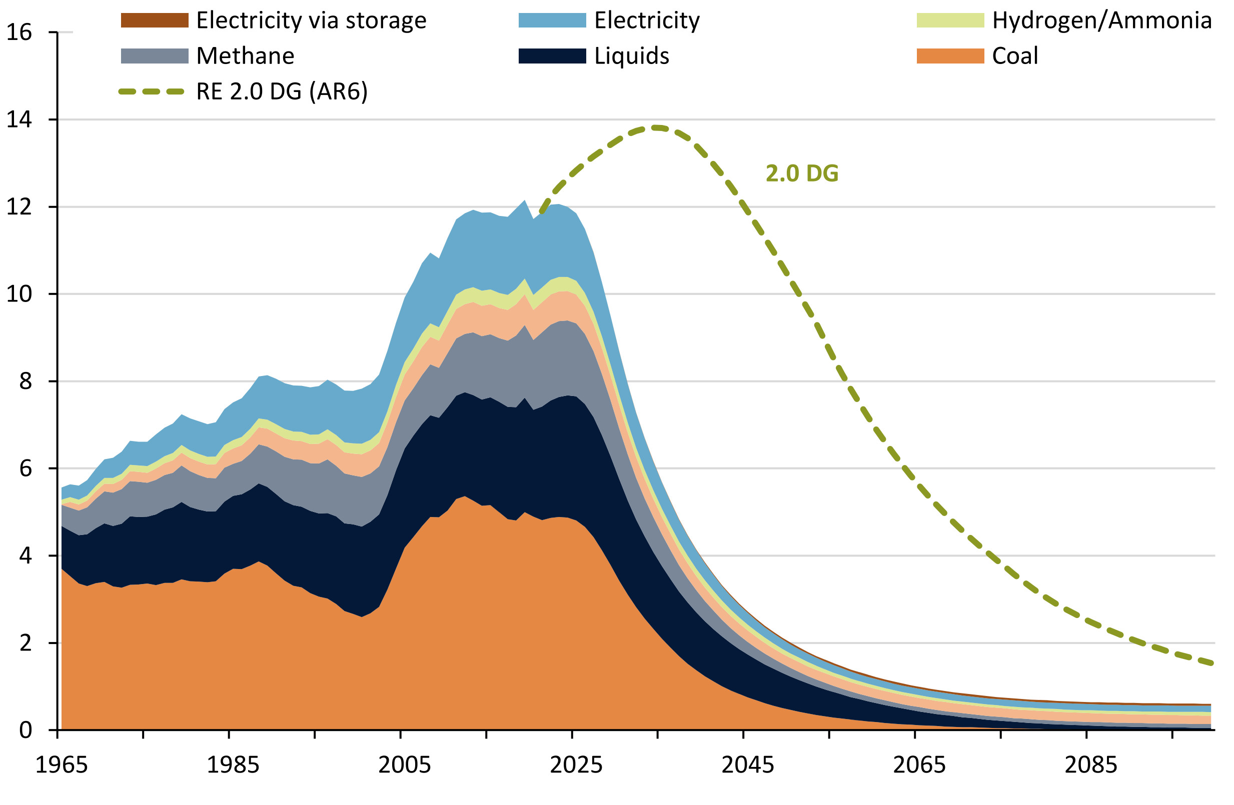
Industry must cut 12 Gt of direct and about 3 Gt of process emissions

Over the last almost 60 years, fuel combustion emissions from the industrial sector doubled as a result of burning fossil fuels.
However, since 2011, emissions reached a plateau at 12 Gt, and on top, comes 3 Gt of process emissions from cement and chemicals .
The top three heavy industries contribute to more than half of industrial energy consumption of 190 EJ. Iron and steel 36 EJ, cement 11 EJ, chemicals 46 EJ, mostly due to high non-energy use.
To reach the 1.5 DG target we need to reduce emissions by 6% per year – even more in 2030s to get to net-zero around 2050.
The 2.0 DG scenario allows for emissions to increase further to 14 Gt, before peaking in 2035, followed by a 4% per year decrease.
Both scenarios will require significant changes to the way we produce and consume energy.

Industrial final energy demand by sector
190 EJ in 2022



Industrial direct greenhouse gas emissions in 1.5 DG and 2.0 DG by primary energy source
Gigatonnes CO2eq (Gt CO2 eq)



Source; Rystad Energy Scenario Cube

Iron and steel production in fast transition scenario needs to change

Global steel output is expected to surpass 1.9 billion tonnes in 2022 after seeing more than a doubling since year 2000. China alone has contributed to 85% of the growth, and currently almost half of all steel globally is produced in China. We forecast global steel production to grow to 2.7 billion in 2050.

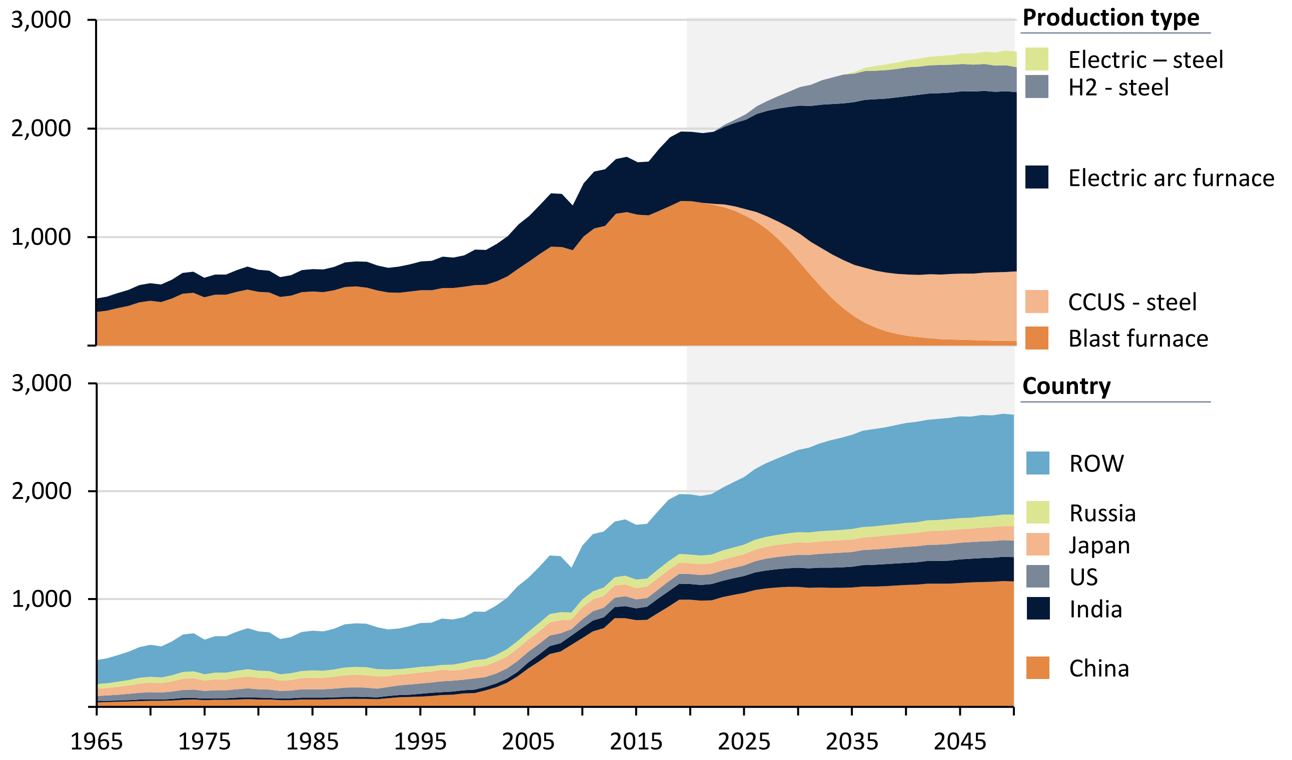
Material efficiency gains of 17 % is reducing the overall demand for steel. This comes from more efficient use in all sectors, including construction, consumer products, energy and transportation.

Increasing use of scrap steel in electric arc furnaces and basic oxygen furnaces help lower energy consumption and emissions. Electric arc furnaces based on scrap steel consume only 10% of the energy needed in a blast furnace. The limiting factor will be the availability of scrap steel, but also the issue that use of scrap steel leads to variation in steel quality as copper contaminate the steel.

In order to reduce emission aligned with the 1.5 DG scenario emissions production from blast furnaces will have to be partly phased out and retrofitted with CCUS capabilities. Rystad Energy estimates that 19% of global steel will be produced using CCUS in 2035 capturing 360 million tonnes of CO_2 annually.

There is also a need to produce steel using hydrogen as a reducing agent. There are already green steel projects in several countries with high renewables potential, like Namibia and Australia, and in some cases, it could be more economical to export green steel instead of a hydrogen derivative given the high transportation and storage costs.

Global steel production by production type and country (1.5 DG)
Million tonnes steel (Mt)



Source: Rystad Energy Scenario Cube

When will green steel compete?

Primary steel produced using a blast furnace (BF-BOF) will in most cases be the most competitive option for steel making in markets with no price on CO_2. Even though the energy intensity is on average 20 GJ/t BF-BOF benefits from low prices for coal and coke when produced locally. However, as seen below in the example of the UK in 2050, assuming a CO_2 price of $100 per tonne of CO_2 will bring the costs way higher than the clean alternatives.

Use of CCUS technology is a cost-efficient options in many countries with access to geological storage. CCUS for DRI-EAF is already commercially available, and the overall capturing costs are lower since the DRI-EAF plant in most cases will be fueled by natural gas. What is bringing up the costs for CCUS is the high amount of energy needed to separate the CO_2 from the flue gas.

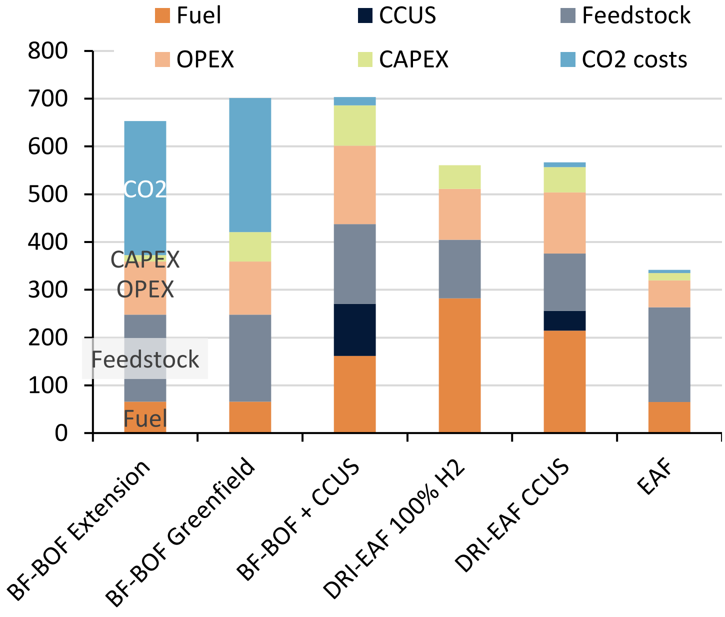
There is a strong push for green steel produced using hydrogen as a reducing agent. All the top steel producers have sustainability plans that includes hydrogen and in the Rystad Energy Hydrogen Market dashboard there are currently 27 projects using hydrogen in steel production.

Future export of green steel is a great market opportunity for countries with superior renewables potential and it will contribute to redraw the future steel production map. In 2050, green steel produced in a low-cost hydrogen country could be 30 % cheaper, which will be a huge advantage in a low margin market as steel.

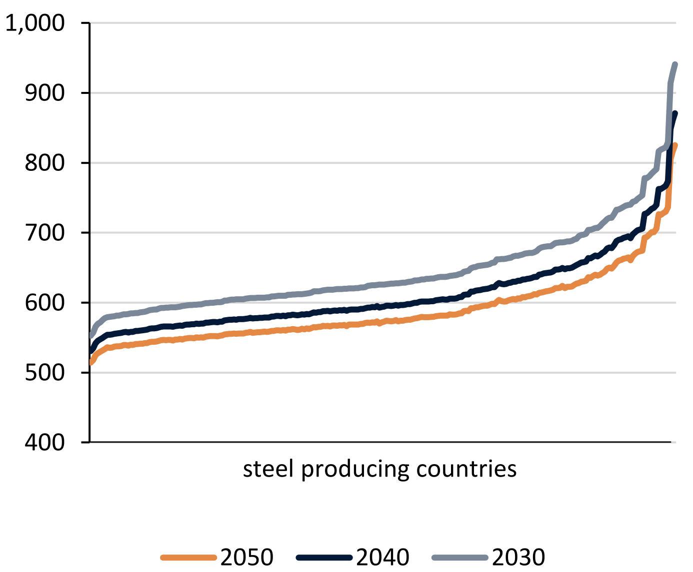
Action list for green steel

1. Enhance recycling rates for steel and use scrap steel whenever possible
2. Ramp-up R&D funding to mature green steel technology
3. Stimulate early market for green steel
4. Put a value on carbon
5. Stimulate necessary costs reductions for CCUS and hydrogen

Levelized cost of steel in the UK in 2050
USD per tonne of steel (USD/t)



DRI-EAF using 100% hydrogen production costs
USD per tonne of steel (USD/t)



Assumptions: Gas price 25 EUR/MWh, coal price 70 USD/tce, plant lifetime of 25 years, plant utilization 90%, capturing rate of 90%, CO_2 transportation and storage cost of 20 USD/t captured CO_2, capture costs 49 USD/t captured, Hydrogen cost 2.3 USD/kgH2 and a carbon price of 100 USD/t of CO_2. Source: Rystad Energy Scenario Cube

Decarbonizing iron and steel

The global iron and steel sector currently consumes 35 exajoules (EJ) or 9,700 terawatt hours (TWh) every year. Coal contributes to 25 EJ of energy consumption as blast furnaces currently make up 72% of steel production.

Transitioning to higher use of scrap steel and green steel production methods will lower energy needs in the iron and steel industry by 40% in 2050 in our 1.5 DG scenario. Electricity will cover half of total energy consumption of 21.5 EJ as electric arc furnace becomes the dominant form of steel production.

Direct emissions from the iron and steel industry currently sums up to 2.7 Gt CO_2 or 1.5 tonnes of CO_2 per tonne steel produced. Indirect emissions from electricity consumption adds an additional 0.7 Gt CO_2 bringing the total CO_2 footprint to 3.4 Gt CO_2.

In the 1.5 DG scenario the emissions in intensity will decrease by 50% by 2030 and be closer to 100 kg per tonne by mid century.

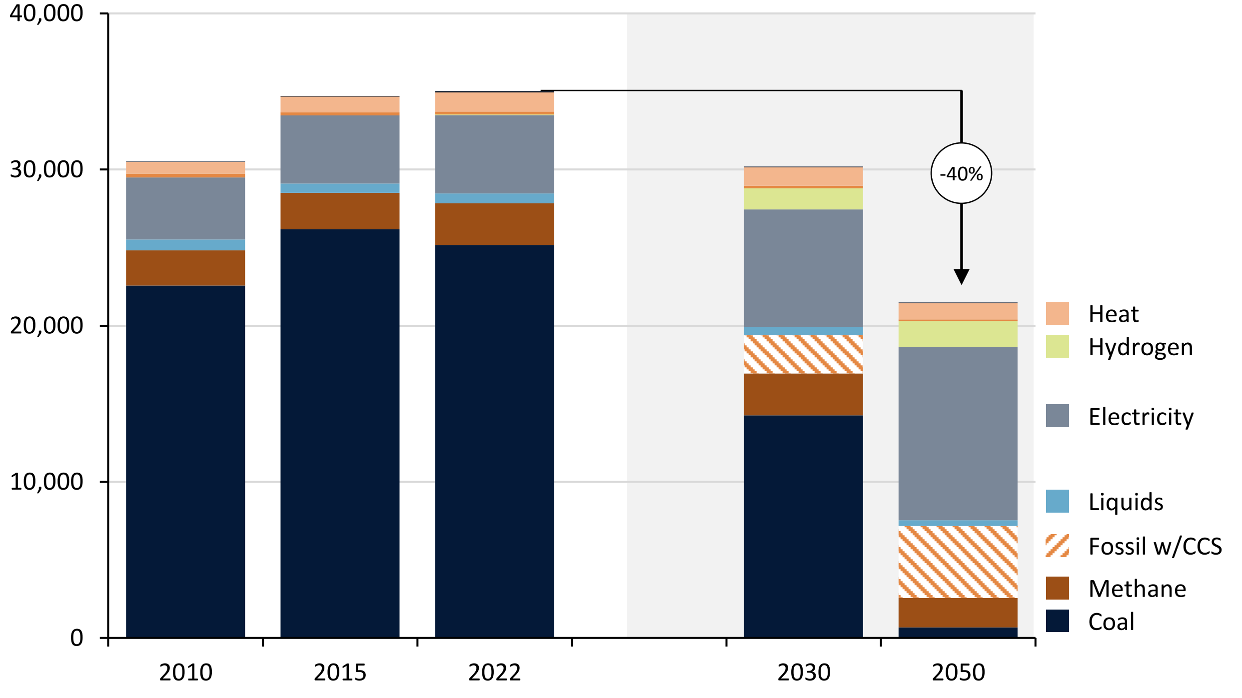
As more steel is being produced by DRI-EAF the amount of natural gas increases by 50% in 2030 compared to the levels of today. By 2050 80% of emissions from fossil fuels combustion will have to be captured to achieve the 1.5 degrees scenario.

Retrofitting existing blast furnaces and direct reduced iron plants with CCUS capabilities is energy intensive and will increase electricity demand by 1,400 petajoules (PJ) by 2050.

Hydrogen will play an important role to bring the iron and steel sector aligned with the goals of the Paris Agreement. Hydrogen consumption will be closer to 1,700 PJ in 2050, which equates to 14 million tonnes of hydrogen.

In the second half of the century novel production methods like electrowinning and others could be more cost efficient than using hydrogen, since electricity is used directly in the steel making process and electrons are used as reduction agents.

Global iron and steel energy consumption by energy carrier (1.5 DG)
Petajoules (PJ)



Source: Rystad Energy Scenario Cube

RystadEnergy

More CCUS projects announced in 2022 than all previous years combined

At the end of 2022, there were 65 commercial carbon capture, utilization and storage (CCUS) projects in operation around the world, capturing over 40 million tonnes per year of CO_2. Statistics indicate almost 48% growth compared to 2021. Additionally, 385 projects are in the pipeline at present, due to enter operation by 2030 and expecting to capture over 523 million tonnes per year of CO_2 when fully operational. This implies close to 100% growth recorded in new announced commercial project capacity in 2022.

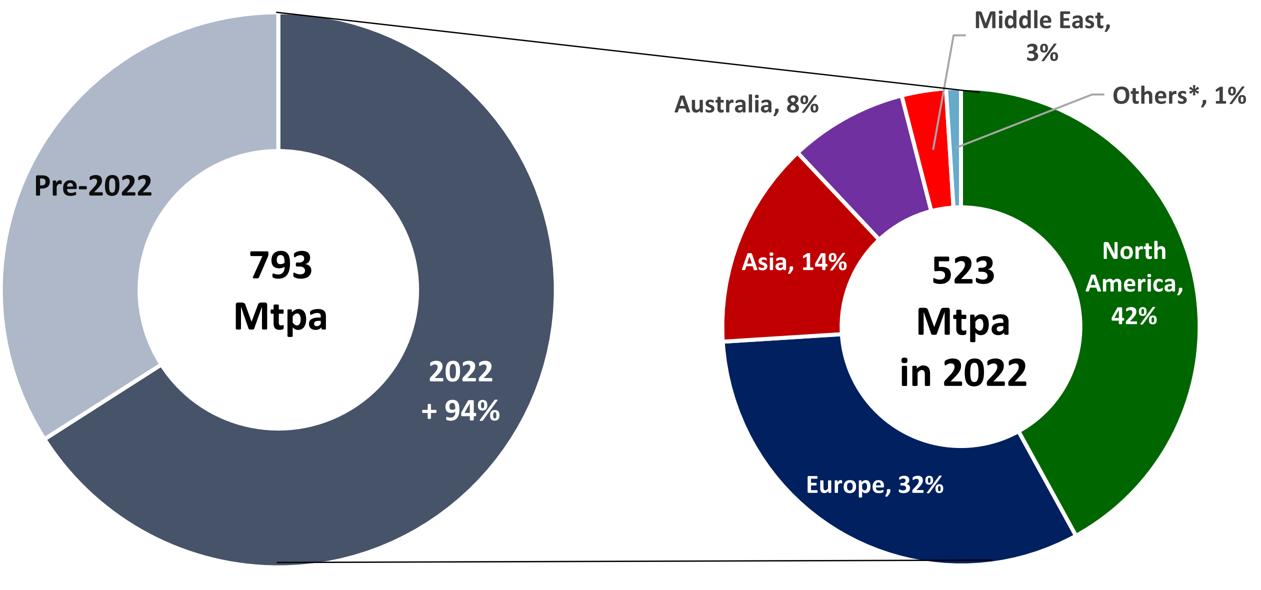
Unlike in 2021, North America surpassed Europe in 2022, landing at the forefront of new commercial CCUS project announcements – more than 42% of the total – followed by Europe with close to 32%. Asia and Australia registered third and fourth place, respectively.

While announcements in Asia continued to be dominated by China, Southeast Asian countries picking up as well with 10 new CCUS projects, raising the total in the region to 17, compared to only seven projects at the end of 2021.

Australia registered close to 70% growth in new project announcements especially in the north-west part of the country. Meanwhile, the Middle East and other parts of the world including Africa, Latin America and Russia continued to lag significantly, accounting for only 4% of the total new project announcements globally.

A well-oriented and focused CCS regulatory framework like the recently announced Inflation Reduction Act in the US, and a flurry of multi-billion-dollar funding schemes across Western Europe, North America, and Australia, were the catalysts for the huge boost in CCUS projects. We expect this momentum to continue in 2023, driven by further government regulated schemes.

Commercial CCUS project announcements in 2022 v pre-2022, and regional split last year



Source: Rystad Energy CCUS solution
Note: Others include South America, Russia, Africa

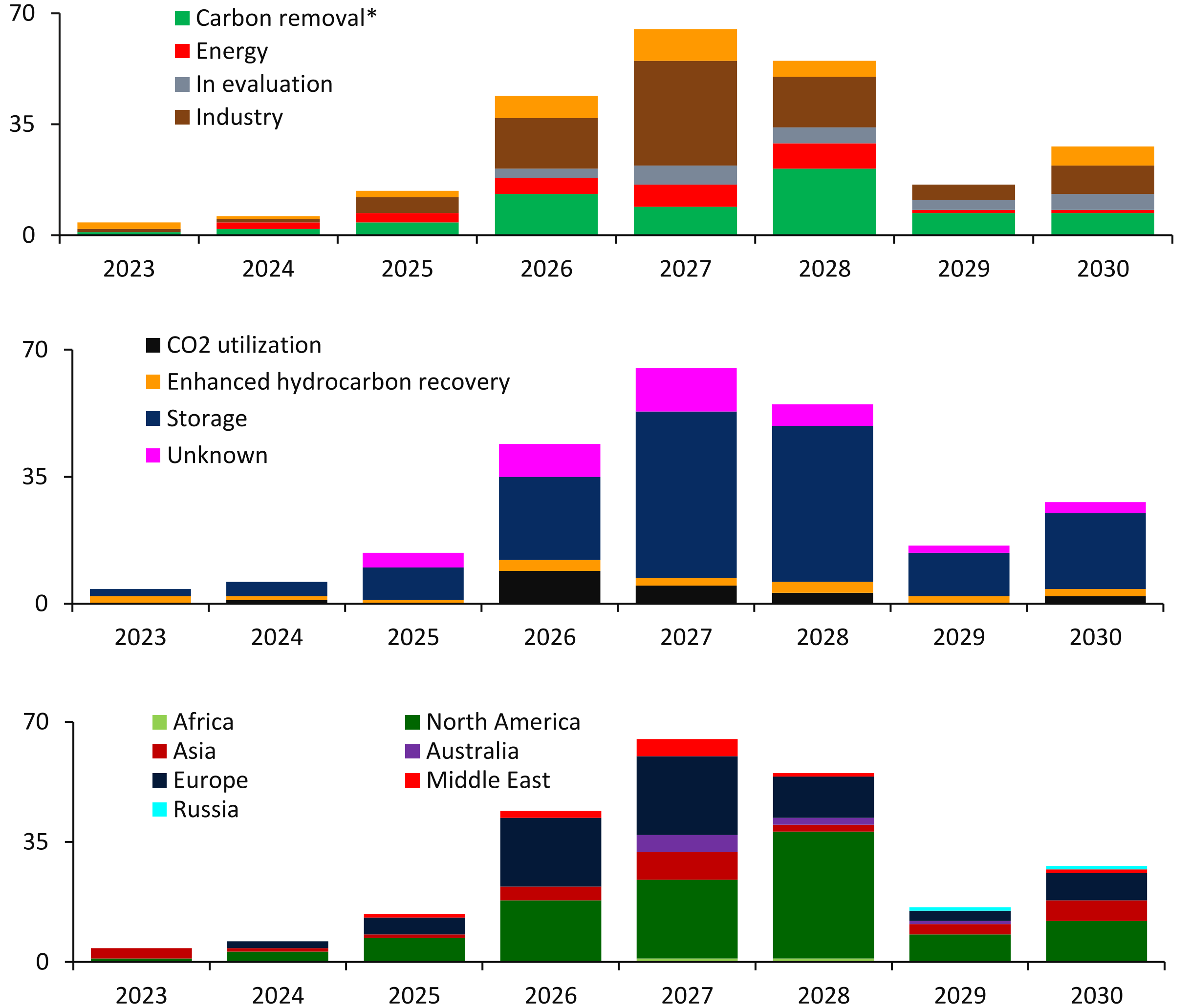
Industries continue to lead followed by a major surge in the power sector

Like in 2021, the industrial sector accounted for most new CCUS project announcements, led by blue hydrogen and ammonia. The demand increase for low-carbon hydrogen is facilitating the deployment of blue hydrogen projects (produced from natural gas coupled with CCS), especially in the US. However, many other hard-to-abate industrial fields, including cement, are also starting to adopt CCUS to abate CO_2 emissions. About 85% of such projects are in Western Europe, which has been at the forefront for funding schemes eyeing the cement sector.

The energy and power sectors have also seen notable growth, especially in the US and China, however not at the same pace as industry.

The power sector will remain an important part of the demand for CCUS to 2030, but as fossil fuels are replaced with renewables, industrial projects will grow faster amid the spike in demand for blue hydrogen or ammonia. On the other hand, the power sector throughout the world requires major decarbonization activity via CCUS especially for early-to-mid-life facilities.

Count and start-up year for the CCUS projects announced in 2022
Split by carbon source, offtake, and region



*Carbon removal entails BECCS, DAC
Source: Rystad Energy CCUS solution

Pilot CCUS projects pick up pace, focus on CO_2 utilization

Demand for carbon removal projects has increased over the past year, as regulations in North American and Europe emphasized their significance, in addition to carbon offsetting projects. Direct air capture (DAC) projects experienced close to 125% growth compared to 2021. Also, several collaborations covering carbon removal projects were announced in 2022, especially in the US. Companies like 1PointFive, Carbon Engineering, and Climeworks are accelerating DAC technologies to lower the overall levelized cost of CO_2 capture.

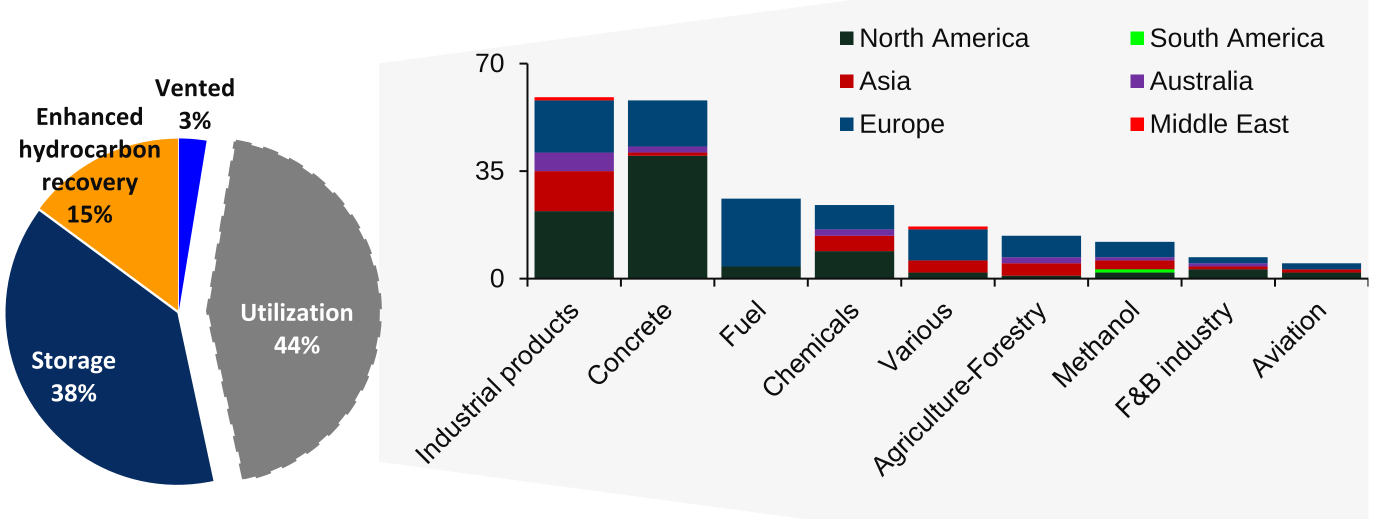
Besides commercial CCUS projects, we have also seen a ramp up in pilot project announcements. To reduce the cost and risk of implementing large-scale CCUS projects, countries are accelerating demonstration and research and development programs. Before venturing into a large-scale project, it is mandatory to test the viability of the emerging technology, and pilot projects are the first step. And as countries and companies progress with decarbonization targets, there has been a significant increase in the number of CCUS pilot programs in the past five years. At the end of 2022, we recorded a 65% year-on-year growth in new pilot projects. Several new countries started to take CCUS initiatives to combat climate change – including the first pilot CCS project in Egypt announced by Italian player Eni, and the first CCS pilot project in Hawaii led by Heimdall. Also, the first CCUS project in Greece for the cement industry at Titan Cement Group's Kamari plant will be led by Recodeh2020 partners. Oil company Repsol Sinopec will develop the first DAC facility in Brazil (also the first in South America).

A trend we observed is the association of pilot projects with CO_2 utilization – 44% of the total pilot projects in the pipeline at the end 2022 were industrial CO_2 utilization projects, with another 15% for enhanced hydrocarbon recovery.

The CO_2 utilization landscape across different verticals including concrete production, methanol, chemicals, industrial materials, and synthetic fuel industry, could be a viable source of revenue generation in addition to enhanced hydrocarbon recovery.

Although CO_2 utilization is in its infancy, it is likely to mature commercially as the technology advances this decade. At this stage, it is difficult to predict the timeline, but we don't expect any large commercial deployment of CO_2 utilization before 2030. Since the uptake of the utilization industry will also require key support from regulatory bodies through sufficient grants and policies, we expect this discussion will be kicked off soon.

Pilot CCUS project count by end-use (left) and region (right)



Source: Rystad Energy CCUS solution

Capture capacity ramps up to 2030

As 2022 has seen many project announcements, the expected global CO_2 capture capacity in 2030 has significantly increased from about 550 million tonnes per annum (Mtpa) in April to over 660 Mtpa at the end of 2022. This 20% increase is largely from the industrial sector (>200 Mtpa in 2030), as countries aim to tackle hard-to-abate emissions. There is also a significant proportion coming from hydrogen production (>90 Mtpa in 2030) largely from North America.

North America and Europe are expected to continue to dominate the global CCUS market, which has mainly been down to policy development throughout the year.

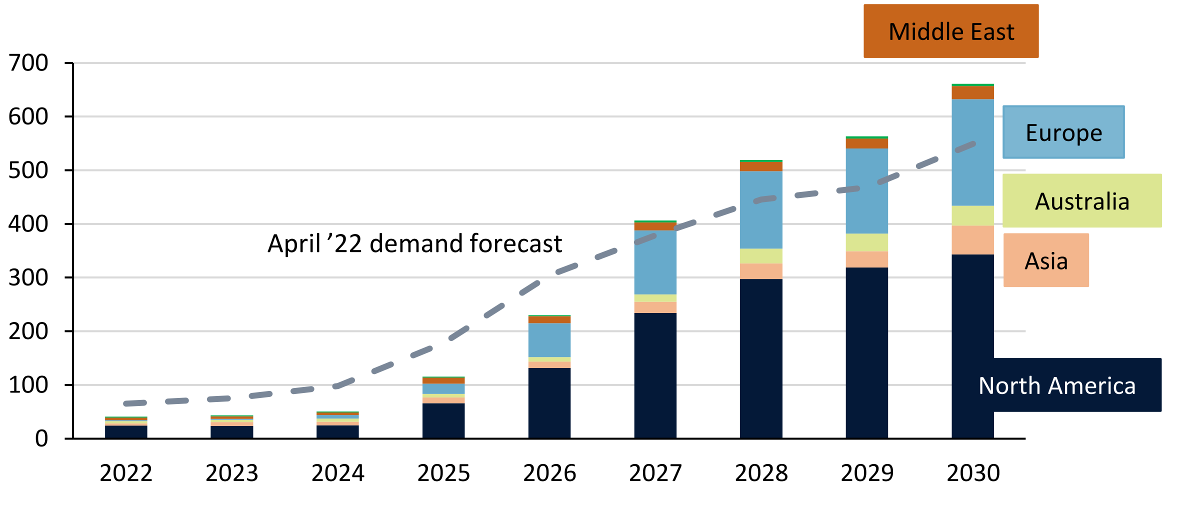
North America has seen quite a few project announcements since passing the Inflation Reduction Act in August 2022. Among the Act's many provisions was the enhancement of 45Q tax credits for carbon sequestration, raising values for CO_2 permanently stored and CO_2 stored for enhanced oil recovery (EOR) to $85/tonne and $60/tonne, respectively. Credit values for DAC were increased to $180/tonne of CO_2 permanently stored and $130/tonne of CO_2 used for EOR or other utilization. New provisions around 45Q tax credits, specifically as it relates to DAC, are helping projects pick up pace in the US as capture capacity requirements have been reduced. We expect this trend to continue, with further project announcements in the region with an increasing proportion of DAC projects.

As Europe has seen significant changes in climate policy throughout the year as well, there will likely be a push for further development and deployment of CCUS in the region. However, most projects are currently still in the planning stages, indicating that the focus will be on getting projects through the FID stage. Out of all current projects in the planning or under-development stage in Europe, about 28% are likely to face delays. This will most likely be due to a deferral in project development, such as the Barents Blue ammonia project. Nevertheless, throughout 2022, Europe made significant progress developing already announced CCUS projects.

Meanwhile, notable growth in the Asian-Pacific region is also expected. Many players are forming partnerships in the region, which if realized in 2023, would display substantial growth. This will largely be centered around multi-asset industrial hub projects. This will require significant government support and incentive, with carbon pricing playing a crucial role. Although the region has historically had low carbon pricing, the recently announced Malaysian CCS tax credit will create greater push in the region.

Capture demand outlook*

CO2 capture capacity (Mtpa)



*Based on announced commercial projects
Source: Rystad Energy research and analysis, CCUS Market dashboard

2030–2050 will be a critical time for climate scenarios

Although 2022 project announcements increased the capture capacity outlook for 2030 substantially and pose a positive outlook for CCUS, the current project pipeline is far from able to deliver on climate commitments. The current pipeline indicates a capture capacity of about 660 Mtpa by 2030.

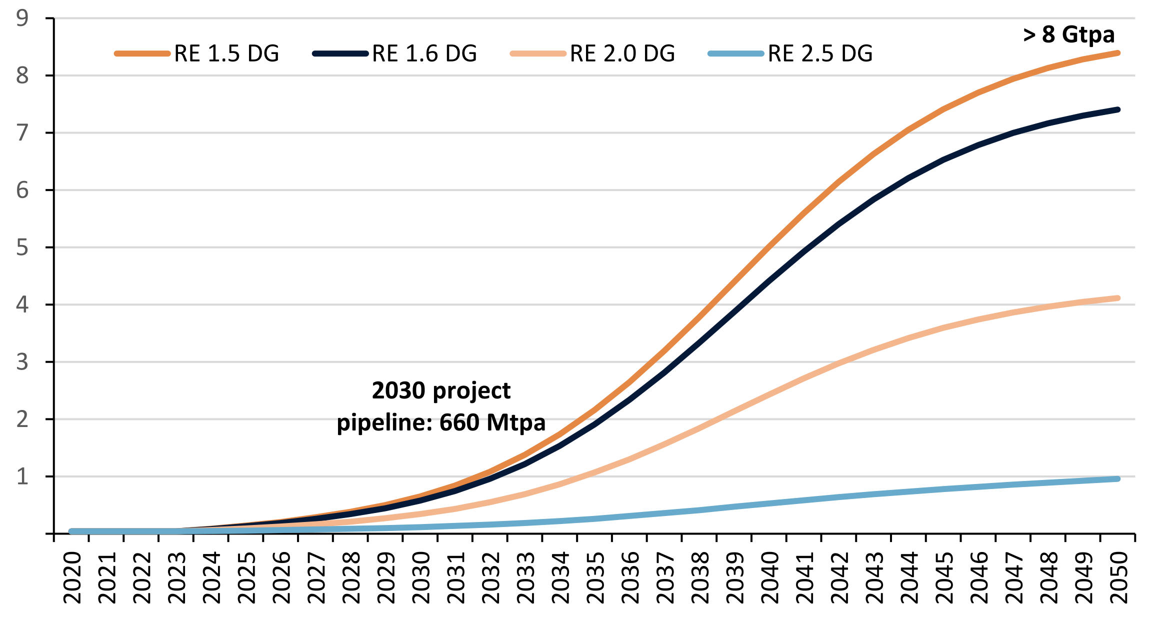
However, to remain within a 1.5-degrees Celsius (DG) scenario as targeted by the Paris Agreement, we estimate contributions from CCUS need to be about 8 gigatonnes per annum (Gtpa) by 2050. This primarily comes from the industrial and removal sectors, where removal includes DAC and BECCS. This creates more than a 7 Gt gap between 2030 and 2050.

This gap, although daunting, is still within reach. Our estimates show, based on the s-curve nature of technological distributions, that the required capture capacity in a 1.5-degree scenario is about 578 Mtpa by 2030. This indicates that the current project pipeline to 2030 is already 14% higher than necessary estimates without considering potential cancellation and delays. However, to see this gap realized, requires rapid deployment of CCUS between 2030 and 2050, including the development of large-scale multi-asset cluster projects. Rapid deployment of CCUS will also require substantial capital. The need for increased government investment as well as private financing will not only be necessary for deployment, but also for the development of new technologies that could significantly lower overall costs. We estimates that 19% of global steel will be produced using CCUS in 2035 capturing 360 million tonnes of CO2 annually. As for cement industry, we estimate that 1.1 Gt of CO_2 will be captured using CCUS by 2050.

A 1.5-DG vision is still alive, but as we move into the 2030s, countries need to double down on climate action to close the gap, specifically narrowing in on industries that struggle to deal with their emissions. Carbon removal technologies will also need increased support, as negative emissions technologies will help to remain within carbon budgets.

Supportive policies have been slow to kick off and without picking up the pace, governments risk making 1.5-degrees Celsius a lost cause.

Capture demand outlook
CO2 capture capacity (Gtpa)



Source: Rystad Energy research and analysis

The next CCUS cluster projects have global reach

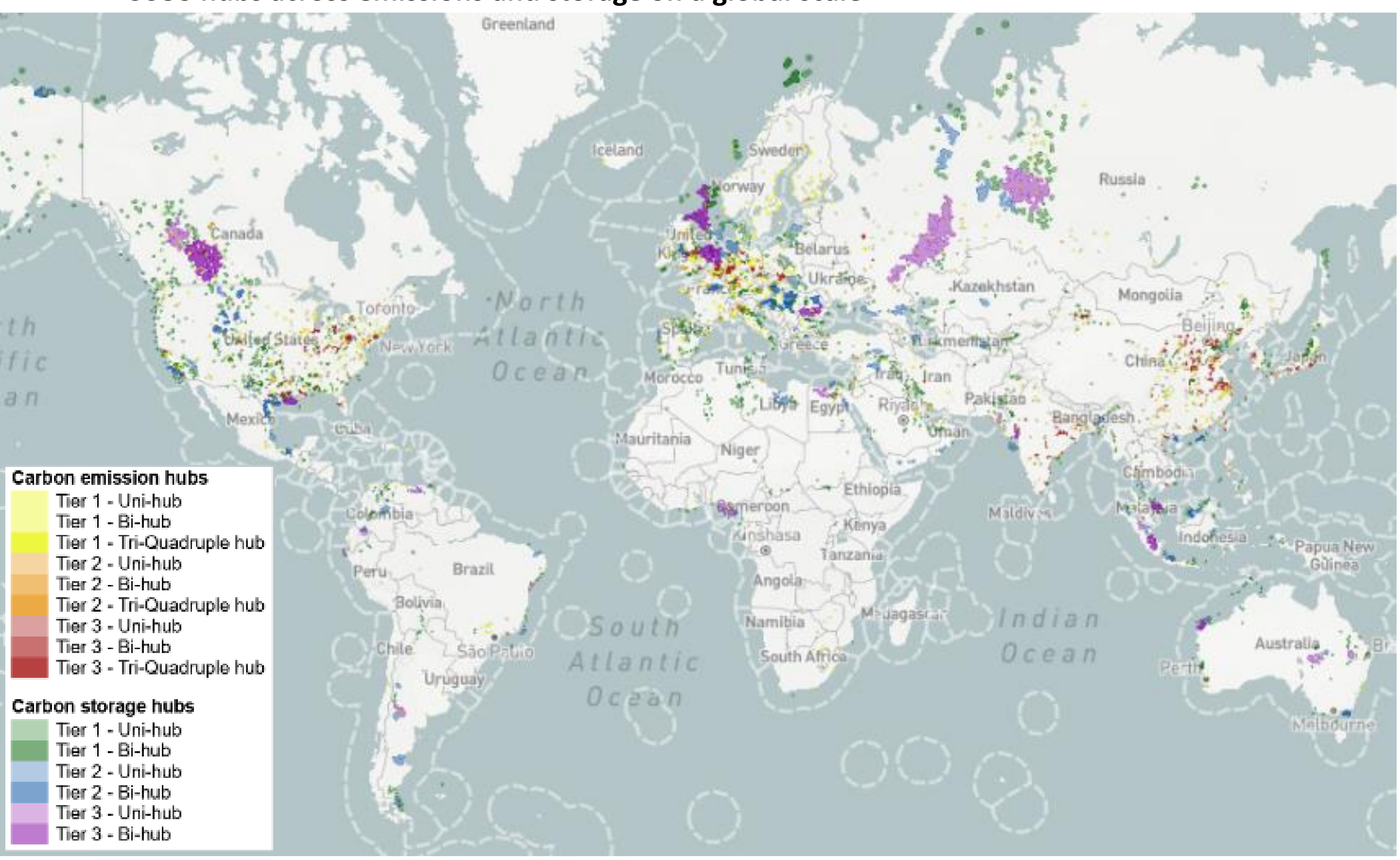
In order to close the gap towards 2050, cluster projects play a major role in accelerating the deployment of CCUS technology across the globe. Rystad Energy has developed an in-house tool leveraging the existence of emissions point source data and CO_2 storage potential across oil-gas fields and saline aquifers to build a CCUS hub tool that can be utilized to identify potential favorable locations for upcoming CCS projects across the world for same-country or cross-border CCUS ventures.

The tool has been built based on certain screening parameters superimposed on the assets which have been categorized into multiple levels across various tiers, giving users the ability to select from a variety of options while planning upcoming project.

For emission hubs, there are nine categories to choose from a combination of Tier 1, Tier 2, Tier 3 and Uni hub, Bi Hub and Tri-Quadruple hub. While the Tier classification is based on the total emissions within a radius of 10 kilometers, filtered by country, Hub types are based on the type of emission sectors within each Tier.
For storage hubs, we have established six categories from a combination Tier 1,2,3 and Uni hub and Bi Hub.

While the tier classification is based on the number of storage assets within a radius of 25 km filtered by country, Hub types are based on the type of storage. The output for both emissions and storage hubs presents polygonal structures color distinguished based on the category it entails into.

CCUS hubs across emissions and storage on a global scale



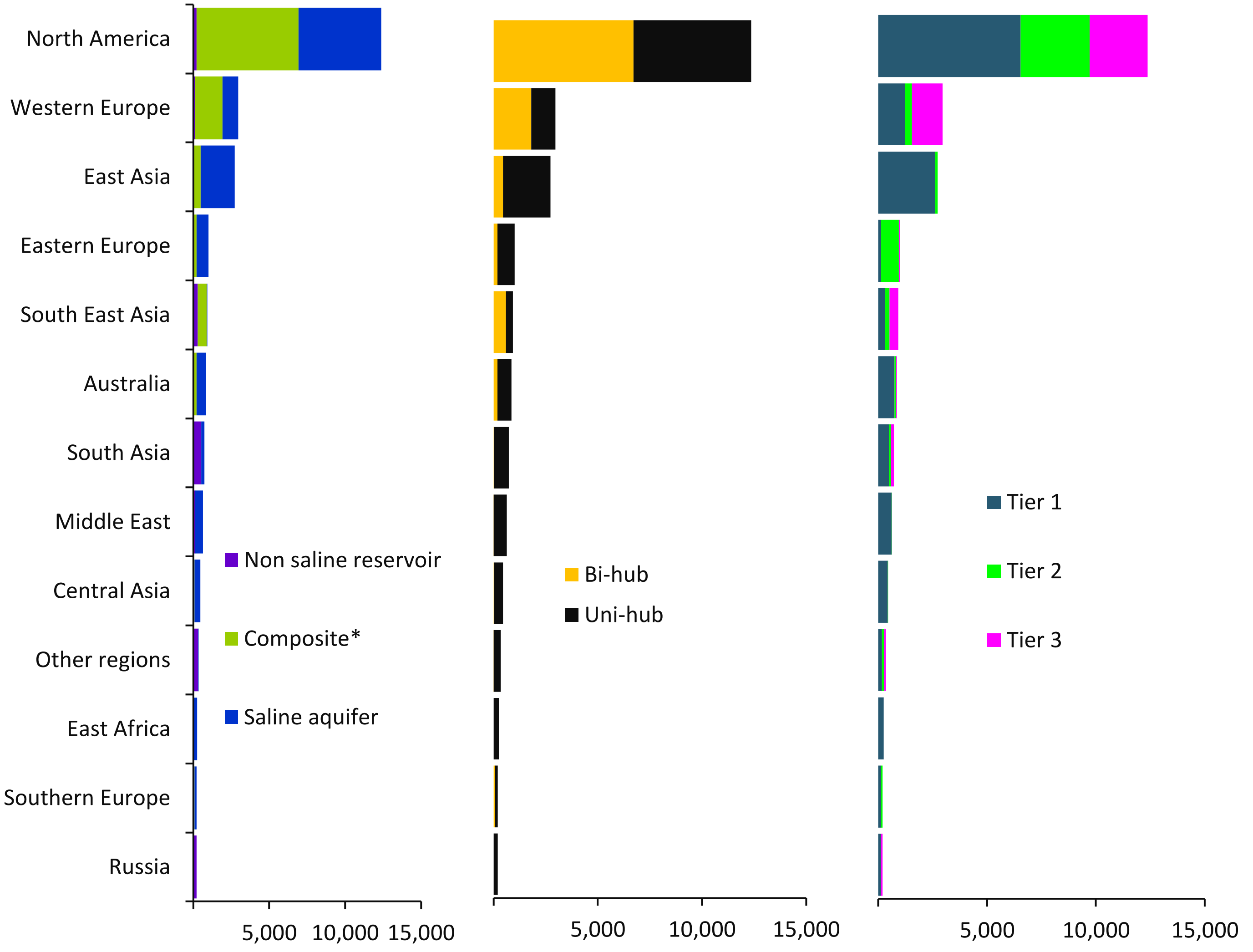
Source: Rystad Energy CCUS solution

North America leads CCUS hubs

Analyzing the CO_2 storage hub model, North America, West Europe and East Asia emerge with the highest number of hub assets. This is due to the presence of already identified and well-researched extensive saline aquifer horizons in addition to a flurry of oil-gas fields suitable for CO_2 storage. Saline aquifers have huge CO_2 storage capacity, thus giving these three regions an upper hand when it comes to hosting most of the suitable hubs across different tiers. Its also why a good proportion of bi-hubs are found here – while other regions are dominated by Uni-hubs on the back of oil-gas fields.

Based on the requirement of a CCS project, different types of storage hubs can be combined or individually leveraged for upcoming cross border or same country project ventures.

Benchmarking regional storage hubs by storage type, hub category and tier classification
Gigatonnes



Note: Combination of the two types of storage – oil-gas fields and saline aquifer
Source: Rystad Energy CCUS solution

Maintaining carbon budgets demands negative emissions

Current short-term forecasts for fossil fuel emissions are substantially above those set out by the International Energy Agency (IEA) in its Net Zero Emissions case, and most new energy initiatives are not set to deliver net zero by 2050. Carbon emissions from fossil fuels, despite declining in 2020, rebounded strongly after the Covid-19 pandemic and the war in Ukraine. Fossil fuel consumption is increasing in the near-term causing carbon budgets to become increasingly strained.

The current energy crunch resulted in binding decisions in favor of fossil fuels. Germany's RWE, for example, announced the dismantling of a wind farm to mine more lignite from its open pit at Garzweiler. This followed a decision to reactivate three coal-fired power stations in September 2022.

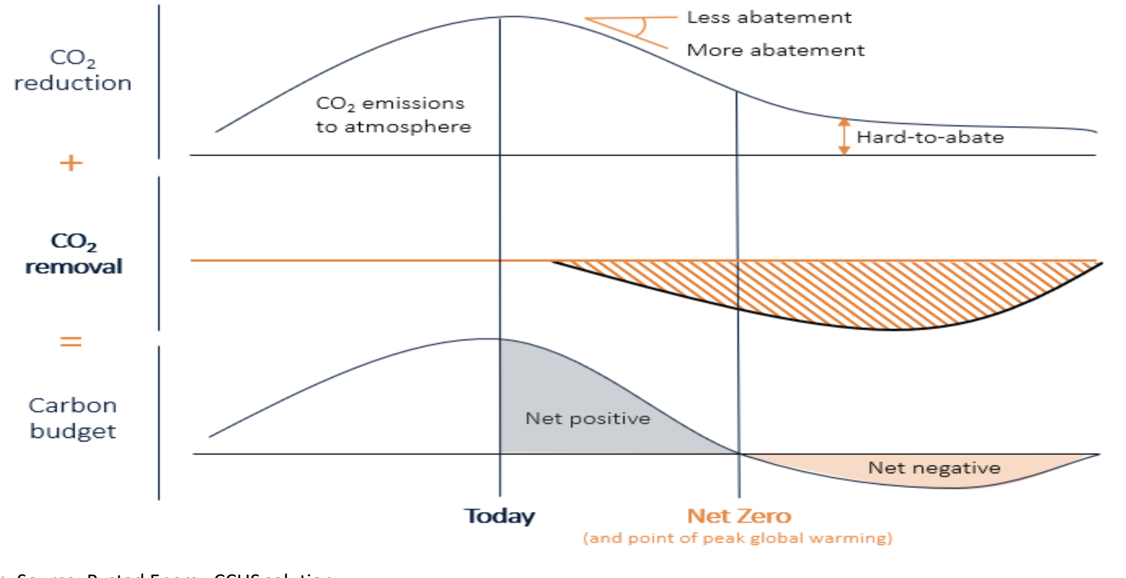
LNG, which is typically much more emissions-intensive than piped gas, is now balancing Europe's gas supply following shut-offs from Russia. China is still adding more coal-fired capacity, contrary to its government's previous statements on reduced coal use by 2026. These are all binding decisions in favor of fossil fuels, further increasing the demand for negative emissions.

Moving towards decade-end and beyond, our analysis suggests the world needs to double down on climate action or risk making 1.5°C a lost cause. The window of opportunity to remain below 2°C global temperature increase is also closing and therefore negative emissions solutions become increasingly necessary. To achieve net zero, a step-change on multiple fronts is required. Wind and solar need to maintain strong growth rates to hit 2030 targets. Hydrogen production needs to increase tenfold while the current CCUS capacity needs significant development. The total need for CCUS is critical in changing the gradient of the current emissions trajectory. As the world is trailing its targets, there is an increasing need for carbon removal and/or drastic emissions reductions.

Increased call on negative emissions

The total amount of CO_2 released into the atmosphere directly contributes to global warming. One year's overshoot must be met with additional removal. Simply put, the longer the delay in reducing emissions, the higher the call for carbon removal. Carbon removals can be seen as deleting historic emissions to meet future emissions targets, but the result is the same – carbon is taken out of the atmosphere, resulting in a negative effect on the overall carbon budget.

Key concepts and terminology for carbon abatement and removal



Source: Rystad Energy CCUS solution

Clean hydrogen supply continues to grow but lags climate targets

In 2022, announcements for hydrogen and derivatives kept almost the same pace as in 2021, adding 22.5 million tonnes to the overall pipeline versus nearly 26 million tonnes in 2021. Green hydrogen dominated again, accounting for 87% of the announced capacity, with little movement from other production methods such as methane pyrolysis amid a wild natural gas market. Natural gas prices in Europe also pushed fossil-based hydrogen production to extreme highs – up to $14/kg from the usual level of $1-$2/kg of H_2 in past years – making hydrogen from renewable electrolysis competitive for the first time in recent years.

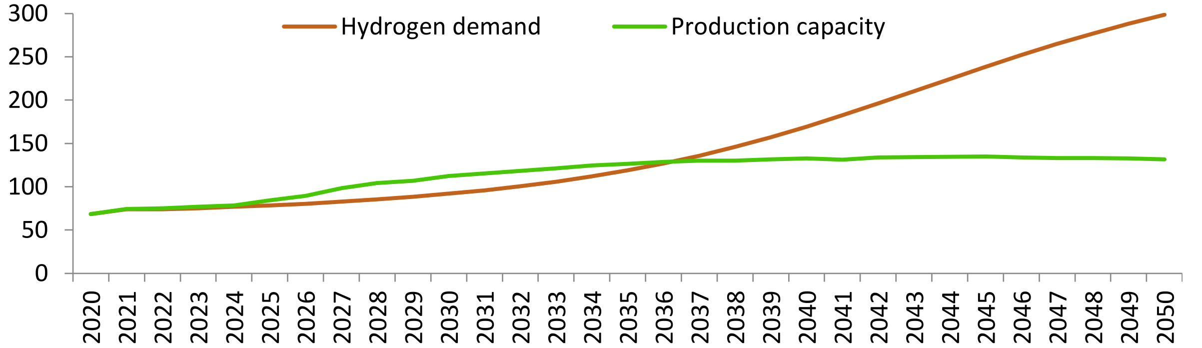
Movement on the hydrogen demand side shows progress and development, from shipping industries to steel production and other uses. While talks around hydrogen use in residential heating are cooling down, momentum picked up again for hydrogen-fueled heavy-duty transport use.

Our mean case for reaching carbon neutrality continues to expect a hydrogen demand level of about 300 million tonnes by 2050. The sum of all existing gray hydrogen production plus the announcements for clean hydrogen capacity indicate an oversupply of hydrogen from 2025 – but this is unlikely to be the reality because this additional capacity will be looking to replace existing gray hydrogen production (as corporations eye asset decarbonization). In fact, most planned offtake for clean hydrogen projects will be used in refineries and fertilizers industries, which combined have a current demand of more than 70 million tonnes of hydrogen.

Significant under-supply is expected after 2035, however, as the current clean hydrogen production capacity is only one fifth of what is required by many national and regional carbon targets. Electrolysis and fossil-based are not the only way to produce hydrogen, and in 2023, research and development of alternative hydrogen production methods is gaining grounds – microbial, hydrolysis, photocatalysis all showing progress.

Nevertheless, policy is still key to enable future clean hydrogen uptake, and 2022 has been a great year for this, with even more advanced developments expected in 2023. Energy security came to the forefront as one of the drivers of the hydrogen economy, pushing big targets for renewable hydrogen in the RePowerEU plan from the European Commission. The US, meanwhile, is the one shaking up the industry with strong business incentives for low carbon hydrogen in the form of tax credits under its Inflation Reduction Act. Europe will swing back in 2023 though, with the European Hydrogen Bank, H2Global and other incentives in the UK.

Global hydrogen demand and supply balance, projects announced by January 2023
Million tonnes of hydrogen



Source: Rystad Energy research and analysis

Countries commit to national hydrogen strategies

Governments in Europe continue to increase support for green hydrogen production.

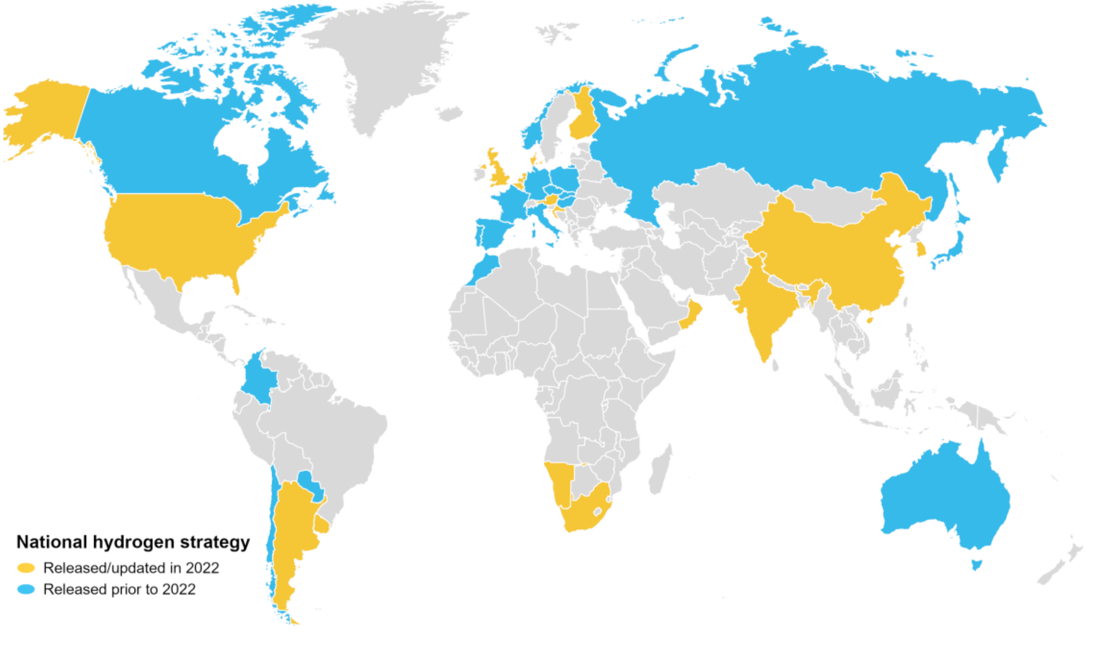
In early 2022, the Dutch government announced that €13 billion will be devoted to renewable energy projects through its SDE++ scheme which, for the first time, will include green hydrogen projects. Denmark aims to build between 4 and 6 gigawatts (GW) of electrolyzer capacity by 2030, producing green hydrogen and e-fuels mainly for decarbonizing hard-to-abate sectors (shipping and aviation). On the other hand, Spain is expected to increase its 2030 target from 4 GW to match the current pipeline of about 17 GW.

However, not only European countries are devoted to green hydrogen production. Published in 2022, the South African Hydrogen Society Roadmap outlined several targets for South Africa, such as the deployment of 11.7 GW of electrolyzers by 2030.

China, meanwhile, set a target of producing between 100,000 and 200,000 tonnes per year (tpa) by 2025 as it unveiled its new hydrogen strategy. South Korea announced a new set of hydrogen economy policies, with a clean hydrogen target of 7.1% of its energy mix by 2036.

In total, 36 countries have now released a hydrogen strategy (by 2022), increasing from 24 (by 2021). Also, five countries updated their strategies in 2022, with the likes of Belgium and South Korea setting new national targets. Moving into 2023, the total number of national hydrogen strategies is expected to increase, as countries like Brazil, Ecuador and Greece prepare their strategies. These strategies have a combination of targets for both the production and application of hydrogen, with industry use and mobility dominating the latter.

17 countries released a new hydrogen strategy in 2022



Note: Belgium, China, Netherlands, South Korea and UK updated strategy in 2022
Source: Rystad Energy research and analysis

Global picture – regional breakdown for our 2030 forecast

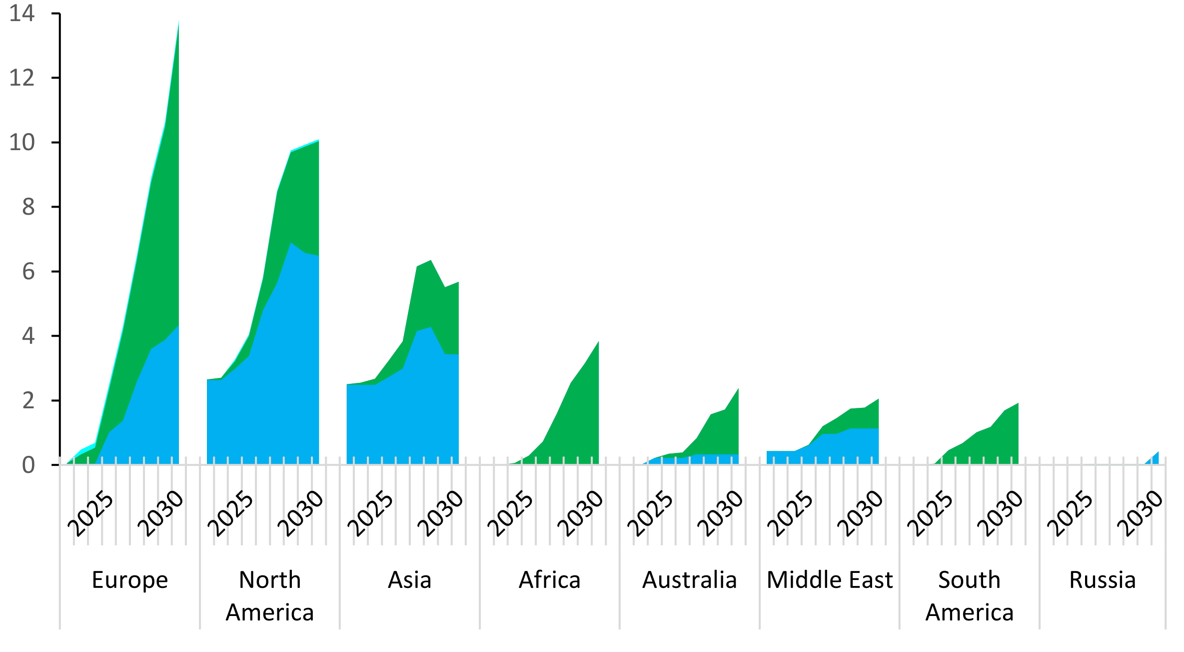
Globally, Europe and North America lead the way for supply of clean hydrogen by 2030. Of the almost 700 announced projects globally, producing around 40 million tpa in 2030, the supply in Europe and North America will account for more than half - around 24 million tpa at the end of the decade. Most of the clean hydrogen production in Europe is green, particularly due to the great offshore wind conditions off the west coast. Blue hydrogen production in Europe will predominantly occur in the UK, Netherlands and Germany, with the CO_2 being stored in the North Sea region.

In total, Europe has about 14 million tpa of clean hydrogen in the pipeline by 2030, 38% above the domestic production target set through REPowerEU. However, as the aim of REPowerEU is to move away from natural gas dependency, the blue hydrogen capacity will not count towards this target, which is exclusively set for green hydrogen. EU's green pipeline is sitting at 9.2 million tonnes by 2030, only 0.8 million tonnes shy of reaching their target. It is important to note that the degree of realisticity associated with this pipeline is subject to the scale up in FIDs over the next few years . For now, the pipeline indicates that North America bets on blue hydrogen, backed by the large number of CO_2 storage assets in the project pipeline in the US and Canada. However, due to direct subsidies placed on green hydrogen production via 2022 Inflation Reduction Act, we expect that there will be a significant uptick in green US production in the near term.

Regions with the best resource potential for good project economics, namely Africa and the middle east, are seen as the emerging green hydrogen production regions in the world. Projects utilizing the unique solar and wind conditions can outperform other regions on cost due to high utilization rates – from producing below 0.01 million tpa green hydrogen today, Africa is expected to produce close to 4 million tpa by 2030 with the current pipeline.

As for Asia, the highest demand region, we expect both green and blue hydrogen to be produced in the coming years. A large portion of the added blue hydrogen will come from repurposing the Jamnagar oil refinery in India, which is the largest oil refinery in the world.

Announced hydrogen production capacity by region – 2022-2030
Million tonnes



Source: Rystad Energy HydrogenCube

Project announcements continue at the same rate as in 2021, and expected to rise in 2023

There were 242 projects announced in 2022, adding approximately 22.5 million tonnes to the project pipeline. Out of this, 64% have hydrogen as end-product with a production capacity of 11 million tonnes, 25% have ammonia as end-product, and 9.2 million tonnes will be converted to ammonia. The rest of the announcements look to make methanol and synthetic fuel after producing hydrogen.

As the industry waits for policy implementation guidelines, we see an increase in hydrogen project announcements but a decrease in large-scale projects in 2022 vs 2021. However, we note that the biggest announcement ever for hydrogen came in 2022 with Spirit of Scotia, which is planning to add 500 GW of electrolyzer and 43 million tonnes of hydrogen. Realistically, given the scale and track record of the developer, we believe a maximum of 100 GW can be installed before 2050.

As things stand at the end of 2022, green hydrogen is positioned to cover 83% of the market share by 2050, totaling 55 million tpa, whereas blue hydrogen will have 17% (at 12 million tpa). Notably, on the blue hydrogen side, Reliance Industries announced the largest project last year at one of its refineries, expecting to produce around 1.1 million tpa. In addition, ExxonMobil announced a 0.9 million tpa project in Baytown, US.

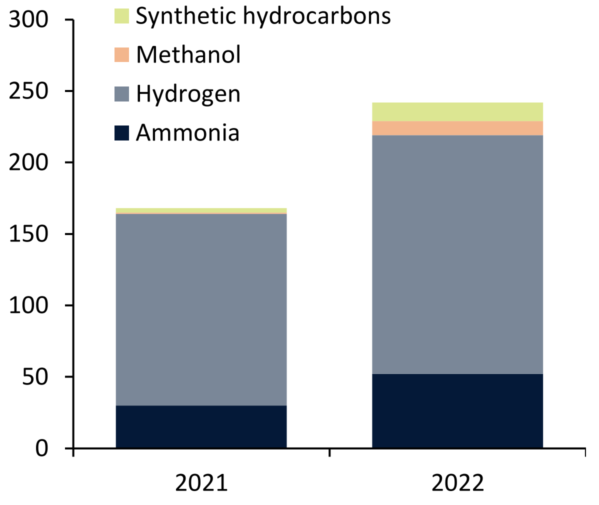
With the policy clarity expected in 2023, we anticipate the same announcement rate for new projects, with even higher proportions aiming towards synthetic fuels as offtake.

Besides the announcement wave, some of the top 10 projects in 2021 moved into advanced stages in 2022. Sinopec Qilu Petrochemical CCS project which has capacity to produce 70,000 tonnes of blue hydrogen per year entered operational phase. Al Wusta Hydrogen (Electrolyzer based) phase 1 asset, expected to produce 100,000 green ammonia per annum in Oman, was approved.

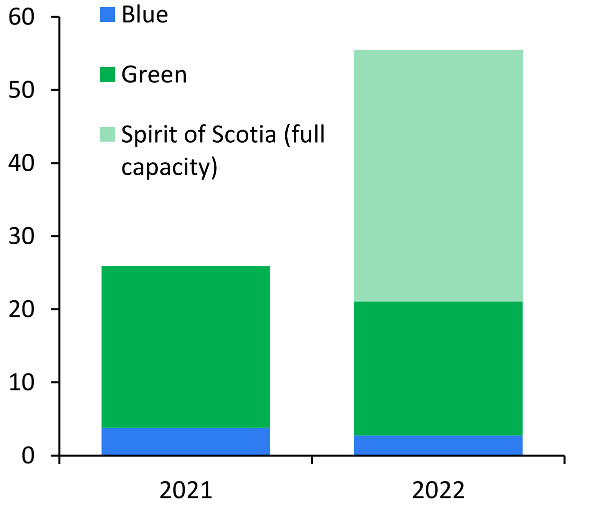
In addition, the Abu Dhabi Blue Hydrogen CCS project with a capacity of 1 million tpa entered the preliminary engineering and FEED study stage.

Project announcements by end-product (left) and total capacity announced (right)

Count of projects



Million tonnes (Mt)



Source: Rystad Energy HydrogenCube

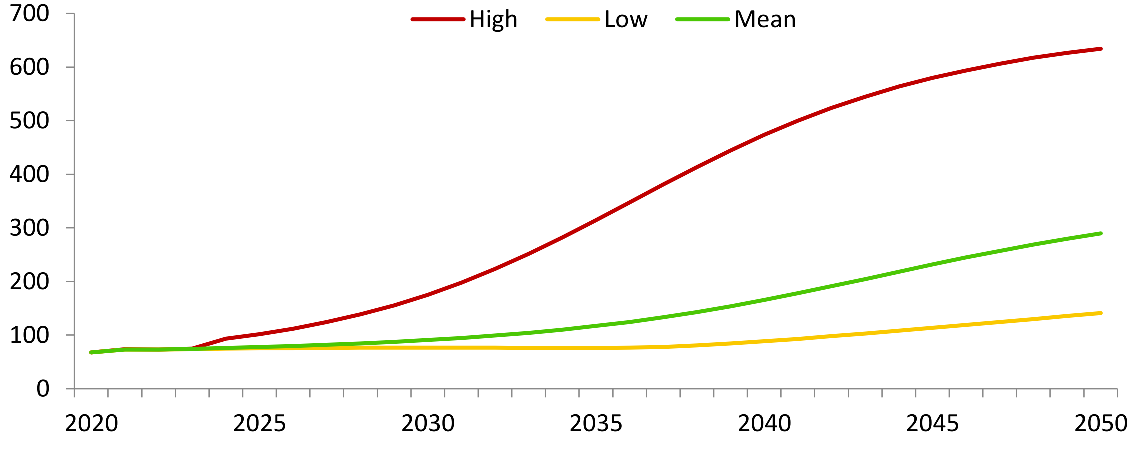
Hydrogen future demand revised following latest market developments

Rystad Energy yearly revision of the hydrogen demand model suggests a lower uptake of hydrogen in the High and Low scenarios into 2050, with minor changes observed for the Mean scenario.

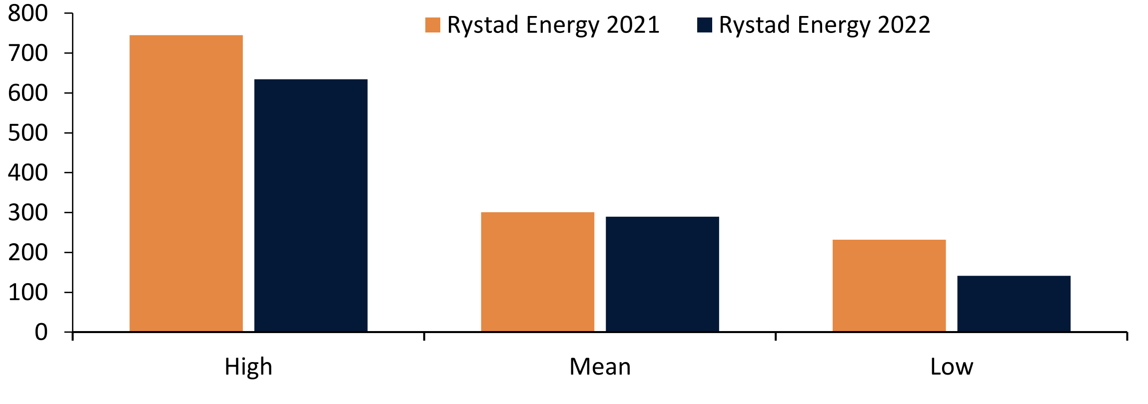
In this 2022 revision, High case of hydrogen demand will pick up rapidly from 2025 across all segments, reaching toward 630 million tpa by 2050 – a decrease of some 150 million tonnes compared to our demand in 2021. The Mean case hovers just under 290 million tonnes in 2050, remaining somewhat unchanged in overall value, albeit a bit different share to some segments. Low case comes in at 140 million tonnes by 2050, a reduction of almost 90 million tpa compared to 2021 revision.

Last year brought more clarity and research in hydrogen use in various sectors. Particularly, residential heating is unlikely to be a big contributor due to strong competition from the adoption of heat pumps. Road transport (heavy duty transport) has also been cut in the high case.

Hydrogen demand scenarios from Rystad Energy's 2022 revision
Million tonnes



Hydrogen 2050 demand differences between Rystad Energy's yearly revision
Million tonnes



Source: Rystad Energy HydrogenCube

The deciding factor for hydrogen demand lies in a few use cases

To focus more on what has changed in the demand mix for hydrogen, we look at the Mean case.

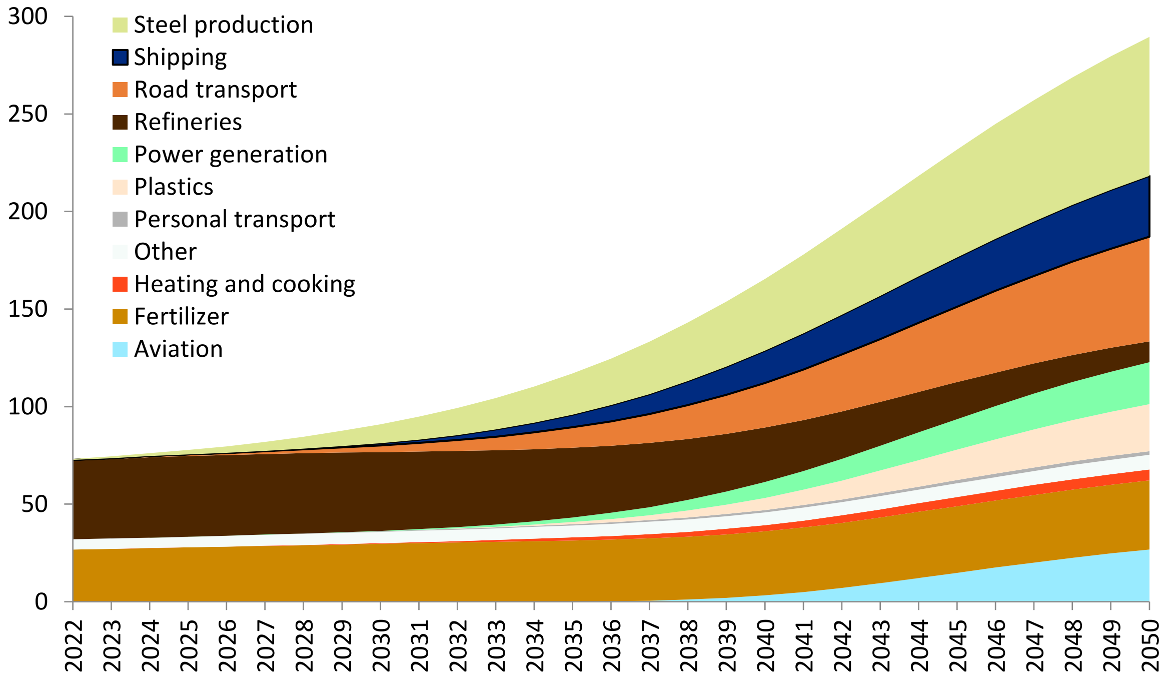
In the 2022 revision, the mean case has two changes, the increase in road transport (heavy duty transport, trains) demand and the reduction in residential heating and cooking use. While there are still plans in some countries and regions such as the UK for hydrogen heating, there are other alternative technologies such as heat pumps that will likely be prioritized going forward for most other places in the world.

With respect to road transport, 2022 sees more hydrogen trucks ordered as well as planned around the world. For instance, in China, Sinotruck and Weichai have received an order of 1,100 trucks whereas Hyundai is looking to deliver 4,000 trucks by 2025. Our recent study shows that hydrogen trucks will be the more economical option once the price of hydrogen is in the range of around $5/kg at the pump. Trains, heavy goods transport and mining vehicles also play into this demand group, and 2022 has seen more development for hydrogen trains across Europe (Germany, Czech Republic, Netherlands) and India.

Other demand categories look to stay on track with more advances in development in 2022. More approval in principle were granted for ammonia bunkering vessels and terminals for NYK, K Line, MOL, Keppel, and Azane.

Hydrogen-based steel making also had a strong 2022 with more top steel makers completing demonstration, trial and announcing billion-dollar investment.

Hydrogen demand outlook at mean case demand scenario – RE 2022 revision
Megatonnes



Source: Rystad Energy Hydrogen Cube

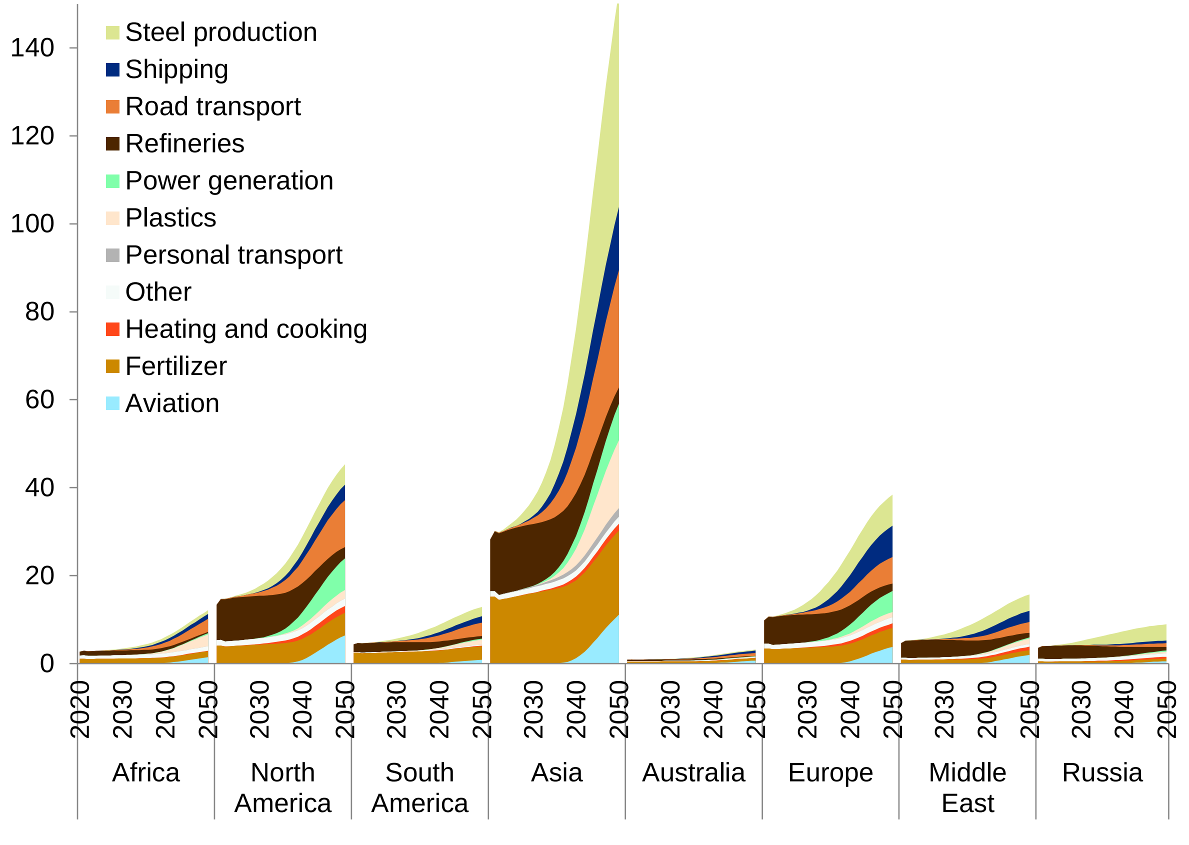
Asia, Europe and North America drive demand outlook

Asia shows the strongest demand for hydrogen into 2050 if carbon targets are to be achieved. Heavy industries in China and India contribute heavily to this demand, which is likely to be matched by domestic supply. Within Asia, Japan and South Korea will likely meet the expected hydrogen demand from imports and hydrogen derivatives.

Europe and North America are closely matched in second and third place, respectively. As expected from current industries, the demand mix of North America and Europe will be different, with Europe being the more diverse market for potential hydrogen applications. Europe will also be another main importing market and is already gearing up for it with plans under the REPowerEU and corporate plans from Uniper, E.ON or RWE. Most other regions do not have as strong a demand for hydrogen from the current make up of their industries. With the strong renewable resources available in Australia, Africa, South America, Middle East, all the projects being planned in these regions are geared for exporting hydrogen. There is also a potential for a global supply chain rearrangement which can shift demand around.

There is a growing case for this, given long-distance transportation of hydrogen is still challenging, which means getting cheaper low to zero-carbon hydrogen to where it will be used is difficult. Iron making is one of these cases, with recent billion-dollar MoU set up between Posco and Australia to produce hot briquetted iron (HBI) from DRI process to Australia.

Hydrogen demand for mean scenario at various continents
Million tonnes



Source: Rystad Energy Hydrogen Cube

Ammonia demand set to more than double by 2050

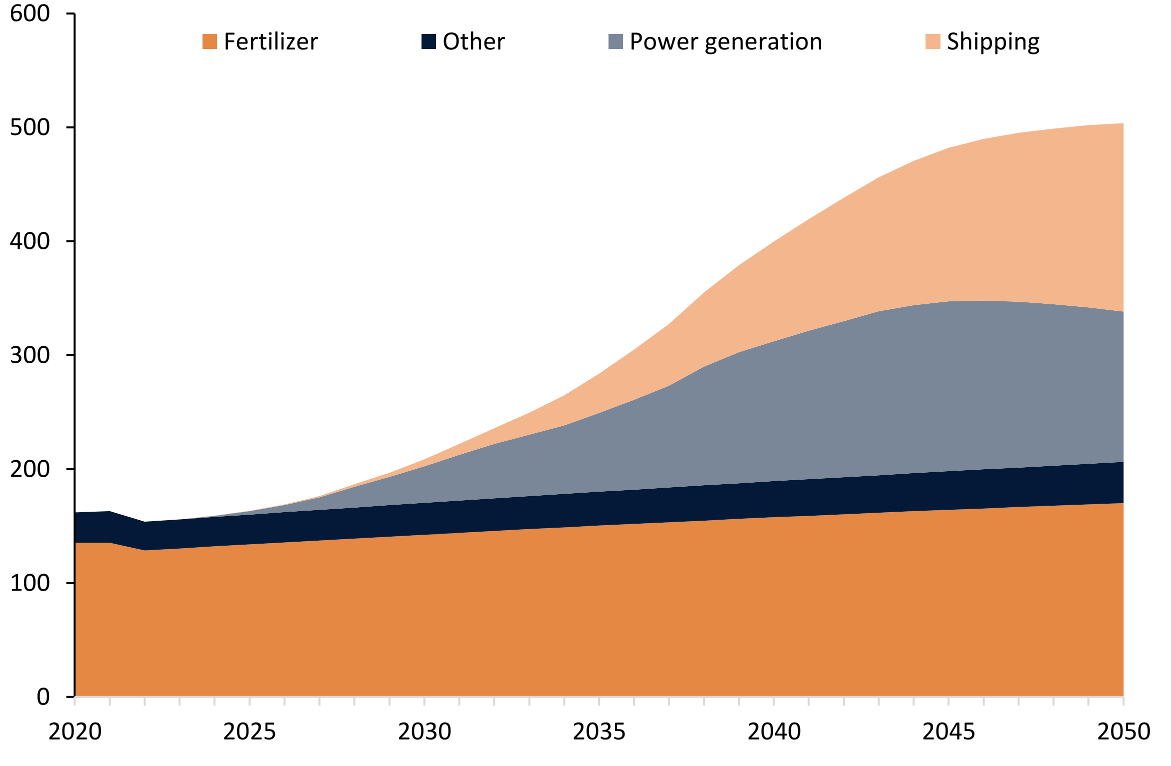
Ammonia will be one of the key derivatives of hydrogen, contributing to hydrogen applications in many key demand sectors. Currently, a considerable amount of hydrogen is used to make ammonia as a pre-cursor for nitrogen fertilizers, which makes up around 130 million tonnes of ammonia demand. Around 25 million tonnes of ammonia is then required for other chemical use, including textiles and industrial explosives. Both these categories will continue to grow into the future as global population increase.

However, the growth rate for these demand segments will not be as much as seen previously in the 1980s and 1990s as population has plateaued in most countries and population-control education has improved in others. Furthermore, alternative food sources such as lab-based food or fermentation could prove to play a bigger role in the future.

Post-2025, ammonia will gain new demand segments in shipping and power generation that can grow to be as big, if not bigger than demand for fertilizer making. Last year saw more development in ammonia-coal co-firing in Asia. Supported by (climate) targets in Japan and South Korea, Japanese companies have started to reach out to regional governments and to coal-plant operators across Asia to trial the technology in places such as Indonesia, Malaysia, China and even India.

This could present a pathway for these young coal power plants to reduce their emissions. Ammonia as a marine fuel continues to gain traction with multiple approval in principle for bunkering solutions and up to 130 ammonia-ready vessels ordered.

Ammonia demand by demand segments to 2050
Million tonnes



Source: Rystad Energy Hydrogen Cube

Methanol demand to surge - shipping main growth segment up to 2030

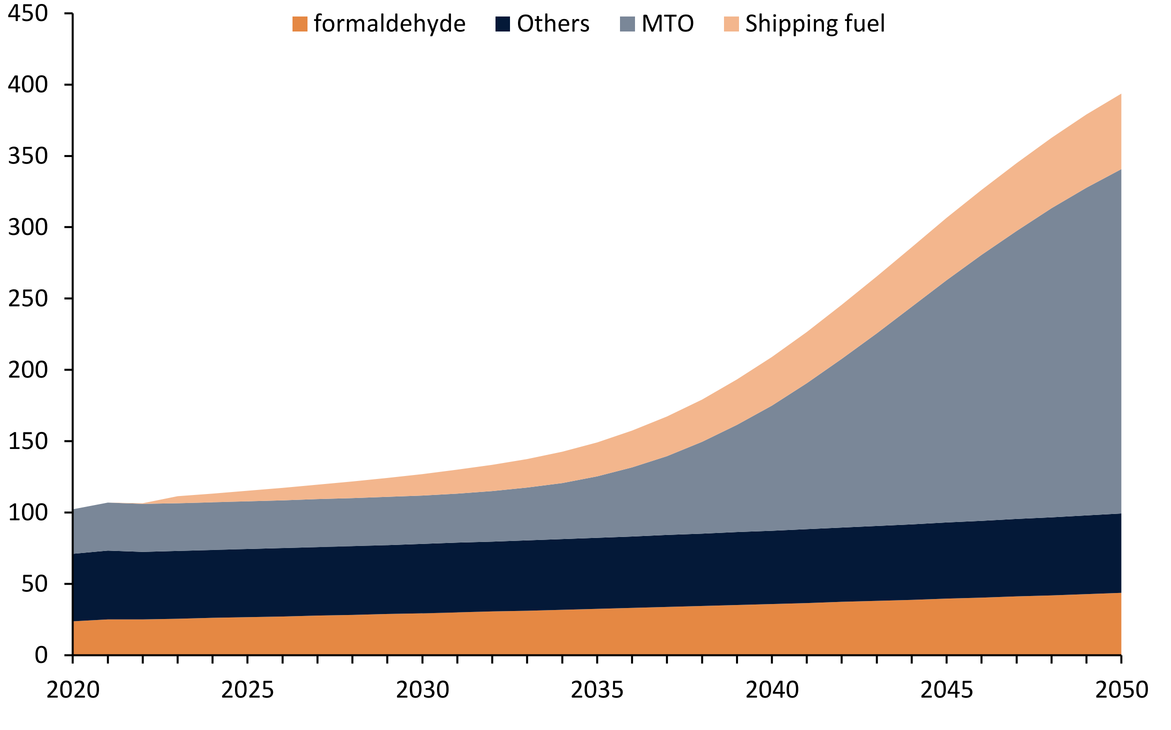
Methanol is another hydrogen derivative gaining traction and supporting the energy transition outside of its current main applications in the chemical industries. Two of the most important uses of methanol in the context of energy transition will be as an alternative fuel for the shipping industry and as a pre-cursors for High Value Chemicals (HVCs) for plastic making.

Methanol has already been used as fuel on cruise ships and the package to convert existing ships to operate on methanol is relatively simple. This led some of the premier ship makers to use methanol as a short-term solution to reduce emissions. Regarding plastics, methanol has also been widely used in China in the Methanol-to-Olefins (MTO) technologies to derive ethylene, polyethylene to feed plastics production.

While Methanol-to-Aromatics is still developing, deriving plastic precursors from methanol can help reduce emissions from oil and gas production and refining.

However, it is crucial in all methanol use case that the carbon dioxide used in methanol synthesis be regulated, to be either biogenic or from Direct-Air-Capture. Cost will be a challenge as not only low-carbon hydrogen costs but also carbon dioxide costs need to come down.

Methanol demand by demand segments to 2050
Million tonnes



Source: Rystad Energy Hydrogen Cube

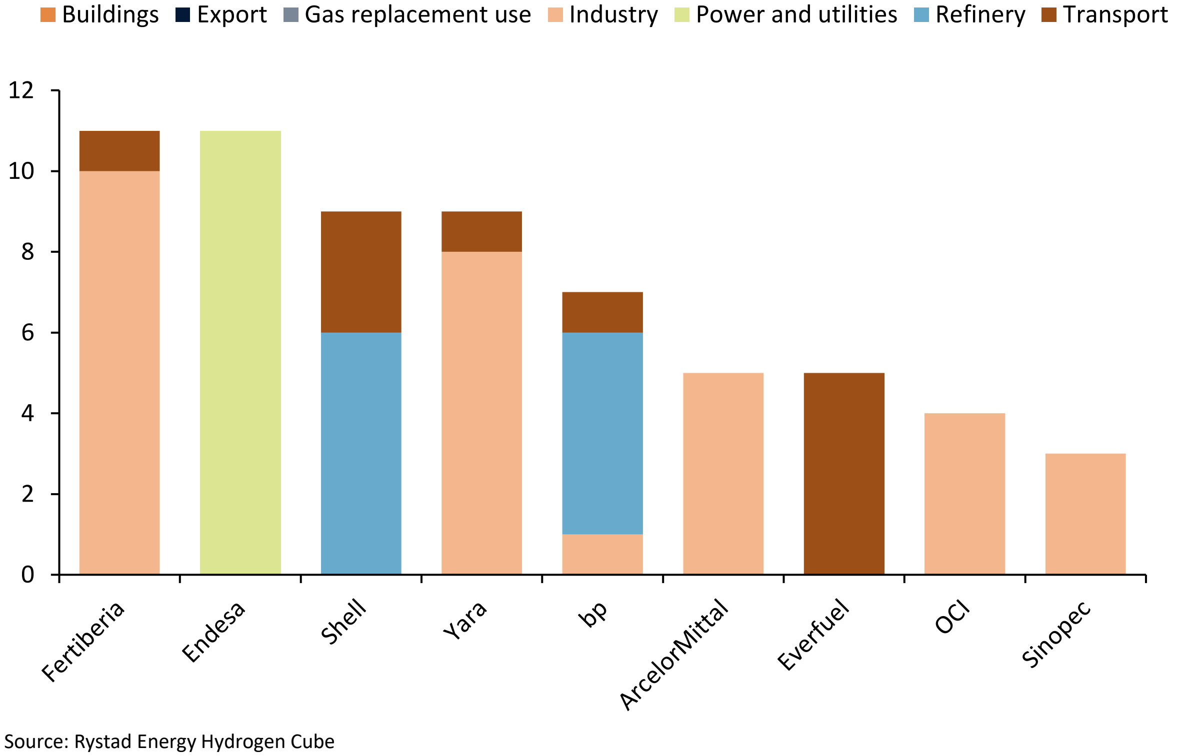
Industry is the key offtake sector

Offtakers for clean hydrogen and its derivatives started to grow in 2022, as observed across all demand segments.

Most of the offtakers are companies looking to decarbonize their own assets and hence, looking to use clean hydrogen to replace the existing gray hydrogen supply. For example, Fertiberia and Yara have numerous plans to produce green ammonia for their fertilizers while Shell and BP are looking to decarbonize refineries using renewable hydrogen. These use case also trigger most of the advancements seen in clean hydrogen projects with FIDs, and construction and commissioning (observed across many assets like Fertiberia's Puertollano, Shell's Holland I or Yara's Yuri , for example).

There were also multiple offtaking MOUs being set up between corporations for overseas trade of hydrogen and its derivatives, mainly from European, Japanese and South Korean corporations with projects and companies in other regions (Lotte-Ma'aden-Aramco, RWE-Hyphen, Uniper-E.ON-EverWind). Some clean hydrogen tenders and auctions have also been announced, domestically and internationally. The most notable ones are JERA's low carbon ammonia and H2Global's green ammonia. It is also worth noting that most international MOU and agreements are for ammonia, rather than hydrogen, suggesting that ammonia is gaining ground as a prime candidate for overseas trade of the clean hydrogen economy.

Top 10 offtakers globally by committed projects
Count of assets



Source: Rystad Energy Hydrogen Cube

Pipelines: the practical way to transport hydrogen

Due to its low volumetric energy density and handling challenges, pipelines are the most cost-effective and feasible way to transport gaseous hydrogen and facilitate imports from neighboring regions. Importing hydrogen by pipeline presents a viable strategy to complement domestic production.

Hydrogen embrittlement of steel and welds, hydrogen permeation, and leakage are often cited as major concerns in steel pipelines. This can be resolved by coatings, sleeves, and casings or by using alternative materials such as reinforced thermoplastic. Technological advancements address these problems in the near term.

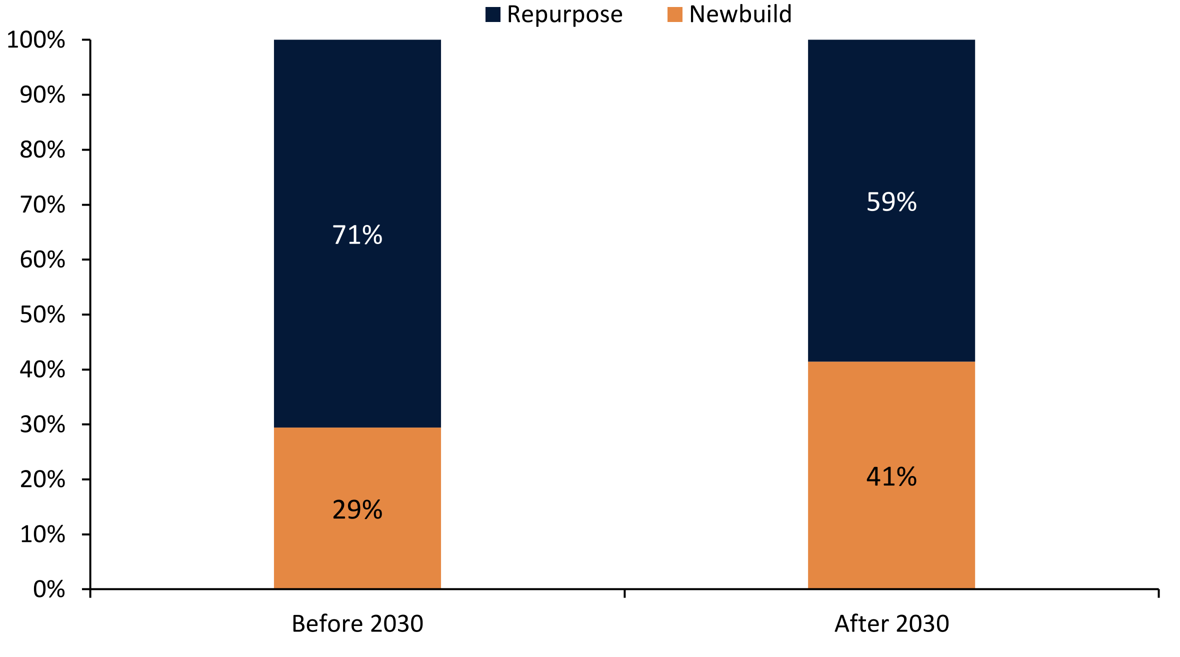
Globally, gaseous hydrogen is already transported by dedicated pipeline through 5,000 km of hydrogen pipeline networks, operated by private companies, and utilized to supply gas to industrial users.

Reusing existing natural gas transmission networks will provide a cost-effective basis for accommodating the predicted long-term hydrogen flows. With modifications, repurposed steel natural gas pipelines can accommodate 100% hydrogen gas – examples cited by German developers will see pipelines dating as far back as the 1990s be retrofitted to 100% hydrogen, while simultaneously having their lifespan extended by around 40 years.

Based on the current announced projects, we expect to see most hydrogen pipelines being retrofits up towards 2030 – after 2030, we exepct to see a balancing of retrofits and new builds, with new builds reaching around 40% of all projects. Estimates also show that utilising existing natural gas grids for hydrogen transport is four times more cost-effective than constructing new pipes. Also, according to one of the European grid operators, there are no significant differences in operating expenses between a hydrogen transmission network based on repurposed natural gas pipelines and a hydrogen transmission network made entirely of new pipelines.

Announced newbuilt vs repurposed hydrogen pipelines before and after 2030

In percentage (%)



Source: Rystad Energy research and analysis

Microbial hydrogen production to resurrect depleted oil and gas wells?

There are tens of thousands of oil and wells across the world that are slated for plugging and abandonment – many hold some proportion of unextracted hydrocarbon content.

Microbial hydrogen production aims to inject specialized bacterial strains into these wells, with the aim of converting the hydrocarbon content into gaseous hydrogen.

This means that existing oil and gas wells can be converted to produce highly cost competitive, clean hydrogen as the solution matures commercially. This would both boost oil and gas companies' journey to net zero and avoid emissions of methane that are traditionally associated with abandoned and often leaky oil and gas wells.

One of the pioneering companies seeking to develope this technology further is Cemvita, a Houston-based startup. According to lab trials conducted by the company, prices at or below $1 per kg have been achieved. We note, the hydrocarbon's carbon content is claimed to be managed by trapping it under ground. Multiple methods such as closing it up in adjacent depleted fiels or using bacteria to fix the carbon are proposed by the company, however it remains unclear exactly how this is to be done.

Source: Rystad Energy research and analysis

Natural hydrogen – the new natural gas?

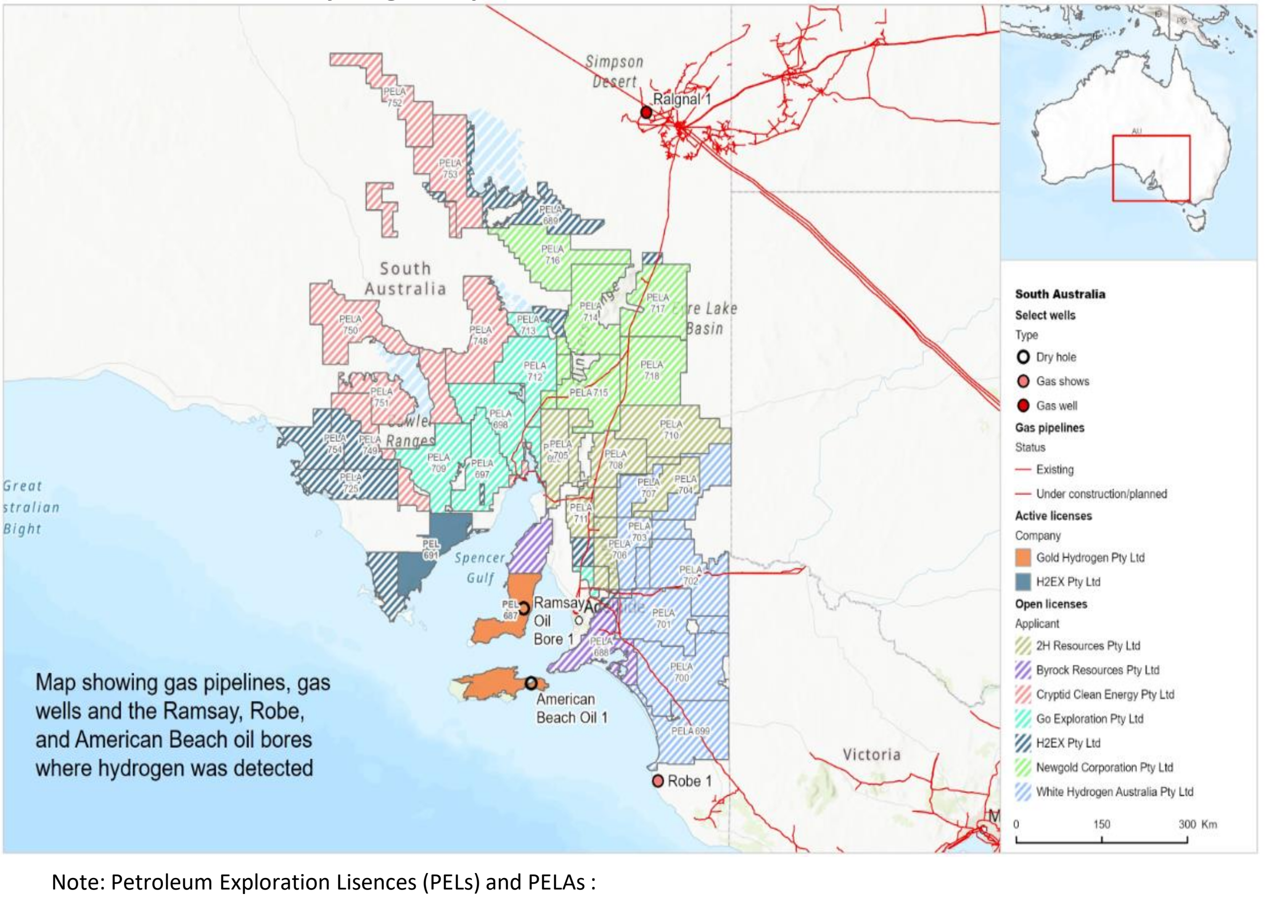
As hydrogen's place in the future energy system becomes clearer, there is a growing interest to understand the potential for hydrogen accumulations occurring naturally under ground.

A little-known natural phenomena, natural hydrogen differs from other types of hydrogen such as green and blue, instead, it shares similarities with fossil fuels.

No energy is needed to split water or crack methane. Holes are drilled into geological reservoirs, meaning it can likely be produced very cheaply. However, there are few estimates of the size of this resource, and our understanding of how natural hydrogen is produced and accumulates is in its early stages.

To accelerate it, recent policy changes in South Australia helped companies begin exploration drilling for natural hydrogen – this could potentially signal the start of an entirely new energy industry. If the efforts of companies pay off in South Australia, governments elsewhere are likely to follow suit and we may see a similar rush for exploration licenses in areas such as Brazil, Russia, and the US. Recent developments in the sector include Hyterra (formerly Triple) acquiring a 30% stake in a joint development agreement with Natural Hydrogen Energy (aka NH2E), which includes an existing hydrogen exploration well that NH2E drilled in the US. The well was drilled in the centre of a 2.5 km diameter "fairy circle" (geological depressions where natural hydrogen is thought to occur) in the Salina Basin in Fillmore County, Nebraska in 2019. We note, the developers claim to have detected significant concentrations of hydrogen.

PELs and PELAs for hydrogen exploration in South Australia

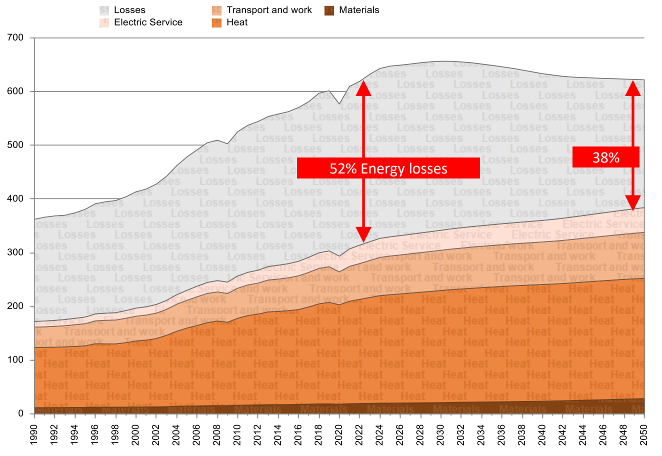


Note: Petroleum Exploration Lisences (PELs) and PELAs :
Source: Rystad Energy research and analysis

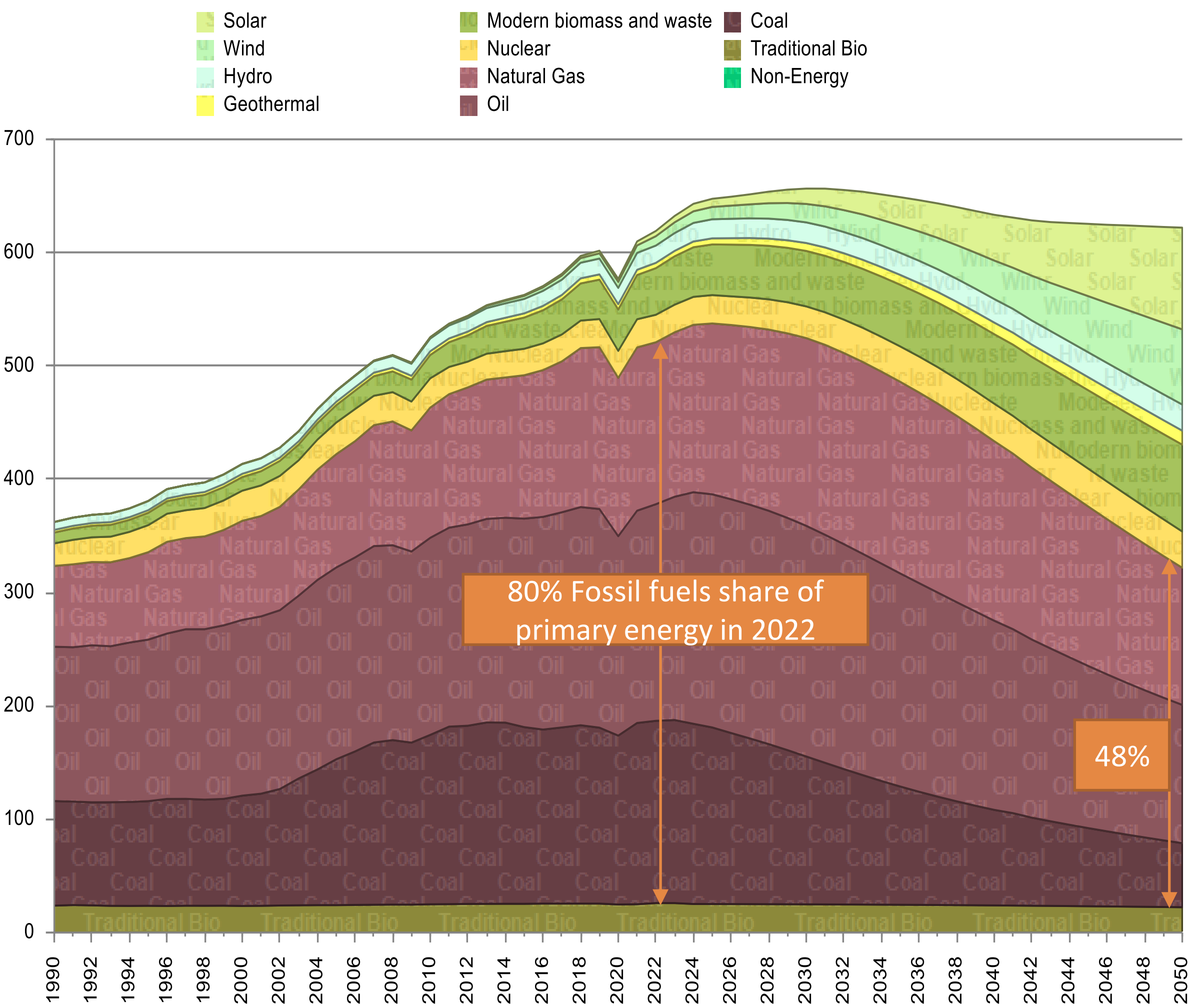
In Mean scenario, fossil fuel share of primary energy sources declines from 80% in 2022 to 48% in 2050 ...

The mean scenario, which is compatible with a rise in global temperature by 1.9 DG Celsius in 2100 compared to pre-industrial era in 1850, as per IPCC definitions, requires a decisive shift of primary energy sources from fossil fuels to renewables (see chart below).

In this scenario, the end-user consumption of energy continues to grow through 2050, while the energy losses, typically associated with fugitive heat from fossil fuel combustion, decrease from 52% in 2022 to 38% in 2050. The energy system becomes more efficient as it transitions away from fossil fuels.



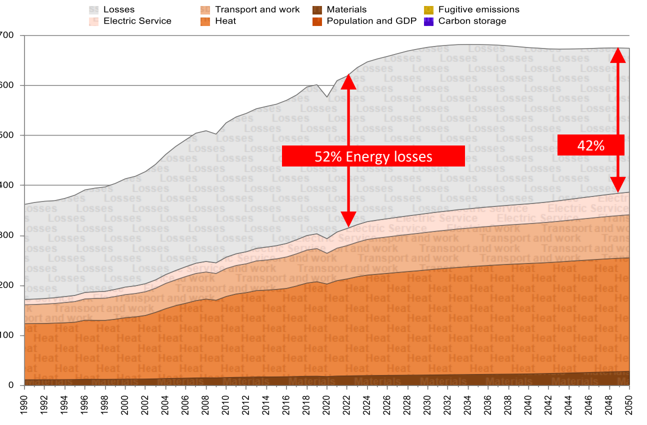
Global Primary Energy Demand
Exajoules



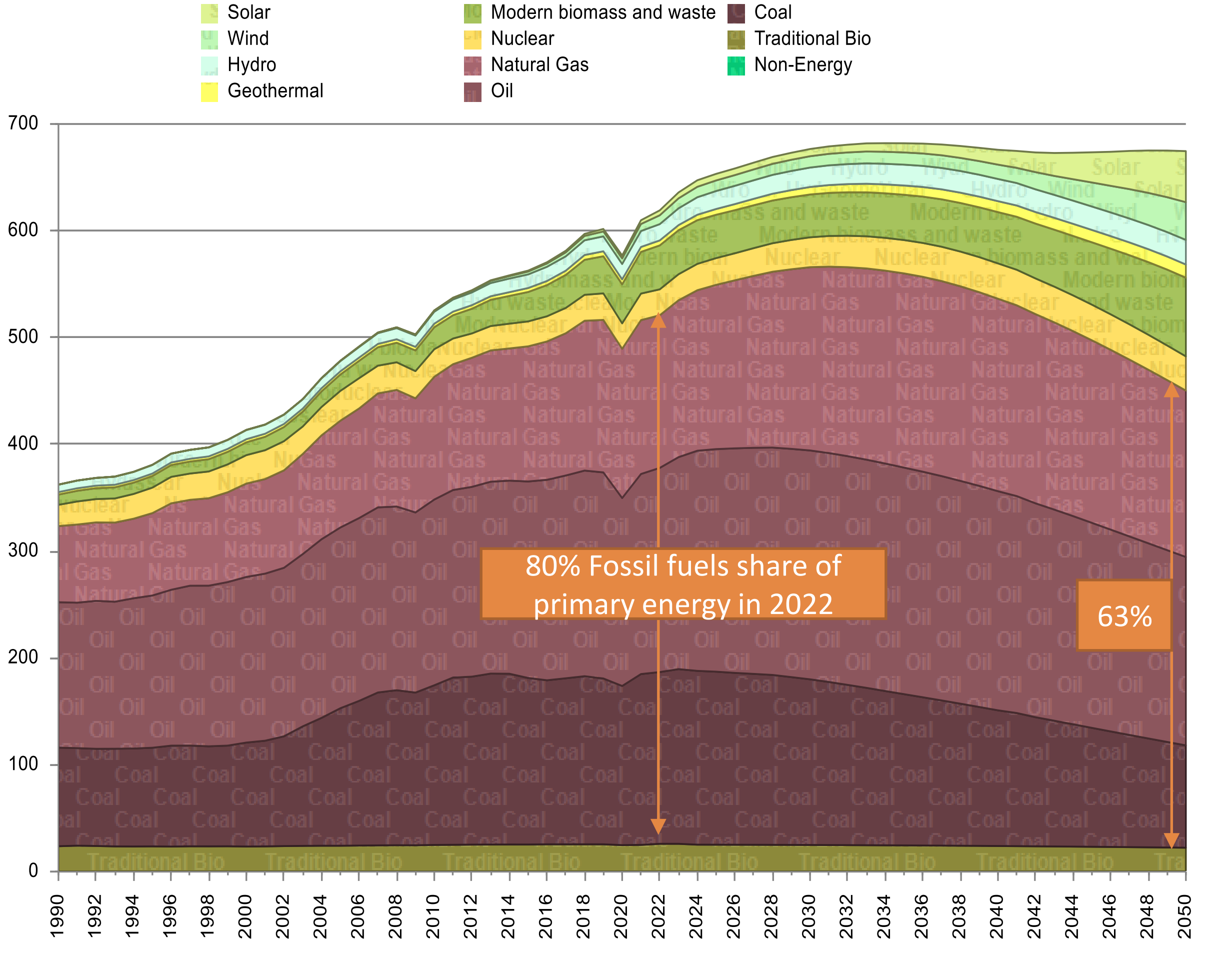
... While it is still close to 2/3 in +Sigma in 2050 ...

The +Sigma scenario, which is compatible with a rise in global temperature by 2.2 DG Celsius in 2100 compared to pre-industrial era in 1850, sees a shift of primary energy sources from fossil fuels to renewables starting in full force no earlier than the mid 2030s (see chart below).

In this scenario, the end-user consumption of energy continues to grow through 2050, while the energy losses, typically associated with fugitive heat from fossil fuel combustion, decrease from 52% in 2022 to 42% in 2050.



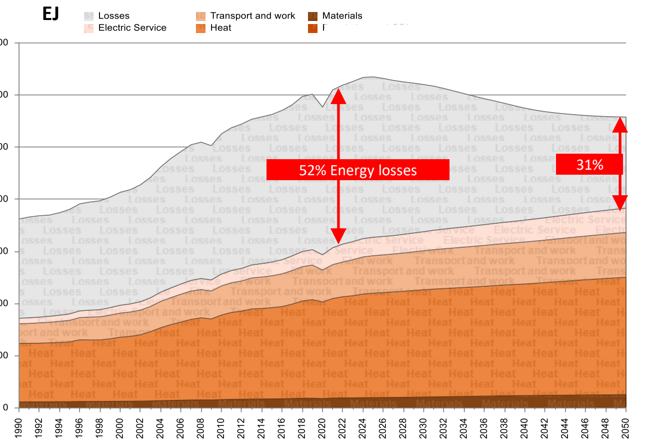
Global Primary Energy Demand
Exajoules



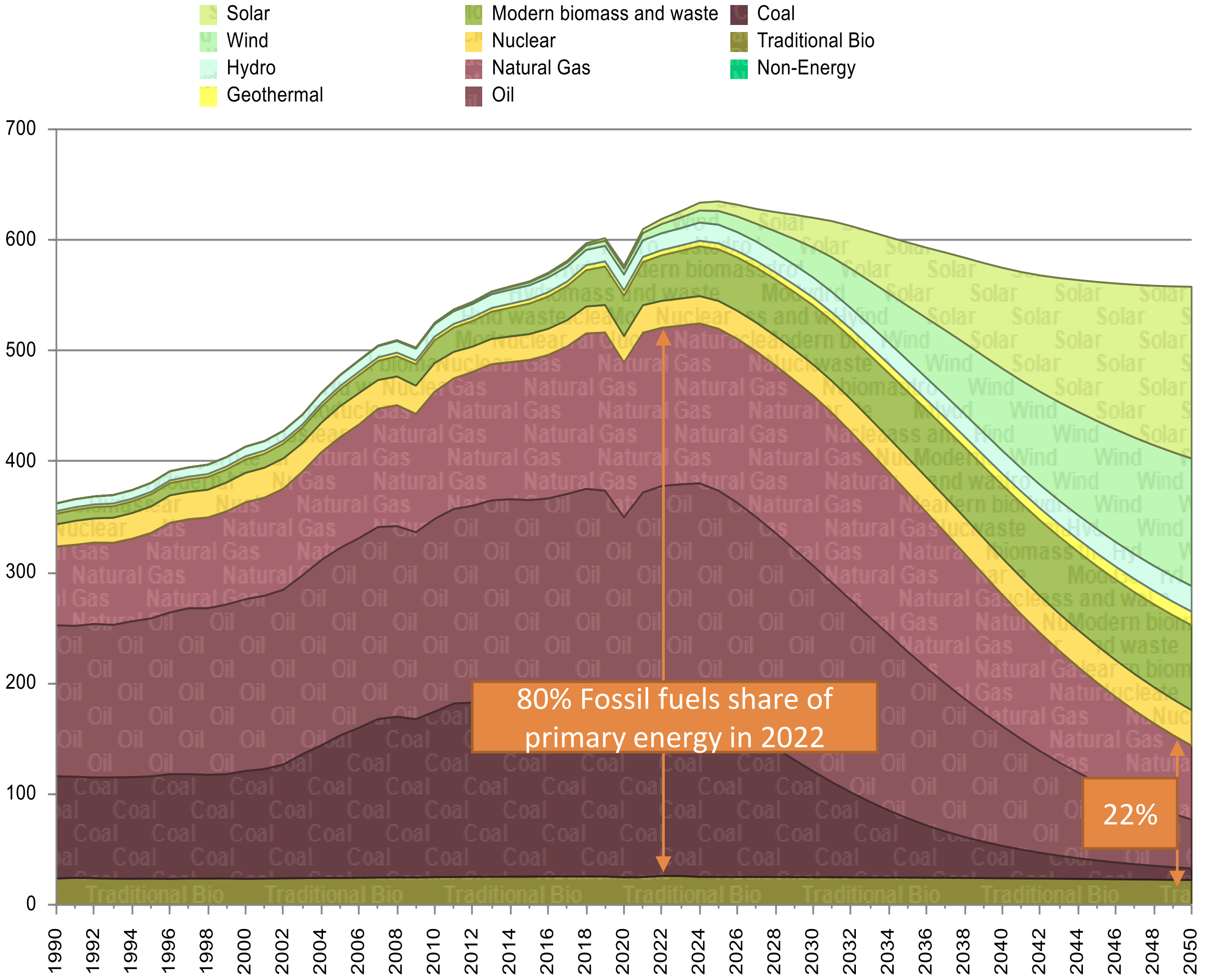
... and it drops to 22% in –Sigma.

The -Sigma scenario, which is compatible with a rise in global temperature by 1.6 DG Celsius in 2100 compared to pre-industrial era in 1850, requires a dramatic shift of primary energy sources from fossil fuels to renewables starting in full force no later than the mid 2020s (see chart below).

In this scenario, the end-user consumption of energy continues to grow through 2050, while the energy losses drop from 52% in 2022 to 31% in 2050. The –Sigma scenario offers a significantly more efficient way to transform and deliver energy than the current system does.



Global Primary Energy Demand
Exajoules



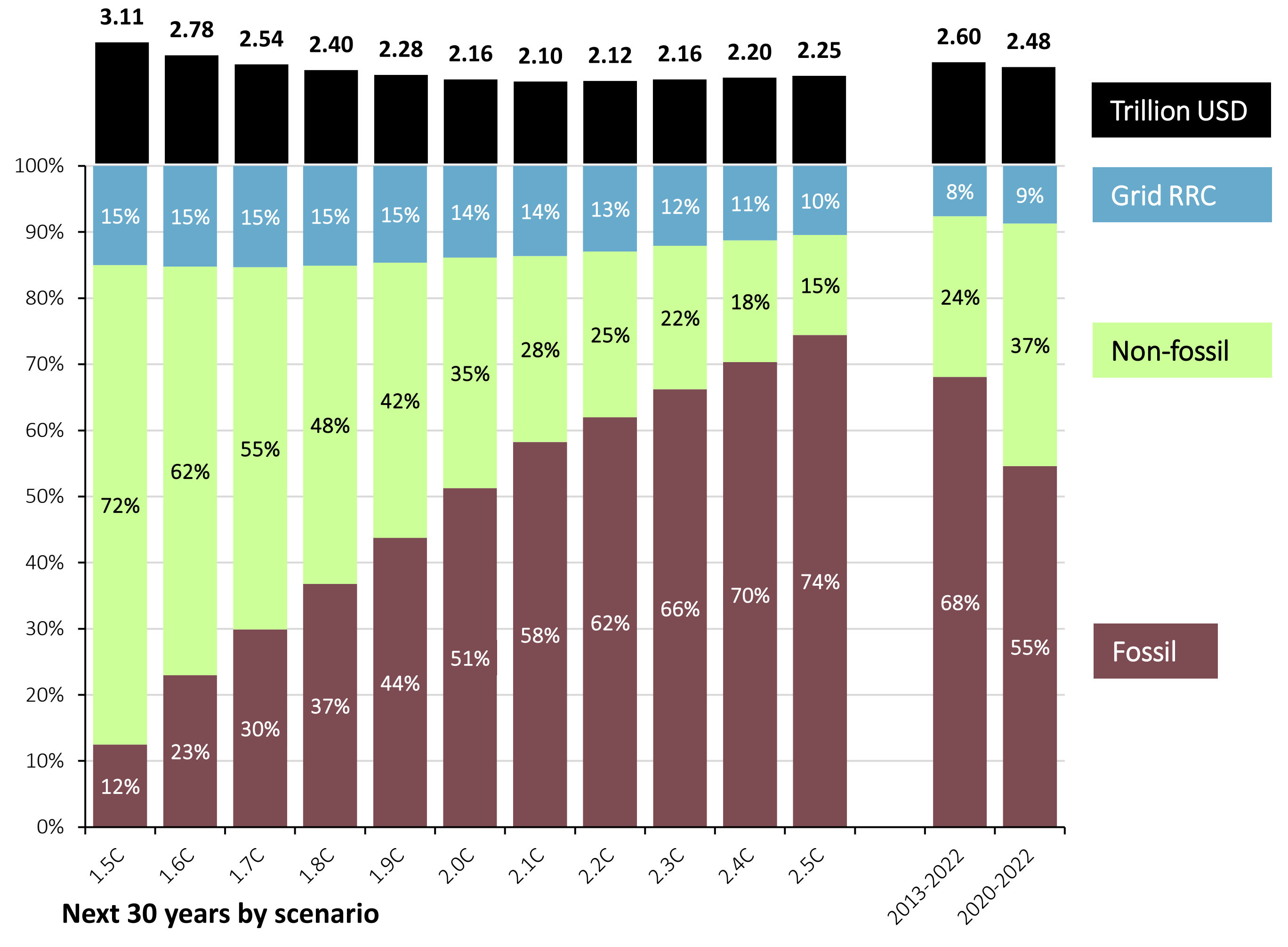
Future <2.0 DG scenarios call for redirection capital flows toward non-fossil energy sources and grid expansion

In 2020-2022, annual energy investment level averaged at $2.5 trillion with fossil fuels accounting for 55% of the total. Flat fossil fuel investment level in real terms in the next 30 years (~$1.35 trillion per year) would be consistent with 2.2-2.3 DG requirements. <2.0 DG scenarios will result in continuous capital reallocation from fossil to renewable energy sources with non-fossil primary energy accounting for 35-72% of total energy investment in the next 30 years. Grid reinforcement, replacement and connections will also become more significant in the structure of total investment requirements with annual spend in $235-466 billion range in 2.5-1.5 DG scenario range (compared to ~$216 billion spend rate in 2020-2022).

U.S. accounted from 26% of fossil spend in the last three years ($350 billion per year) and 10% of non-fossil and grid spend (i.e., $115 billion per year). Hence, recent total energy annual spend in the US has been at $460-470 billion per year - slightly less than 20% of global spend level, and around 1.8% of US GDP. As the global energy spend vs. global GDP is around 2.5%, the US are investing in energy less than the rest of the world in terms of share of their GDP.

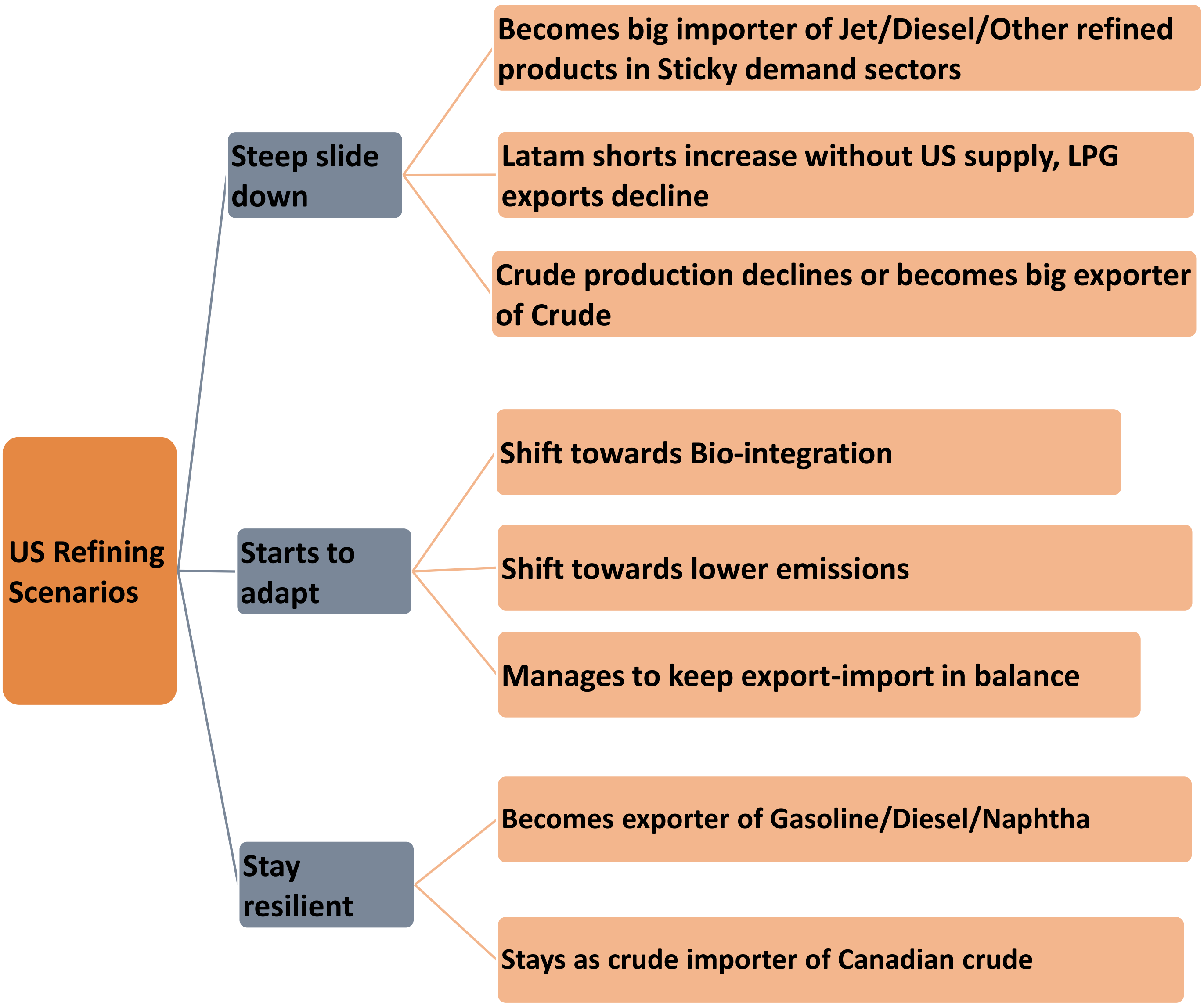
Another way to look at this is by calculating US share of global GDP (25%) and compare it to its share of global spend in energy (20%).

World annual investments in Energy*



*Grid RRC includes reinforcement, replacement and connections; all values are in real 2022 USD terms
Source: Rystad Energy EnergyScenarioCube

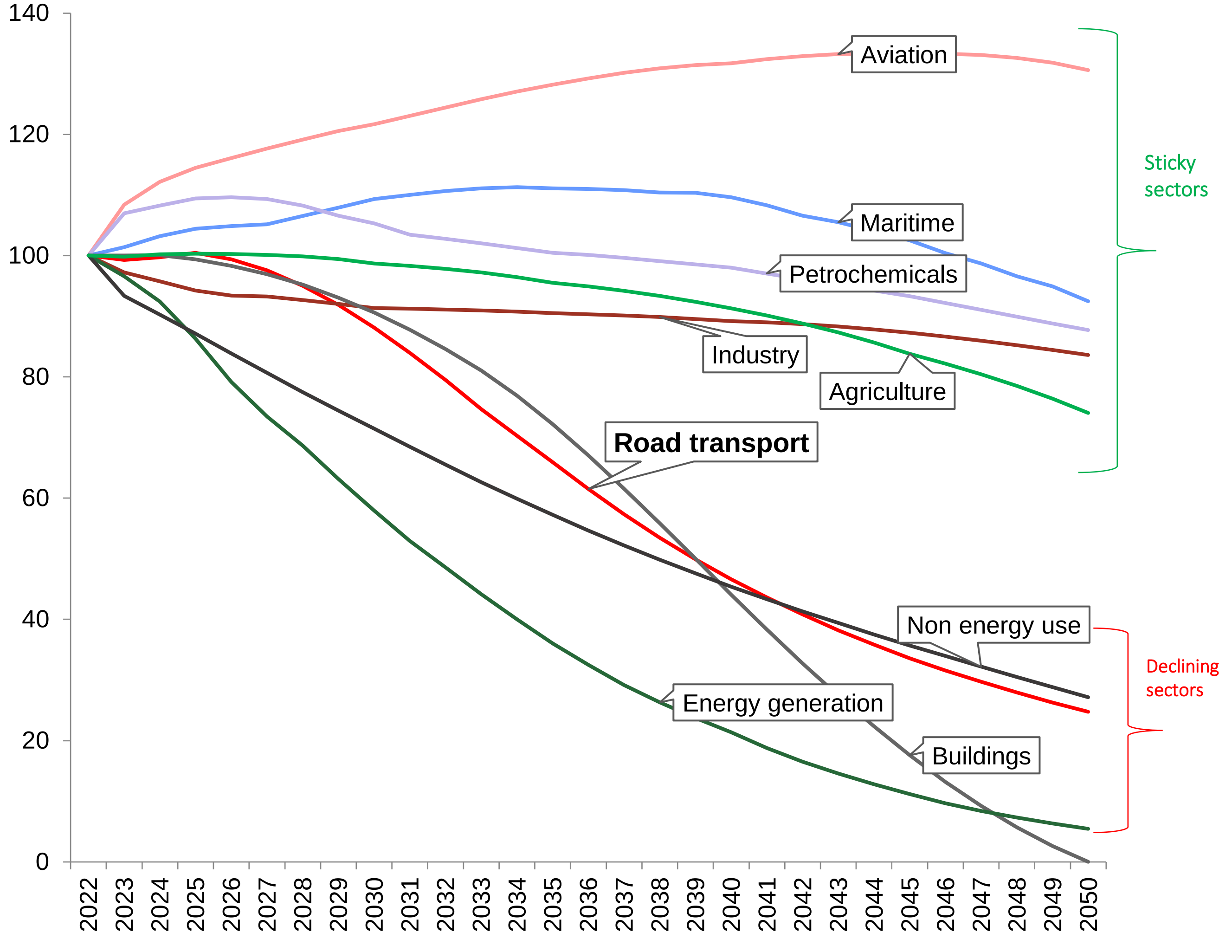
The US Refining sector faces structural shifts, which require strategic repositioning



Source: Rystad Energy Research and Analysis

In US, aviation, maritime & petchem oil demand will be resilient, while road transport will start to decline …

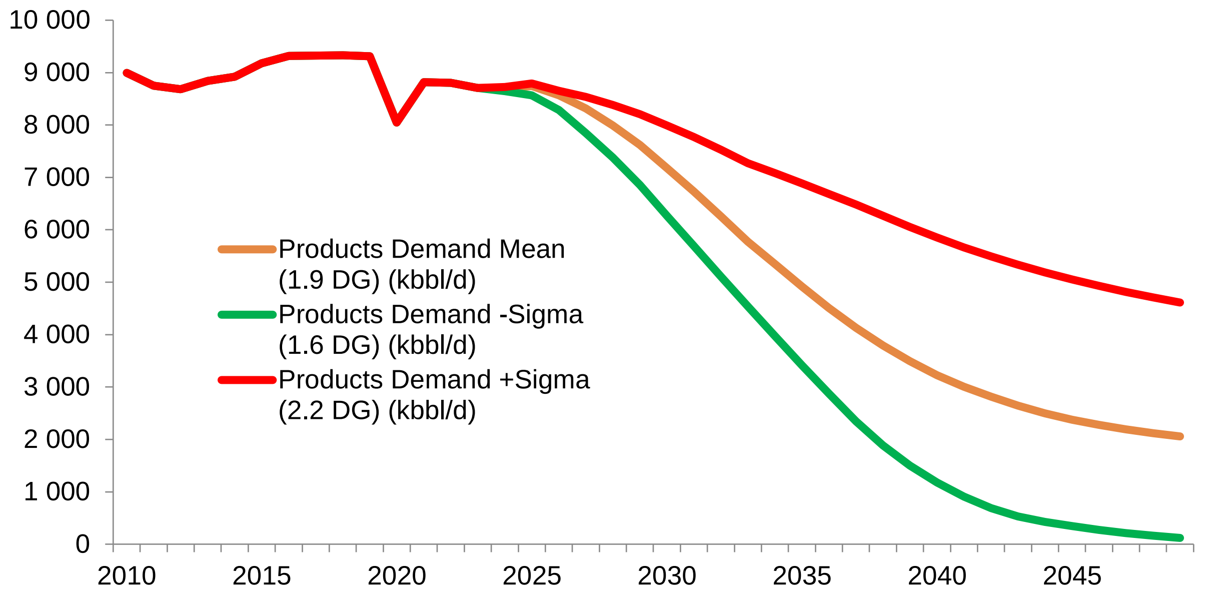
US demand index to 2022 , %



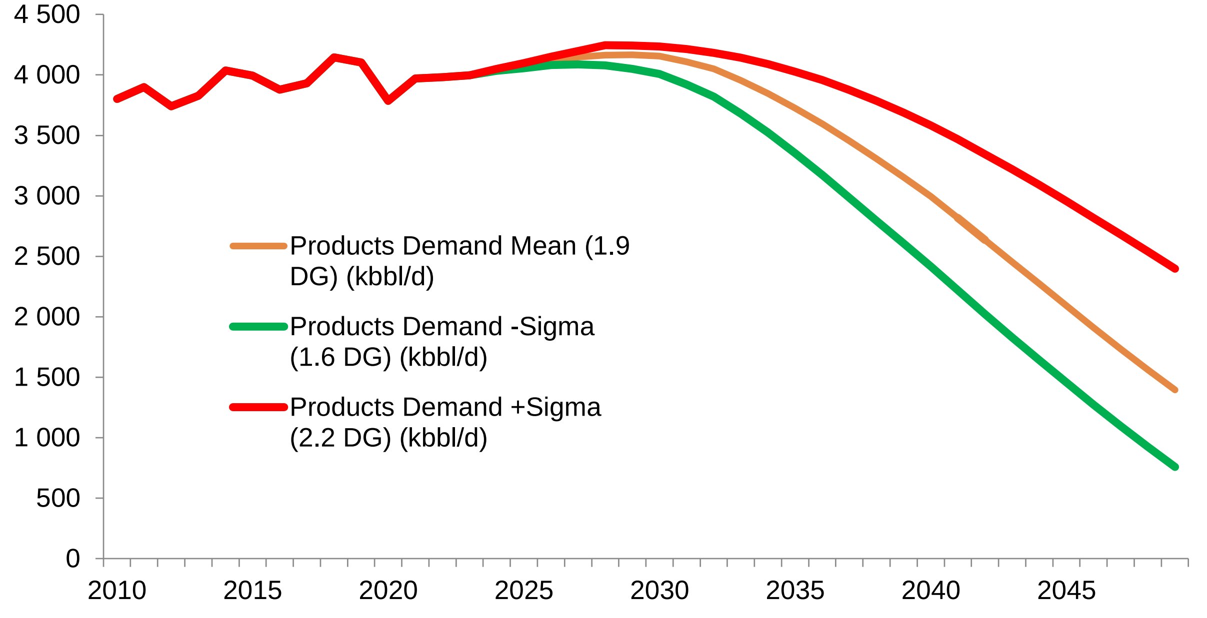
Source: OMCube

… In road fuels, US gasoline demand will decline in all scenarios, while diesel will be resilient thru mid-2030s

US gasoline demand
million barrels per day



US diesel demand
million barrels per day



Source: OMCube

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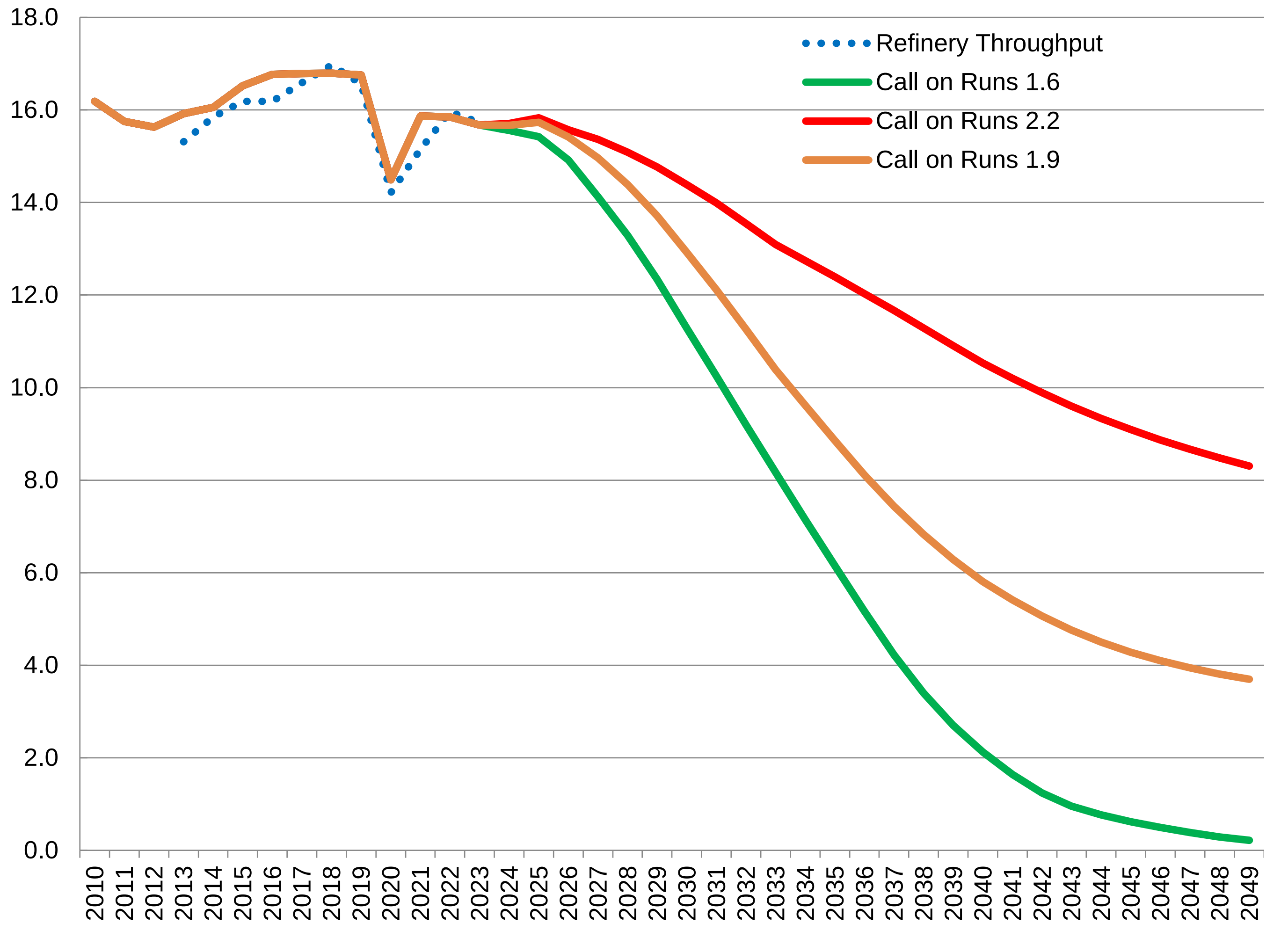
With Gasoline demand decline, the call on refinery runs will fall to 4 million bpd in the Mean scenario by 2050 …

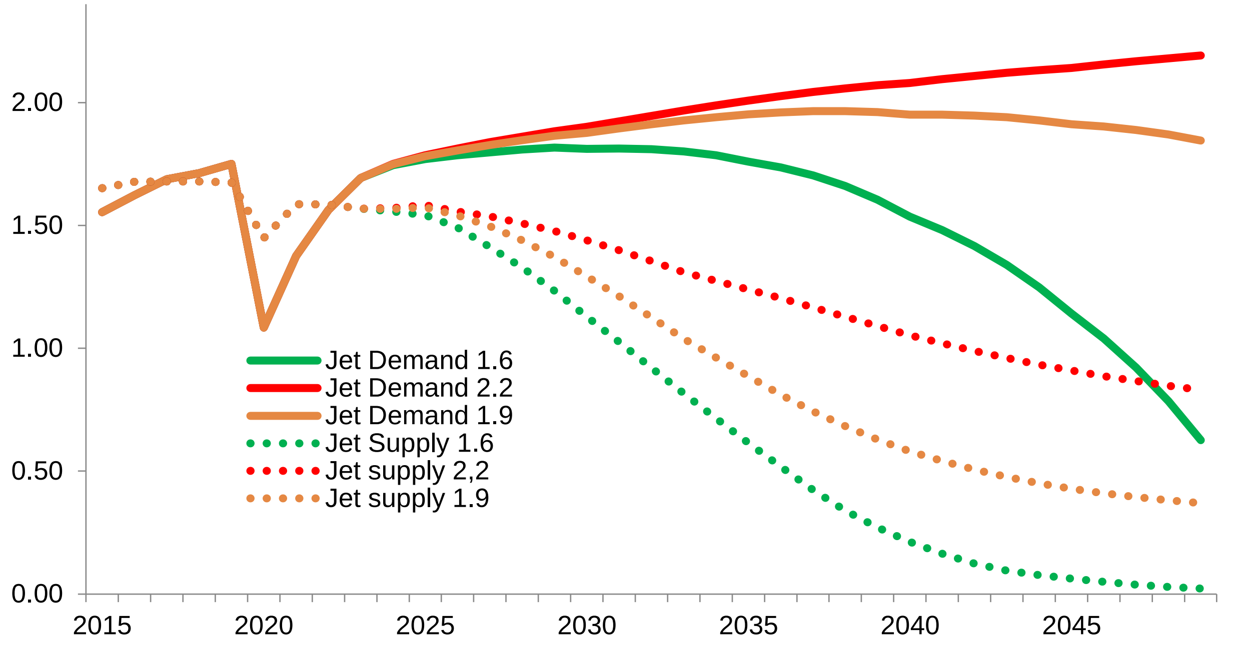
US call on refining runs
million barrels per day



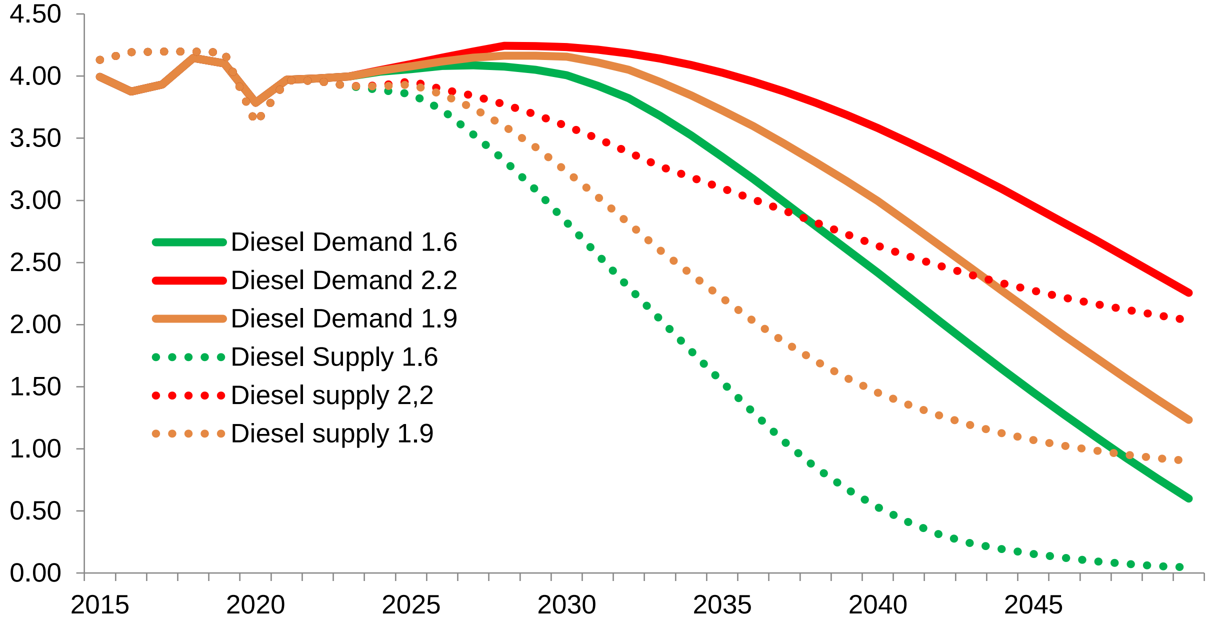
Source: OMCube

… which will result in US importing jet/diesel already in the 2030s, and increasing crude exports significantly

US jet fuel demand & supply
million barrels per day



US diesel demand & supply
million barrels per day



Source: OMCube

Resilient US shale resource base in the last five years

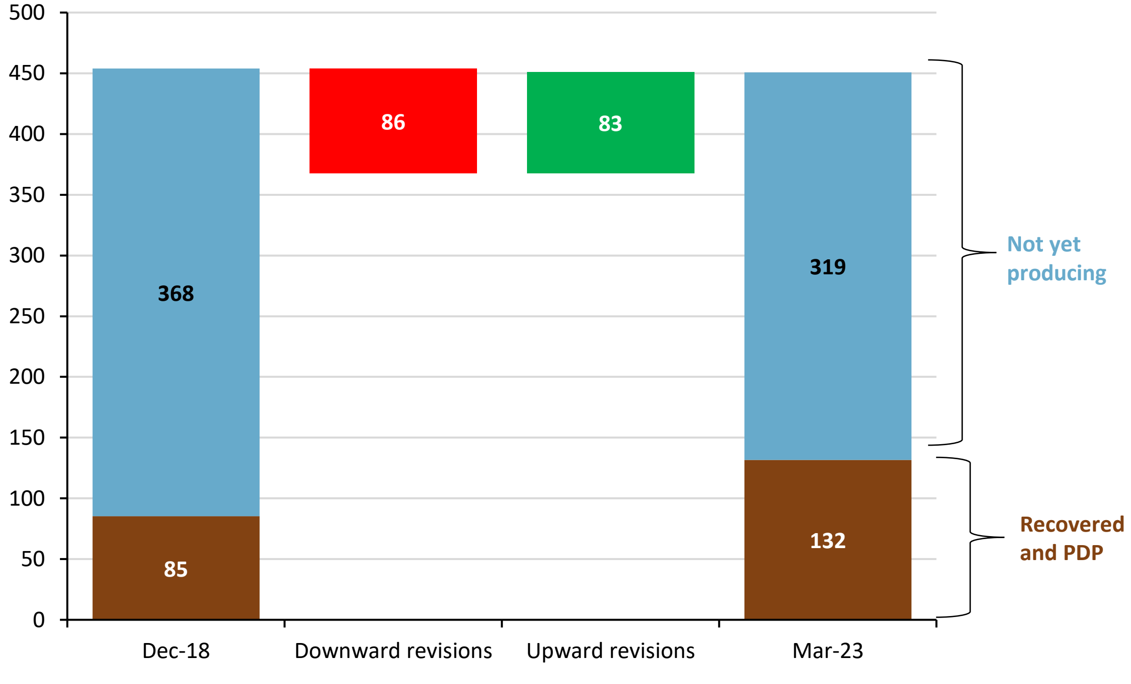
In the last five years, US domestic oil and gas producers experienced multiple market shocks along with structural changes in their business model. Global energy transition was among the factors which indirectly resulted in business model changes through the reduction in consensus long-term projections on global fossil fuel demand (and ultimately reduction on the call on the US oil and gas production).

Simultaneously, US Shale has been accompanied by continuous concerns around feasibility of long-term supply projections with Tier 1 inventory depth and overly optimistic type curves frequently mentioned as two most common arguments against ambitious long-term projections.

We find that despite the presence of concerns, US Shale has delivered exceptional resiliency in the size of its economically recoverable resource base (at $65 WTI and $3.00 Henry Hub long-term price assumptions). In December 2018 we estimated economically recoverable US Shale resource base at ~453 billion boe, out of which 85 billion boe had already been recovered or developed. By now, the size of the developed and recovered part grew to 132 billion boe, but the total size of recoverable resource base remained unchanged at ~415 billion boe.

In the last 4.5 years, we observed ~86 billion boe downward revision in economically recoverable resource base on the back of looser well spacing, disappointing well results, cost inflation, Tier 1 inventory degradation and stranded assets. However, this downward revision was almost entirely offset by ~83 billion boe upward revision driven by structural learning curves, continuous acreage delineation, operational M&A synergies and selected new plays turning economic.

US Shale, economically recoverable* resources by Rystad Energy forecast time stamp
Billion boe, three-stream



*Based on long-term WTI and Henry Hub prices of $65/bbl and $3/MMBtu
Source: Rystad Energy research and analysis

Yet, expected resource development schedule has already been impacted

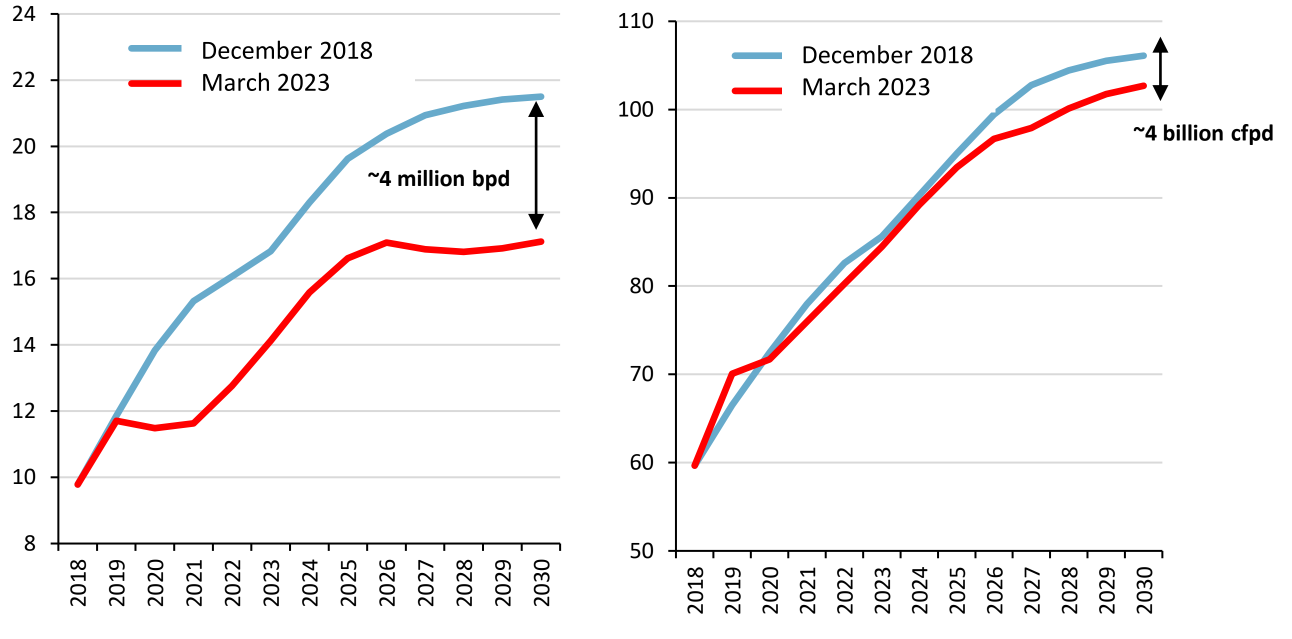
While US Shale economic resource base of ~450 billion boe is unchanged compared to our view five years ago, the base case outlook for expected development schedule today is significantly more conservative than it was back then.

A combination of M&A activity and natural maturation of the US Shale business model reduced long-term call on shale liquids (crude oil, lease condensate and NGLs) from ~22 million bpd to less than 18 million bpd in terms of plateau production. It should be emphasized that COVID-19 downturn was the primary driver of tight oil production underperformance in 2020-2021 (compared to December 2018 forecast timestamp), but the structural changes in the US oil and gas business model also resulted in prolonged impact and more conservative long-term targets than oil-focused producers had prior to COVID-19 pandemic.

We note that contrary to liquids, shale gas production demonstrated exceptional resiliency during the COVID-19 pandemic, with the growth pace nearly matching pre-COVID projections. Base-case shale gas forecast for the second half of 20s was revised down by ~4 billion cfpd in the last 4.5 years, which is less significant in relative terms compared to the revision for oil output. This relatively immaterial gas revision is driven by the fact that the US Shale gas business model maturation was already embedded into base case views in 2017-2018 period, and nearly all additional downward revisions were offset by the growing call on the US LNG exports in medium-term.

US Shale medium-term base case production outlook revisions

Liquids* (million barrels per day) | Dry Gas (billion cubic feet per day)



*Crude oil, lease condensate, NGLs
Source: Rystad Energy UCube

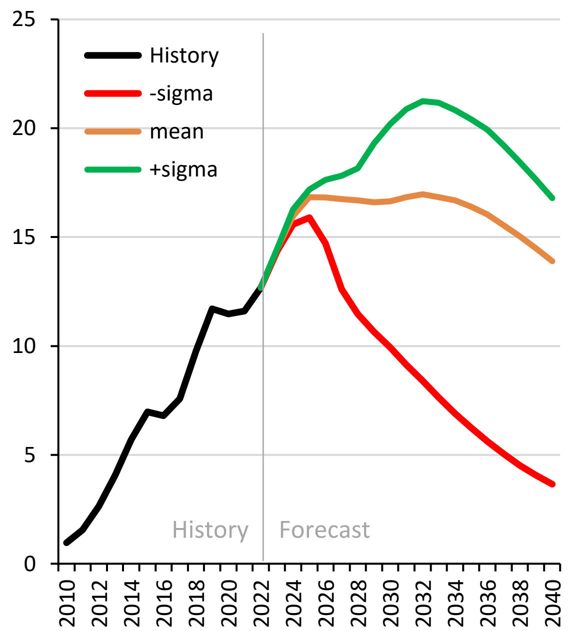
Significant sensitivity of the US Shale production to energy transition pace

As we look into the future, we acknowledge the presence of significant sensitivity of US Shale production and value creation potential to global energy transition scenarios. In our mean demand scenario, we expect US Shale liquid production to grow towards the plateau of 16-17 million bpd and stay in that range until mid-30s. More ambitious +sigma (2.2 DG) scenario will require US Shale to contribute with more than 20 million bpd of liquids output at the peak in the first half of 30s (i.e. comparable to the call on peak shale contribution from our base case five years ago).

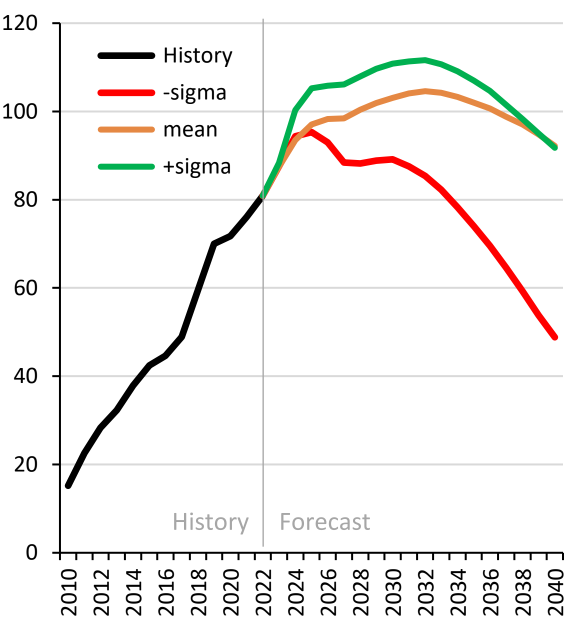
However, rapid push towards global decarbonization compliant with 1.6 DG carbon budget will result in structural US Shale liquids production decline already from the second half of 20s. Very limited infill drilling will be needed from 2030 (implying impact on domestic upstream spend will be even more dramatic) and shale liquids production will fall under 5 million bpd in late 30s.

Shale gas production is expected to be more resilient in faster energy transition scenarios in the next 10-15 years, but 1.6DG (-sigma) scenario will still induce structural decline in US shale gas output from 2030 onwards. In turn, both mean and +sigma scenarios still require significant US Shale gas production growth, with production peaking at 105-110 billion cfpd in the early 30s, which is ~25 billion cfpd higher than the current output level.

US Shale long-term production scenarios
Liquids* (million barrels per day)



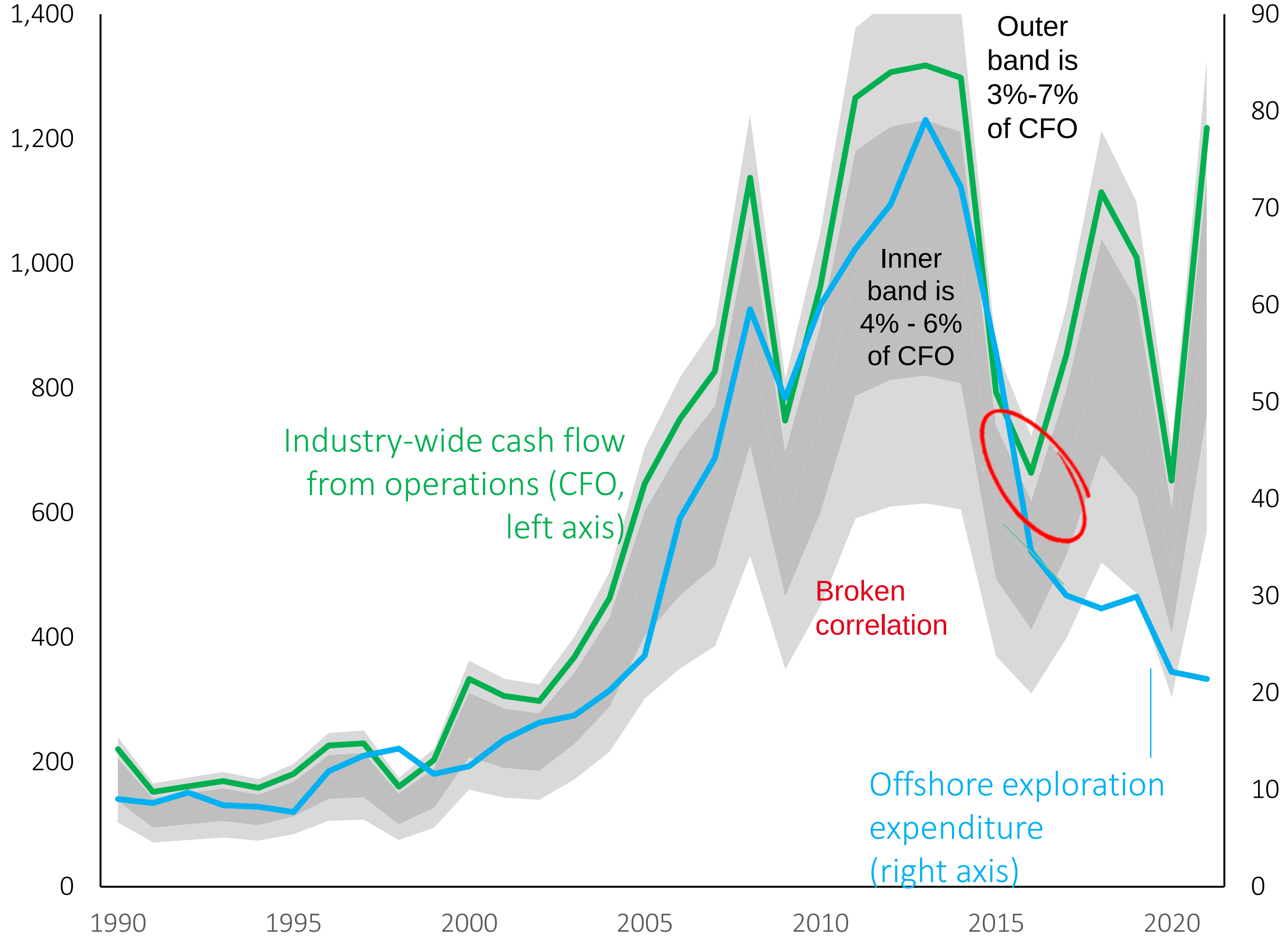
Dry Gas (billion cubic feet per day)



*Crude oil, lease condensate, NGLs
Source: Rystad Energy UCube

The appetite for capital allocation to long-cycled projects is diminishing

Operating cashflow[1] (left axis) vs. Offshore exploration spending
Million US$



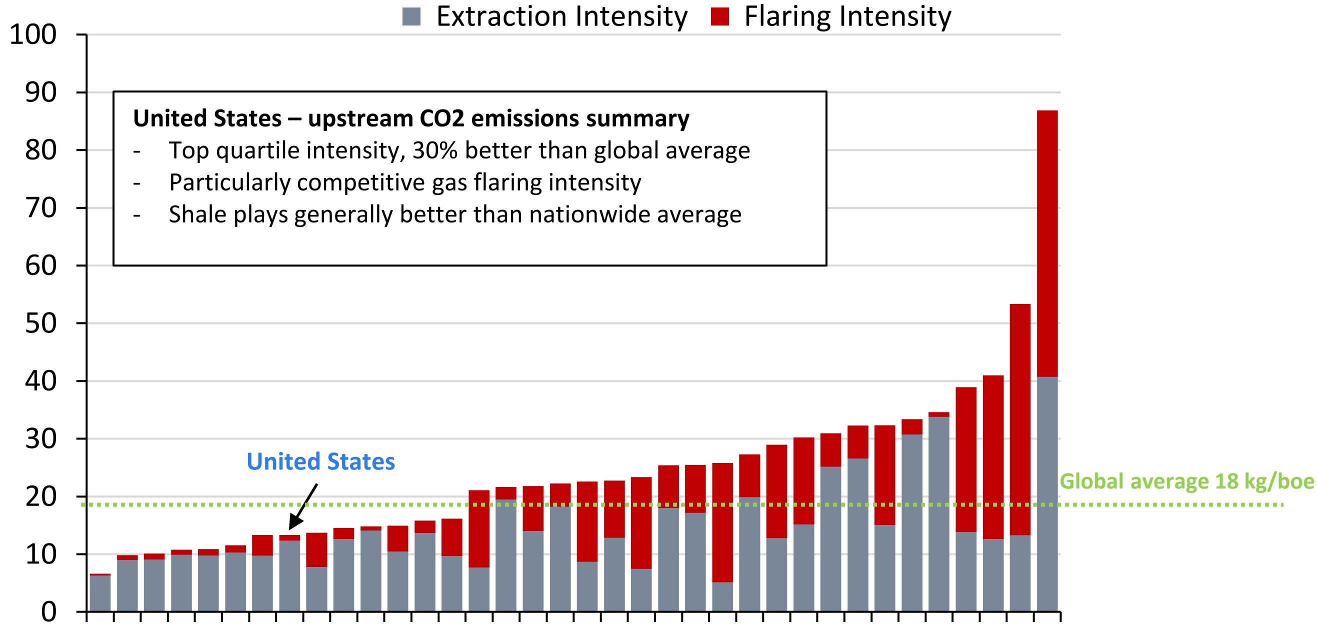
1. Operating cash flow is revenues minus operating costs and direct taxes.
Source: Rystad Energy research and analysis

Top quartile carbon intensity in global context for US oil & gas producers

Domestic oil and gas upstream sector in the United States exhibits average Scope 1 CO2 intensity of 13-14 kg per barrel of oil equivalent (total three-stream production). This bring the US to the top quartile globally on carbon intensity performance among major oil producing countries. Global average CO2 intensity for upstream oil and gas in 2021 was observed at 18 kg per boe with Norway, Qatar and Saudi Arabia having the lowest CO2 intensity in 7-10 kg/boe range. Among 35 largest oil producing countries globaly, nine exhibit CO2 intensity above 30 kg/boe.

Despite the presence of selected areas with challenging gas flaring situation (Bakken, selected parts of the Permian Basin), United States on average scores particularly well on gas flaring in global context. Gas flaring provided only 1 kg/boe contribution to nationwide average for the total upstream intensity in the US compared to 10 kg/boe average contribution among 35 largest oil producers. Shale gas basins (Haynesville, Marcellus) and tight oil basins like DJ basins exhibit particularly low, nearly negligible gas flaring helping to push nationwide average down.

United States and other countries*, upstream CO2 intensity benchmarking in 2021
Kg of CO2 per boe of total hydrocarbon production

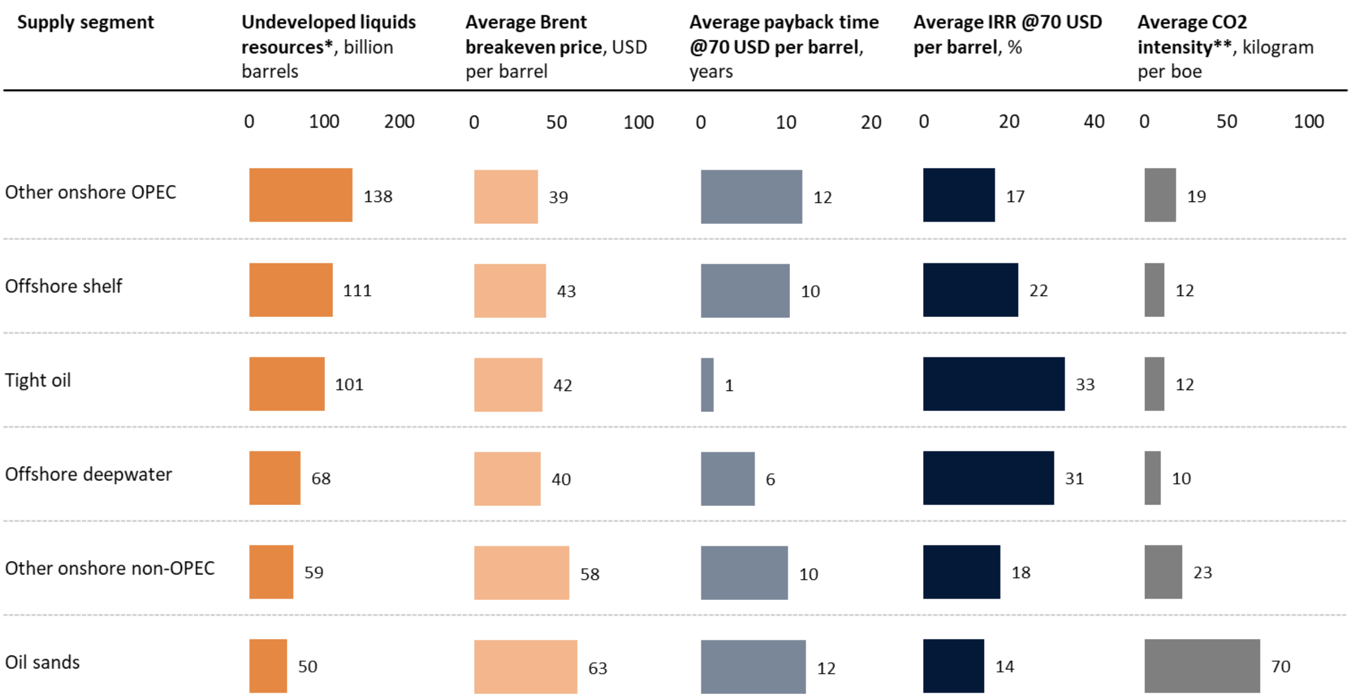


*35 largest oil producing countries globally
Source: Rystad Energy EmissionsCube

Economic case for US Shale in the global context

US Shale offers competitive economics among significant oil supply sources globally. Thanks to very competitive and efficient Lease Operating Expense cost structure, the breakeven prices for already producing tight oil wells are generally observed in low 20s. Lower breakeven prices for producing facilities are only observed in selected OPEC countries (e.g. Saudi Arabia), North Sea, and pre-salt development in Brazil

However, those volumes decrease rapidly, and new drilling is needed to maintain supply. The average future tight oil well in the Permian, Bakken, Eagle Ford or minor basin requires $42 per barrel to generate 10% after-tax return, in nominal terms. This puts US Shale at an advantageous position, with one of the most attractive breakeven points globally, although selected OPEC countries and various greenfield deepwater initiatives across the globe do have lower breakeven prices than US Shale from full cycle economics perspective. It is worth highlighting that these breakeven costs do not include the upfront cost of land acquisition, block bids or leasing rights.



*Includes discovery life cycle **Includes full life cycle upstream emissions
Source: Rystad Energy UCube and EmissionCube

Authors

Claudio Galimberti, SVP & Head of Demand, North America Research Director

Artem Abramov, Partner & Head of Clean Tech

Espen Erlingsen, Partner & Head of Upstream

Mukesh Sahdev, SVP & Head of Downstream, Trading

Sindre Knutsson, SVP & Head of Natural Gas Markets

Alexandre Ramos-Peon, VP & Head of Shale Analysis

Navigating the future of energy

Rystad Energy is an independent energy consulting services and business intelligence data firm offering global databases, strategic advisory and research products for energy companies and suppliers, investors, investment banks, organizations, and governments.

Headquarters:
Rystad Energy, Fjordalléen 16, 0250 Oslo, Norway
Americas +1 (281)-231-2600
EMEA +47 908 87 700
Asia Pacific +65 690 93 715
Email: support@rystadenergy.com