Decarbonizing Energy: From A to Zero

Section 2
Navigating the new route

A practical guide to navigating the decarbonization process. Make the move towards a more affordable, sustainable and available future.

We call it positive energy.

Oil and gas companies looking to establish winning positions in the Decarbonization Transition and beyond can't achieve that goal by themselves.

They will need the help of their customers, particularly those that are heavily dependent on hydrocarbons, and adjacent sectors. Only by participating in, and architecting, cross-sectoral actions can oil and gas companies hope to mitigate emissions across the energy system. This will be a new and valuable role for the industry to play.

In this section, we analyze and describe actions to be taken within the six critical sectors that are not only most impacted by the Decarbonization Transition, but also critical in making it a reality.

For each sector, we have identified three key levers for emissions abatement and the corresponding implications and actions for the oil and gas industry. Greater emphasis has been placed on analyzing trends in the hydrocarbon extraction and refining, power and transportation sectors. Our focus on the hydrocarbon industry relates very directly to the near-term actions that oil and gas companies will have to take. Our focus on power and transportation highlights why and how these sectors will have the greatest impact on gas and oil demand, respectively.

1. Hydrocarbon extraction and refining

2. Power generation

3. Light-duty passenger vehicles

4. Heavy-duty and commercial transportation

- **4.1** Heavy-duty road transportation
- **4.2** Aviation
- **4.3** Shipping

5. Heavy industry

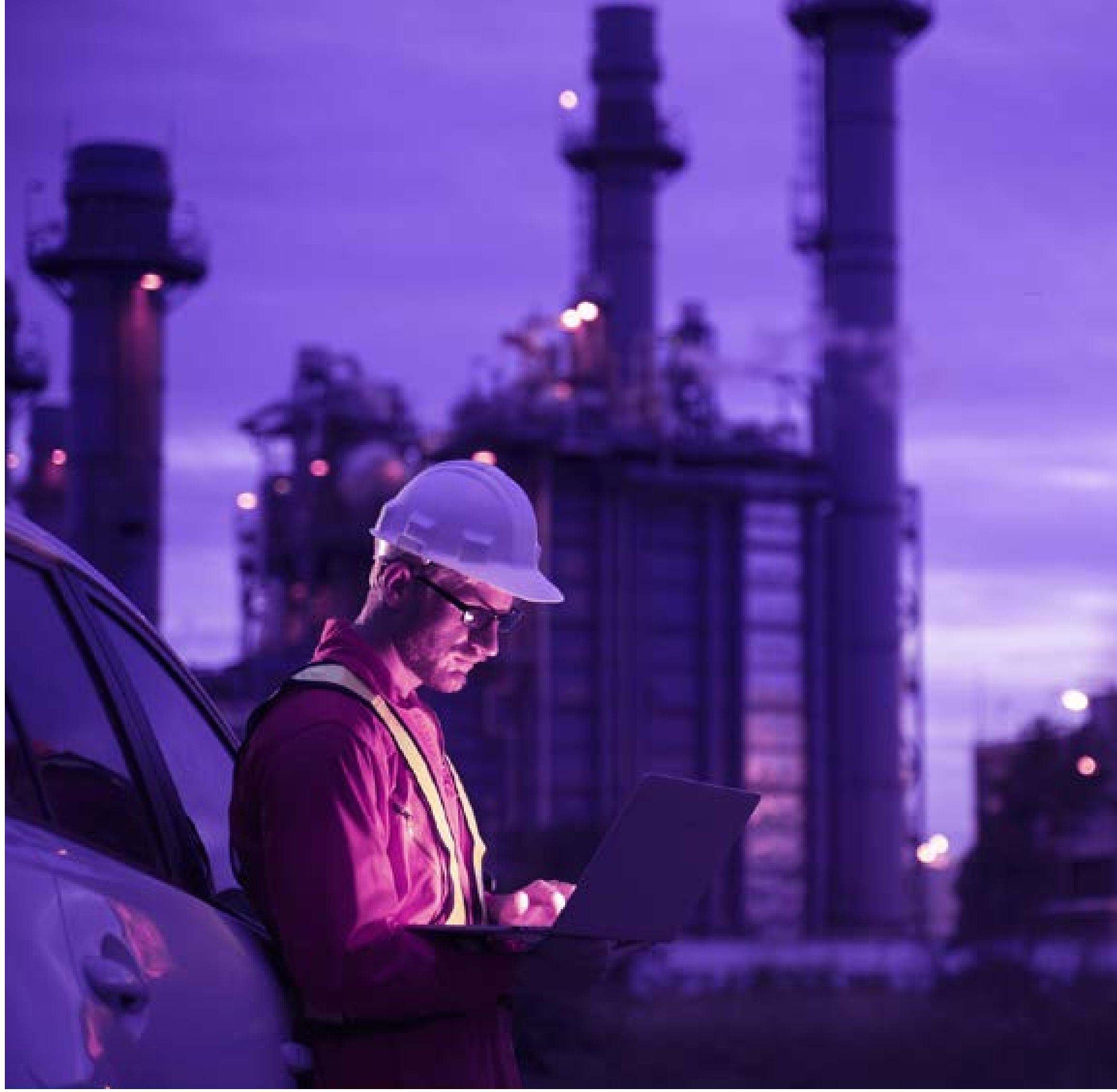
- **5.1** Cement
- **5.2** Iron and steel
- **5.3** Chemicals

6. Commercial and residential buildings

Hydrocarbon extraction and refining

Accenture 2050 stretch goal

93 percent reduction from 2050 business-as-usual emissions through near elimination of Scope 1 and 2 emissions.



The brief

Our top levers to reduce emissions from operations in the hydrocarbon extraction and refining sector.

1. Construct a low-cost, low-emission portfolio to ensure continued capital investment (Clean the Core).
2. Reduce Scope 1 and 2 emissions by managing methane leaks, venting and flaring (Clean the Core).
3. Reduce energy intensity with operational efficiency and low-carbon operations (Clean the Core).
4. Scale up CCUS deployment in enhanced oil recovery (EOR) with a view to monetizing the technology in other industries (Extend the Frontier).

The production, transport, processing and consumption of oil and gas products accounts for 60 percent of all global greenhouse gas emissions, with a quarter of those (15 percent) directly attributable to the oil and gas industry[2] (Scope 1 and 2 emissions).

Emissions from oil and gas operators' existing portfolios are equivalent to 5.2 MtCO2e per year (more than five times the emissions from the aviation sector)[19].

Even with recent acceleration in the electrification of light-duty and heavy-duty road transport, oil demand is expected to increase by 5 to 10 percent by 2030 before flatlining to 2040. Gas demand, on the other hand, is expected to grow by more than 30 percent to 2040[20]. These increases will raise industry emissions even further unless oil and gas operators take strong action to tackle both upstream and downstream emissions. For operators that have set net-zero targets—which include Scope 3 emissions—this presents a huge challenge[21].

Regulators (through carbon pricing and reporting and activity bans), activist investors (through fossil-fuel divestment) and consumers (through preference for cleaner energy supply) are all coming together to increase the pressure on the industry to decarbonize. It is estimated that the most emissions-intensive 50 percent of existing oil reserves and 48 percent of existing gas reserves are incompatible with achieving the Paris Agreement and might never get produced[22]. These numbers will only increase if coal is not rapidly phased out.

Gas decarbonization is particularly important given its demand outlook. Despite more than 100 emission-reduction initiatives announced over the last three years, the level of emissions per barrel of oil equivalent per day (BOEPD) has decreased by less than 1 percent per year over the last decade. That trend appears likely to continue through 2030 unless immediate actions are taken[5].

Moving to a structurally lower emissions intensity portfolio will make it easier for first-mover operators to achieve cleaner core oil and gas operations and reduce the risk of stranded assets.

Poor returns, environmentally driven fund divestment, and growing alternative investments are squeezing access to capital in the oil and gas sector. In addition to these malaises, future hydrocarbon projects are increasingly factoring in shareholder-driven shadow carbon pricing, which at $50/ton would add on average an additional $6/BOE to global production costs.

Therefore, as oil and gas companies look ahead to the next decade, a competitive portfolio will no longer solely be determined by its breakeven price, but also by its environmental impact from Scope 1 and 2 emissions. These two concerns will converge as higher carbon pricing is factored into project-level economics.

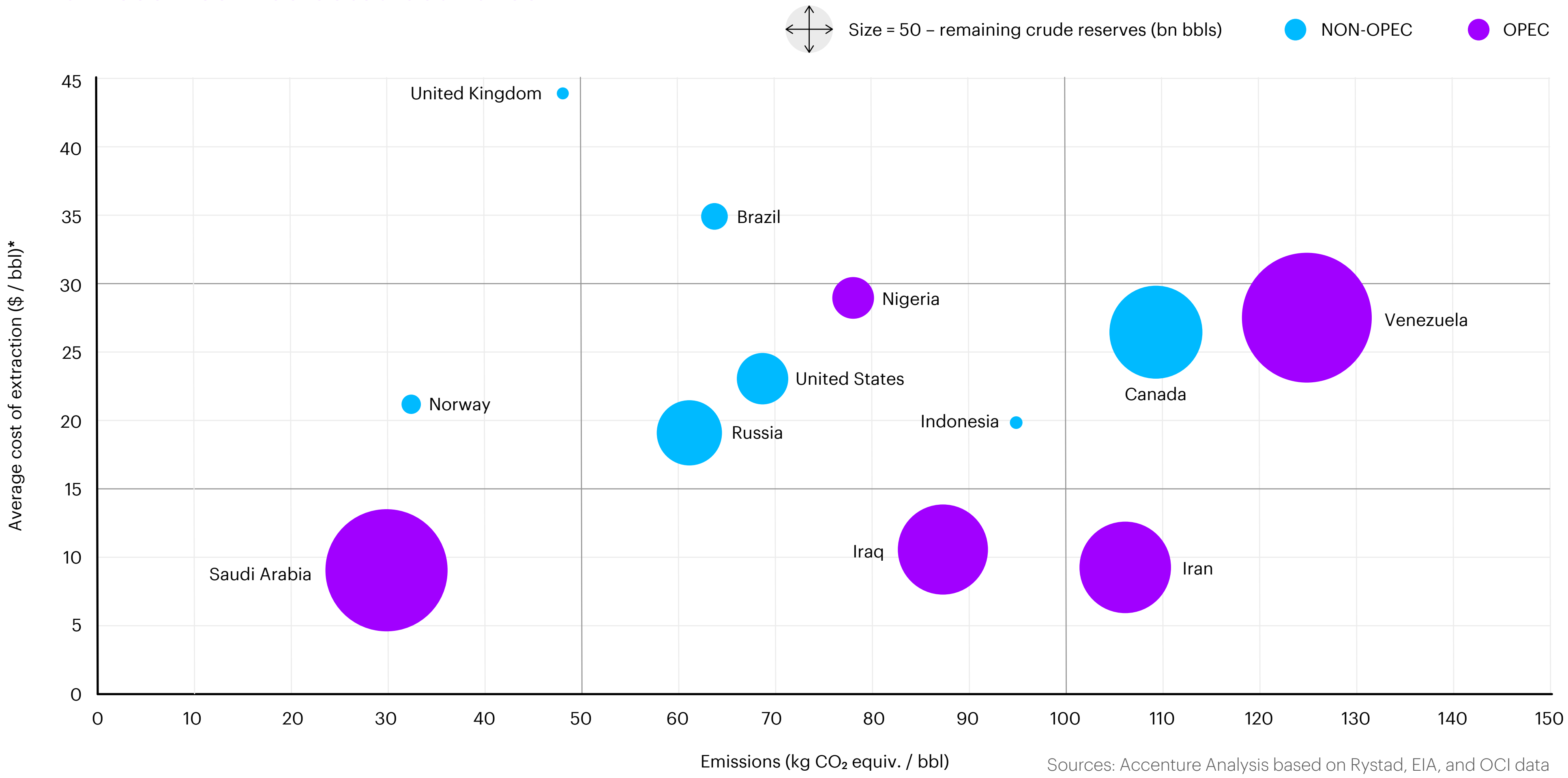
Emissions intensity is, therefore, becoming an increasingly important metric in portfolio strategy. And, as with the breakeven metric, not all oil and gas reserves are equal in terms of emissions intensity. Oil from Canada and Venezuela, for example, creates emissions four to five times greater than that of Saudi Arabian oil, in addition to having a breakeven price more than twice as high.

Over the next decade, the competitiveness of an oil and gas company's portfolio will no longer solely be determined by its breakeven price, but also by its environmental impact.

Figure 14

Emissions versus extraction costs for oil reserves in selected countries

*Average cost of extraction includes CAPEX, production, transportation and taxes



Sources: Accenture Analysis based on Rystad, EIA, and OCI data

Even within a single country, the emissions intensity disparity between different fields can be large. In Nigeria, for example, there is a 500 percent difference between the OML 118 and OML 58 fields, driven largely by flaring and venting.

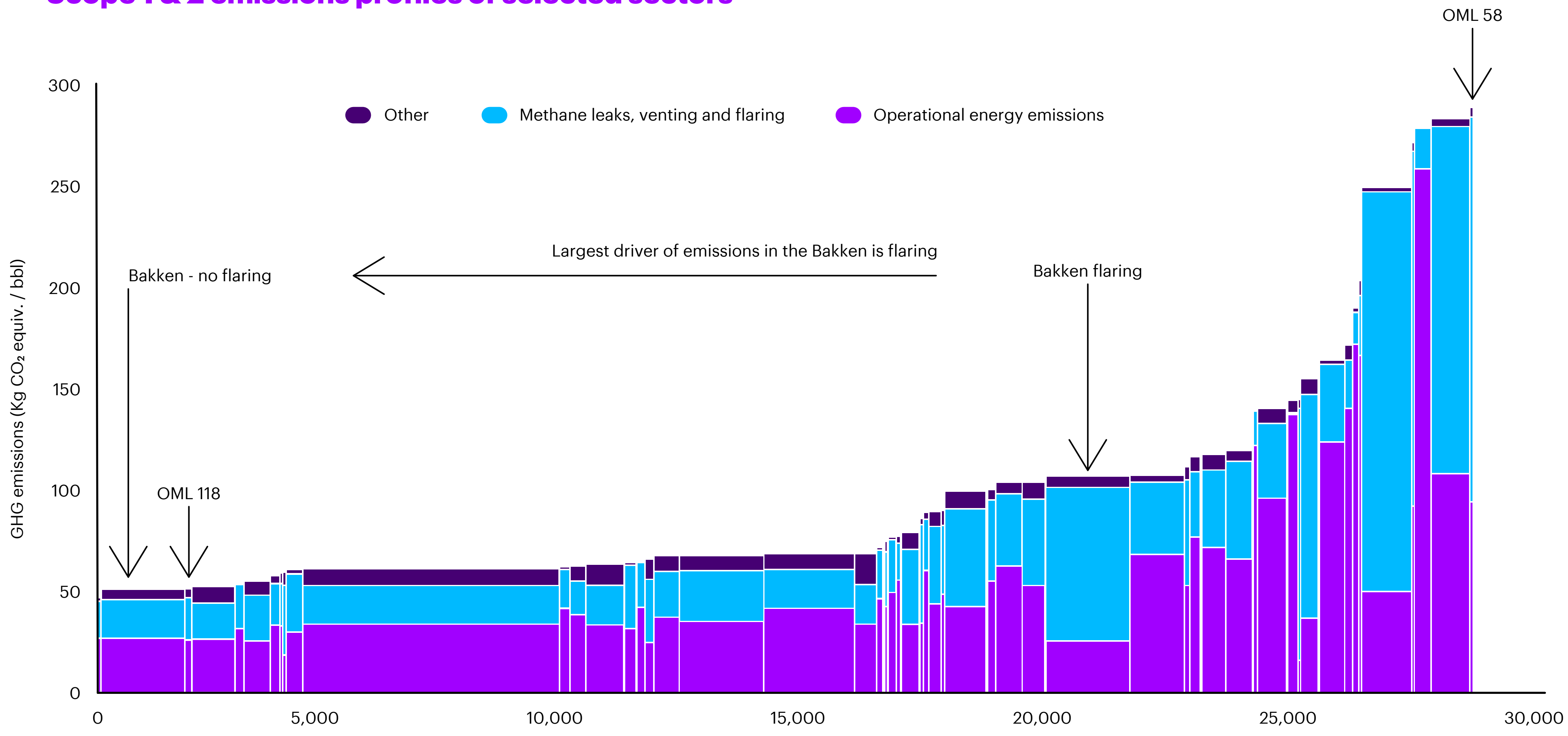
Having granular visibility into the emissions intensity of an oil and gas field, along with an understanding of the drivers of those emissions and the operator's ability to reduce them, is evolving to be another branch—and competitive advantage of—portfolio strategy. For example, fields where methane represents a high percentage of intensity today could eventually become lower-intensity fields if the industry acts quickly and strongly to prevent methane leakage. For example, eliminating all flaring in the US Bakken shale play would reduce its emissions by around 50 percent. Operators specializing in reducing particular emission sources could create a business model focused on fields with higher emissions in that particular category.

Although outside the scope of the hydrocarbon sector's direct emissions, an important step in reducing Scope 3 emissions is choosing barrels with products like lighter oils, natural gas and natural gas liquids that are less emitting. While the emissions intensity differences between fields for Scope 3 emissions are not as great on a relative basis when compared to Scope 1 and 2 emissions, on an absolute emissions-per-barrel basis, field differences have a similar impact in determining a barrel's overall impact across Scope 1, 2 and 3 emissions.

Figure 15

Sources: Accenture Analysis based on global data and OCI data

Scope 1 & 2 emissions profiles of selected sectors



For current assets, tackling methane leaks and reducing venting and flaring could decrease sector emissions by up to 50 percent.

Methane leaks alone (often known as fugitive emissions) account for approximately 2.2 billion tons CO_2e of emissions from upstream and midstream activities.

We believe that there is a significant opportunity for existing players to generate positive net present value (NPV), while reducing up to 45 percent of methane emissions (approximately one billion tons of CO_2e) by leveraging proven technologies and solutions. For example, leak detection and repair systems, together with predictive maintenance and intelligent asset management capabilities, have demonstrated the ability to lower methane emissions by about 25 percent. Additional carbon pricing and technological advances such as tracking methane emissions through satellite data will make the reduction of the remaining 55 percent of methane emissions increasingly economical.

Another source of emissions, and lost value, is deliberate venting and flaring. In 2018, oil and gas operators flared 145 billion cubic meters of gas[23]. That equals the total annual gas consumption of Central and South America combined. It also translates into $20 billion of wasted revenue annually and accounts for roughly 0.3 billion tons CO_2[2].

Venting and flaring are practiced when the costs of capturing, storing and transporting associated gas to market outweighs the market value of the gas. However, in response to strict regulatory policies focused on reducing flaring, oil and gas companies are now investing in infrastructures to alleviate storage and takeaway constraints and deploying onsite technologies to monetize the gas produced. Thirty-six oil and gas companies have already endorsed the World Bank's "Zero Routine Flaring by 2030" Initiative.

However, despite these developments and a commitment "to do the right thing," global flaring has only been reduced by 10 percent over the last decade[23].

We have determined that solving for infrastructure constraints and deploying onsite monetization technologies such as gas-to-power (for example with microturbines and gas-to-product as in the case of gas-to-fertilizers) could reduce flaring by 25 percent, while generating positive returns.

To reduce the remaining flared volumes, economic incentives can be used to push the gas to market rather than flare it. Nigeria, for example, has introduced a fee of $2 per thousand cubic feet of flared gas, driving a reduction in flaring by 50 percent over the last decade[24].

The energy used in the process of extracting and refining hydrocarbons accounts for almost 40 percent of sectoral emissions and has potential for NPV positive reduction.

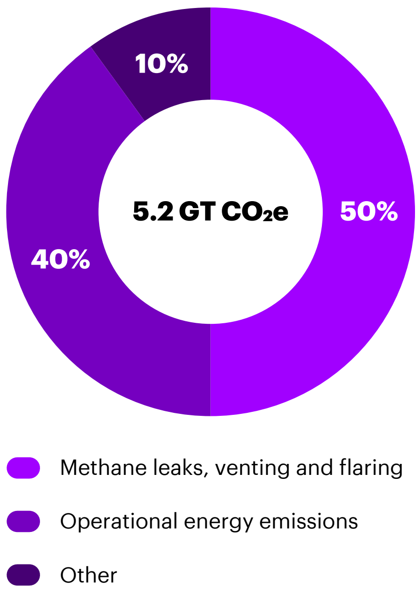
Direct emissions from energy required for upstream, midstream and downstream activities make up 39 percent of the total direct CO_2e emissions that are released by this sector[25]. Direct emissions are expected to increase as production volumes continue to grow and as resources that are easier to extract are replaced by more energy-intensive ones.

Some upstream operators have achieved 15 to 20 percent energy efficiency gains, equivalent to a 5 to 7 percent reduction in total sector emissions, by deploying only those initiatives that are proven NPV-positive before factoring in a carbon price[2]. Energy efficiency improvement gains downstream, on the other hand, are likely to be more limited. That's because energy usage in this part of the value chain has a greater impact on margins and is, therefore, more optimized today. Enhancing performance and predictability of current operations can also bring energy intensity down. This involves ensuring that equipment is operating within its envelope and reducing frequency of events.

Operators can further reduce energy intensity during extraction by shifting to power generation from low-carbon sources and replacing existing fleets with electrified equipment. Recent deployments of "power-from-shore" and "floating wind/solar farm" solutions for platforms have the potential to deliver up to 20 percent of the offshore energy requirement by 2030. This is equivalent to a 2 to 3 percent total emissions reduction, while increasing sales revenue from produced gas by up to 2 percent[2].

Figure 16

Global greenhouse gas emissions from hydrocarbon extraction and refining



Source: IEA; The Oil and Gas Industry in Energy Transitions; Accenture Analysis

Increased deployment of CCUS technologies could reduce sector emissions by up to 80 MTCO2e per year by 2030.

Despite only having limited potential for an impact on the sector's emissions, increased CCUS deployment would open opportunities for monetization in other sectors, such as heavy industry, which are likely to rely on it heavily for decarbonization.

The oil and gas industry is the world leader in deploying CCUS solutions, particularly through enhanced oil recovery (EOR). Oil and gas companies are rapidly scaling their use of CCUS technologies as a crucial means to meet emission-reduction targets. As of February 2020, 16 large operators had launched or announced CCUS projects. We expect CCUS technologies to attract $25 billion in investments by 2030 and reduce emissions by up to 80 MTCO2e per year[26].

Oil and gas operators have a competitive advantage over other industries in deploying CCUS technologies. They have access to an abundance of high-concentration CO_2 streams from natural gas liquids (NGL) processing facilities, reservoir access for underground sequestration and utilization, and the availability of pipeline infrastructure for CO_2 transportation. If they are to meet net-zero targets, including Scope 3 emissions, oil and gas companies will need to sequester a great deal of CO_2 emitted during final hydrocarbon consumption in other industries.

Implications and actions for oil and gas companies

As they look ahead to 2030, operators will need to increase the sophistication of their portfolio strategies to balance breakeven price, emissions intensity and evolving demand outlooks to increase returns, while reducing the risk of future asset write-downs. Being able to show clear linkages between company targets, portfolio decisions and the Paris Agreement target is likely to become increasingly important as a factor in attracting capital to the sector.

In parallel, immediate action is needed to Clean the Core of oil and gas operations. Reducing the emissions intensity of existing portfolios through methane leakage reduction and reduced flaring will have the single greatest impact on the sector's emissions, and much can be done to generate a NPV positive return. Decreasing energy intensity of operations through increased operational efficiency and low-carbon power sources can, likewise, be NPV positive.

As part of a holistic approach to emissions reduction, choosing service providers with the lowest carbon footprint will become increasingly important. Oilfield equipment and services (OFES) firms, as well as engineering, procurement and construction (EPC) companies, need to increase the transparency of their emissions-reduction efforts and demonstrate a clear pathway to reducing the emissions intensity of their activities.

Finally, what the oil and gas industry learns as it decarbonizes can be reapplied to drive new growth opportunities across other industries. For example, the CCUS technology pioneered in upstream oil and gas can be leveraged by heavy industry, opening up new monetization opportunities for the hydrocarbon sector.

We see four discrete sets of actions that oil and gas companies can take to mitigate the risk to core business.

1. **Increase sophistication of portfolio management and capital planning to balance financial and environmental objectives.**
   - A. Utilize a dynamic approach that evaluates the competitiveness and fit of assets (based on their economic and emissions profile) and allows for optimization within the hydrocarbon portfolio and across the extended enterprise portfolio, which may include non-hydrocarbon assets and capital-light new energy solutions businesses.
   - B. Include carbon pricing consistent with net-zero objectives in all capital investment decisions and asset lifecycle forecasts.
   - C. Aggressively manage exploration and M&A/A&D activity and set up mandates to build up low-emission assets.

2. **Monitor and reduce Scope 1 and 2 emissions across portfolios and services.**
   - A. Build capabilities to measure and evaluate emissions and the overall carbon footprint at a granular level.
   - B. Manage methane by taking advantage of leak-detection programs and satellite information to detect and repair leaks. Integrate predictive analytics to enable changes in operational processes ahead of a leak event.
   - C. Reduce venting and flaring. Re-assess brownfield capital opportunities to install vapor recovery units and gas collection infrastructure. Prioritize NPV positive investments linked to commercial opportunities for the gas. Over time, install vapor recovery as a matter of course. Evaluate and adopt zero-flaring policies.
   - D. Collaborate with supply chain partners by letting them play the decarbonization role in some cases and reward / select them based on it. Share the burden of CAPEX investment in turning over the equipment capital stock with the services and equipment sector. Incent the supply chain to adopt low-emissions solutions. Operators should be selective as to where they, themselves, can develop the capability versus leveraging partners.

3. Reduce the energy intensity of operations.

A. Build operations consistency. Take an emissions-centric approach to maintenance and ensure assets operate in the windows that minimize emissions and maximize energy efficiency.

B. Drive automation and digitization. Reduce the need for transportation to and from facilities, reduce the size and complexity of facilities through automation, and reduce the requirement for people on board (lowering requirements for helicopter trips and supply vessels).

C. Shift to low-carbon intensity energy sources. Add solar and wind assets to displace diesel and grid power. Potentially add nuclear power to, for example, reset the emissions profile for oil sands. Focus on reducing waste energy. For example, a leading service company installed automatic hydraulic fracturing pump startup and shutdown and significantly cut fuel wasted during idling.

D. Deploy circular solutions to reuse energy in the field, reduce emissions as waste, and lower demand for materials.

4. Continue to increase CCUS deployment for EOR.

A. Build on the industry's technological advantage in this area with a view to leverage to other industry sectors.

Power generation

Accenture 2050 stretch goal

86 percent reduction from 2050 business-as-usual emissions through accelerated displacement of coal by gas and 70 percent renewables penetration.

The brief

Our top levers to reduce emissions from operations in the power sector.

1. Pause construction of new coal power plants and phase existing coal out of the system through:
   - A. Accelerating transition to competitive "clean" gas (Accelerate the Transition).
   - B. Achieving 70 percent penetration for renewables (Accelerate the Transition).
2. Solve for long-term storage / carbon-free baseload to completely decarbonize the sector (Extend the Frontier).

The power sector is the single biggest contributor to greenhouse gas emissions, accounting for approximately 38 percent of global CO_2 emissions.

Out of this 38 percent, coal-fired generation alone accounts for around 30 percent, with gas and oil making up the remaining 8 percent. The sector is also the single biggest market for gas, making up almost 40 percent of total demand[26].

Globally, today's electricity demand of 28,000 TWh is expected to rise to 41,400 TWh by 2040 (+2.1 percent per year)[27]. That increase is driven by multiple factors: the increased electrification of buildings, transport, and industry; population growth of two billion people; 0.8 billion more people with access to electricity grids; and increased energy usage per capita in developing economies. The contribution of the power sector to emissions, coupled with increased electrification of other sectors, means the success of the Decarbonization Transition is highly dependent on what happens in power.

Gas should play a significant role in the power transition, but economics may get in the way, given that by 2025, LNG costs will need to drop up to 40 percent to ensure gas displaces coal in key markets such as India[28].

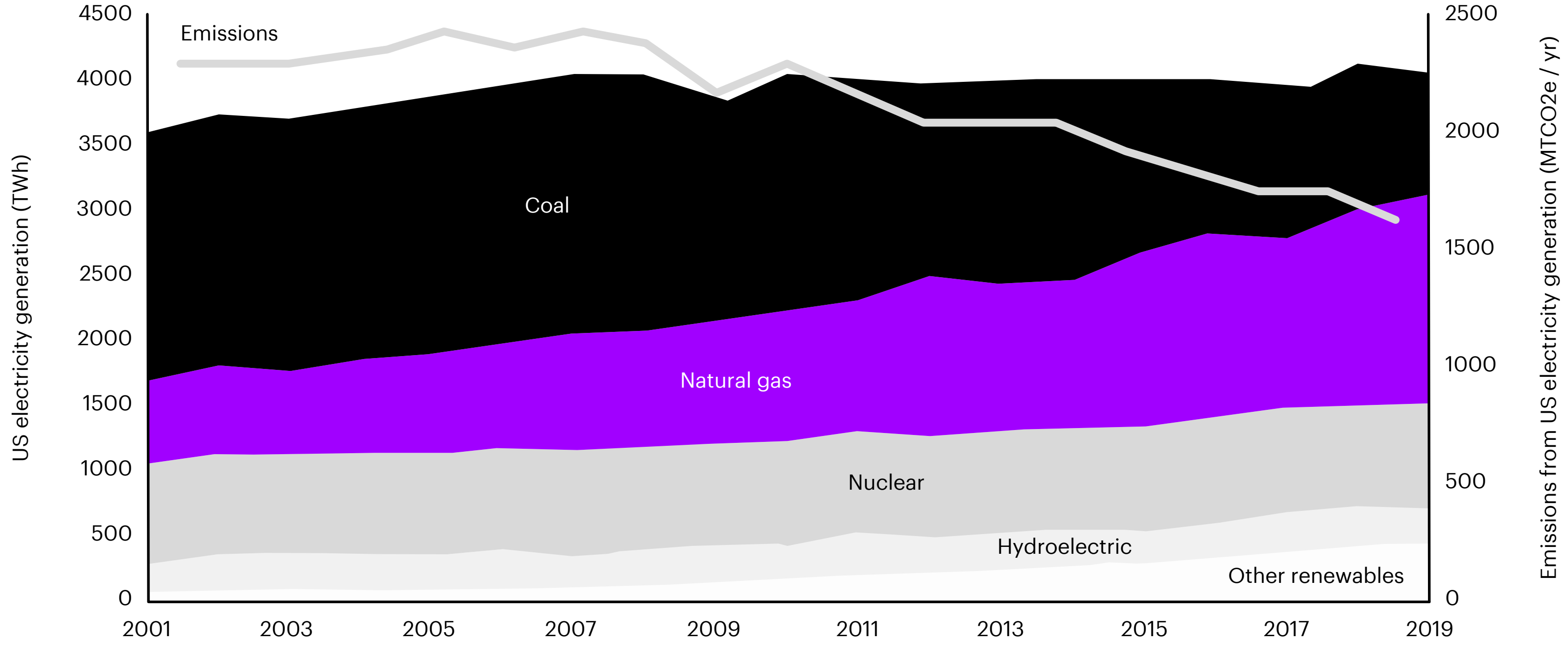
Globally, coal power generation is the single largest contributor to greenhouse gas emissions. The acceleration of its removal from the power sector is the biggest lever that can be pulled in the near-term. Despite coal generation being in relative decline in the OECD, global capacity has doubled since 2000 to 2045 GW, largely driven by India and China. With a further 200 GW of capacity under construction and further 300 GW planned, active intervention will be required to reverse the increase in coal-related CO_2 emissions.

To date, the primary lever used to abate power-generation emissions has been the switch from coal to gas generation, on the basis that CO_2 emissions per unit of energy from gas are about half those from coal.

Historically, gas has replaced coal in markets where cheap gas or implicit carbon pricing—in which the cost of emissions is passed to the polluter—has made the transition economically feasible, and where the stock of existing coal plants was older and less efficient. In Europe, for example, the switch was driven by implicit carbon pricing; in the United States, it was enabled by the availability of inexpensive gas.

Figure 17

US power mix and power-sector emissions 2001 to 2019



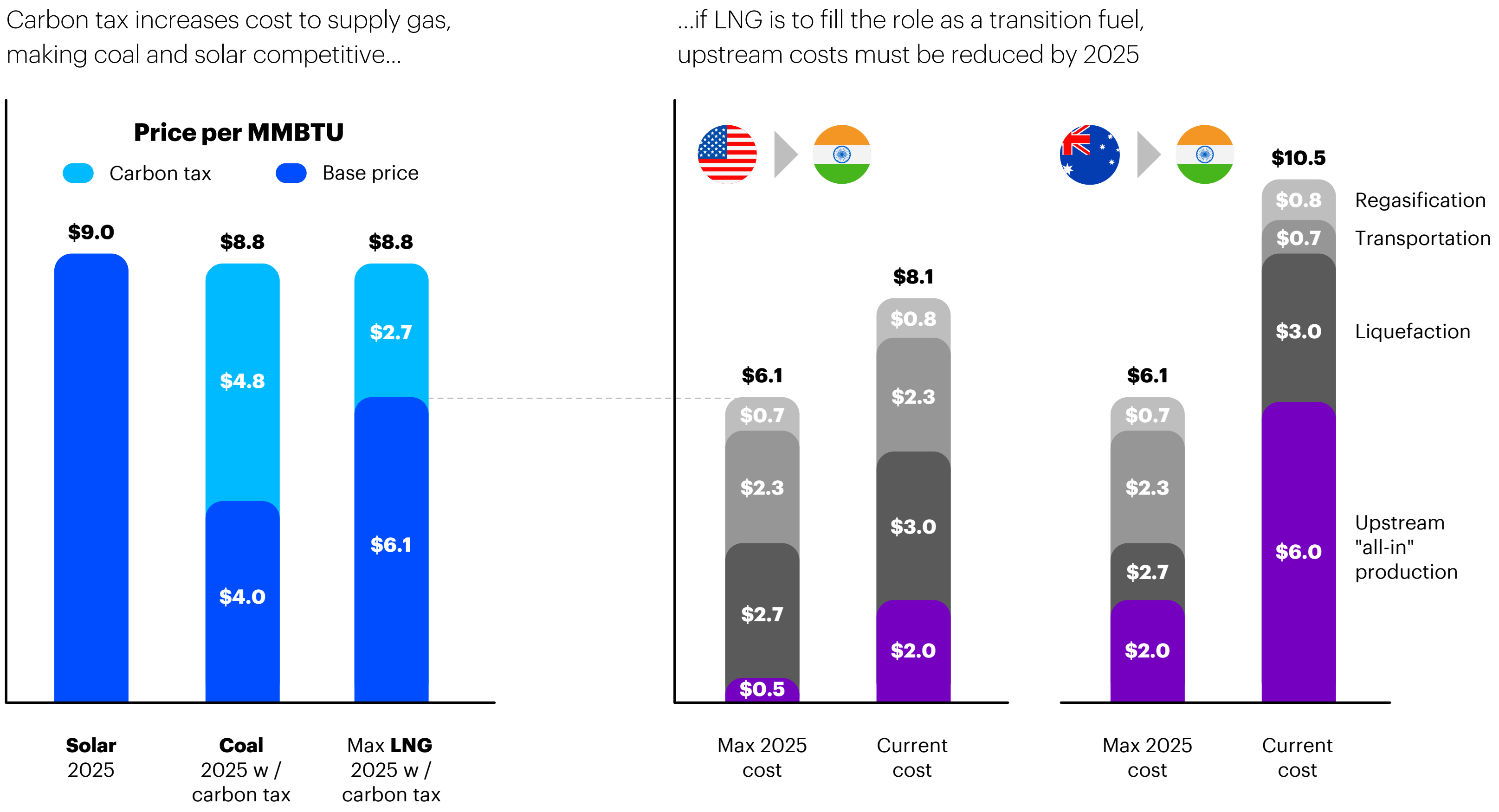
Source: EIA; Accenture Analysis

In most markets, however, the pace of transition to gas is now slowing since remaining coal generation and the opportunities for economic transition have diminished. In China and India, gas continues to be more expensive than coal, requiring a carbon price of \$50-\$100 per total carbon dioxide (TCO_2) to be cost-competitive[29]. In addition, coal generation in these countries is produced by modern, efficient plants many years off retirement.

For gas to increase its presence in these markets and compete with the ever-decreasing costs of renewable generation, there will need to be either a significant decrease in the cost of landed LNG, a significant increase in carbon pricing, or direct state intervention through mechanisms such as subsidies. For example, in India, our modeling shows that the cost of source gas required to economically land LNG would have to go down significantly to compete with coal and solar, even at a carbon tax of \$50/ton[5].

Figure 18

Costing scenarios for gas to enable Decarbonization Transition in India



(a) Coal base price held constant over period. (b) Max LNG prices do not consider cost of expanding LNG production facilities. (c) Carbon tax set to \$50/ton
Source: EIA; Accenture Analysis

Up to 70 percent intermittent renewable penetration is now possible without a long-term energy storage solution.[6]

Intermittent renewable costs associated with solar photovoltaics (PV) and wind have plummeted in recent years. During 2019 auctions, renewables were competitive at prices which, just two years previously, were not forecast to occur until 2030. Recent solar PV auctions in Portugal were as low as $16/Mwh. And North Sea offshore wind is now competitive at around $50/Mwh[30].

New-build renewables are now forecast to become cheaper than operating existing gas and coal plants in most emerging markets by 2030. That throws further doubt on a transition to gas at current LNG costs. Once renewables are cheaper than existing hydrocarbon generation, their deployment is likely to accelerate.

There is a second, previously unforeseen, consequence of the falling price of renewables and storage. The new price points have opened up the possibility of having up to 70 percent intermittent renewable generation in the grid before the cost of managing the intermittency becomes greater than existing coal and gas generation. At previous price points, there was just 40 to 50 percent penetration. Admittedly, this will require a shift in mindset from using every kWh of renewable power produced to an acceptance of overcapacity and curtailment.

At a price point of $20/Mwh, 40 to 50 percent renewables overcapacity can be built in and still be economically competitive with alternative power sources. Beyond 70 to 80 percent penetration, the exponential increase in overcapacity required to cover the more extreme supply and demand fluctuations makes it unlikely that the requirement for long-term energy storage or renewable non-intermittent resources will ever go away.

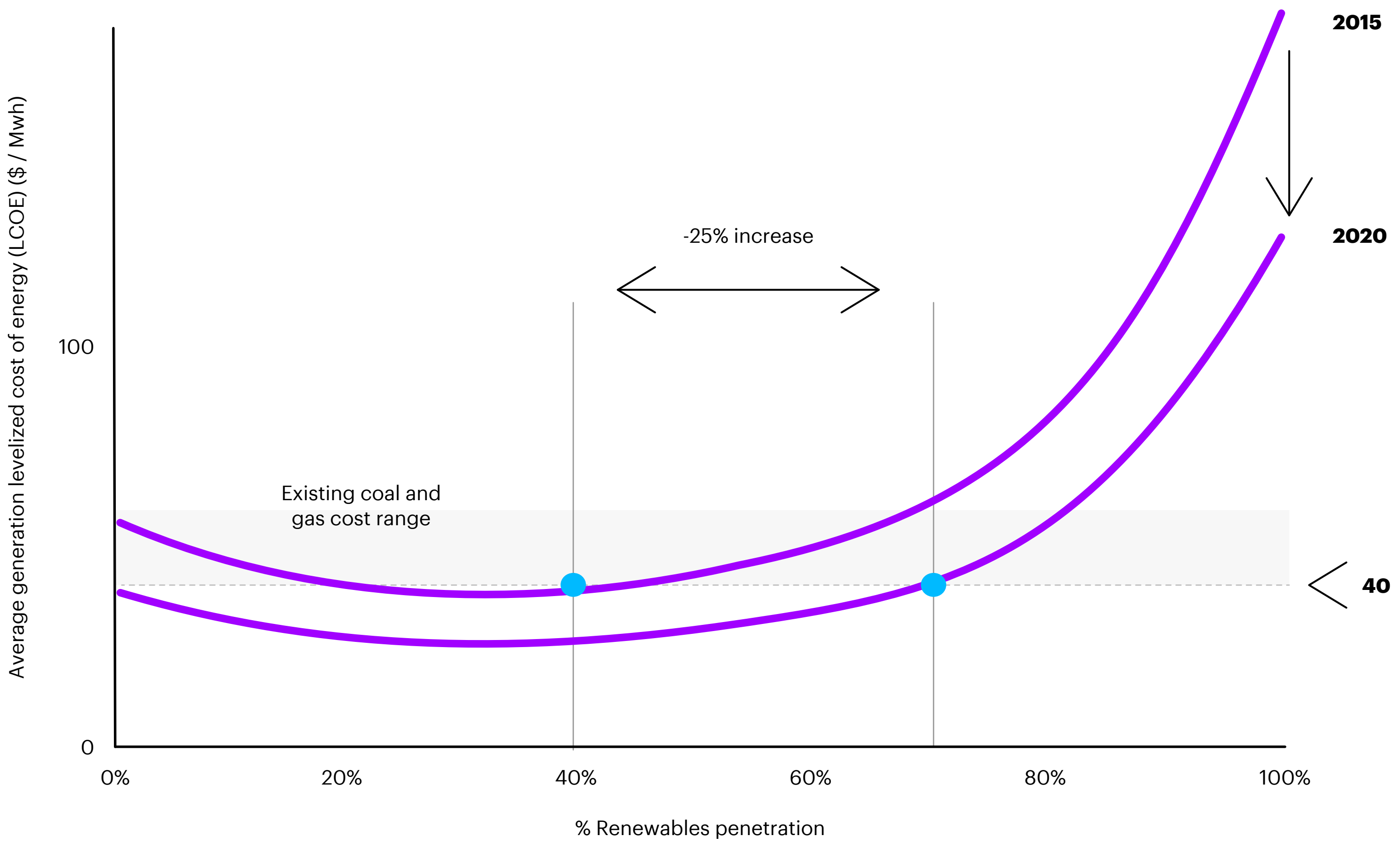
This development does, however, buy time. At the current rate of capacity increase, most countries and regions are many years away from reaching this limit of 70 percent penetration (25 years in China, 60 years in Europe and the United States). This suggests that renewables capacity can continue to increase in an uninhibited way, and the pressure to solve the long-term, inter-seasonal storage problem will recede. The infrastructure focus will instead switch to upgrading and increasing transmission and distribution capacity[5].

Moving from a mindset of "we must use every megawatt hour produced from renewables" to "we can accept a degree of overcapacity and curtailment" significantly reduces energy storage demand and opens the possibility of "free" surplus electricity to produce hydrogen. Meanwhile, the costs of short-term energy storage for day-to-day balancing have plummeted as lithium-ion battery technology has matured. With economic constraints receding, the other capacity constraints of land use and materials requirements will come to the fore.

Figure 19

Source: IEA; Accenture Analysis

Percentage of renewables penetration possible before intermittency management cost is prohibitive



A completely decarbonized power system will require either a solution to long-term energy storage or expanded sources of non-intermittent, economical carbon-free generation.

At present, there is not an economical solution for completely decarbonizing the remaining 20 percent of the grid that cannot be filled by intermittent generation plus current storage technology. The most likely route for this appears to be nuclear, which is economically uncompetitive and politically sensitive as a viable solution to the long-term energy storage problem.

At this time, the cost of nuclear power generation is more than double the cost of renewables. The proposed Hinkley Point nuclear power station in the United Kingdom has a cost of nearly $100/Mwh, compared to $40/Mwh for offshore wind[31]. Nuclear would, therefore, require subsidies to compete.

Furthermore, nuclear disasters such as Chernobyl and Fukushima have made the future of nuclear power generation extremely uncertain. Countries such as Germany have already turned off their plants and replaced generating capacity with coal. Although small, modular nuclear reactors offer the potential for multiple applications and are considered safer, they are not yet commercially viable and will struggle to compete with other energy sources on a levelized cost of energy (LCOE) basis.

While short-duration battery storage for operating reserve, power fleet optimization and grid shutdown/restart service applications are increasingly economically viable, long-term inter-seasonal storage requirements to allow 100 percent intermittent generation remain unmet. And that is despite investments in areas such as compressed air energy storage, pumped hydro and hydrogen.

Implications and actions for oil and gas

The direction and pace of the Decarbonization Transition in the power sector have stark implications for gas. Many oil and gas companies have shifted their portfolios to gas in the past decade. They believe that gas will act as a transition fuel between coal and renewables, primarily through a sizable share in the growing electricity sector. They further believe that gas demand growth will hold up more than oil. However, the rapidly plunging costs of renewable generation and day-to-day storage facilities put this strategy at risk. By 2030, existing gas generation will be uncompetitive with new-build renewables. The implication is that the number of new gas plants built will be limited.

In some geographies, transition in the power sector, as a whole, may happen faster than expected. And based on current projections, gas demand looks unlikely to keep pace with growth in electrification. In addition, once coal is transitioned out of the power system in OECD countries, gas will increasingly find itself in the crosshairs of decarbonization policies in developed countries.

Gas will still play a key role in peaker plants and in geographies with cheap supply. But it will need to also play a dominant role in pushing coal generation out of the system in countries such as India and China if it is to reach its potential as a transition fuel. Without gaining a significant share of the power supply market in these countries, the role of gas as a transition fuel in power generation may be a localized phenomenon in markets with cheap gas such as North America, the Caucasus and Middle East. Simply put, its prospects as a "true" commodity could be stunted.

We see three discrete actions that oil and gas companies can take to secure a role in the provision of cheap, clean and available power to the world in next 30 years.

1. **Drive a step change in the competitiveness of gas.**
   - A. Value chain economics must improve by up to 40 percent to drive coal out of the system in developing countries.
   - B. Scope 1 and 2 emissions must be cut by 50 percent by working together to collectively decarbonize the gas value chain through methane and flaring reduction, clean gas blending, and the creation of a carbon market for economic CCUS solutions. Deploying and enhancing CCUS during LNG liquification must be a particular focus.

2. **Refine "transition to gas" portfolio strategies to reflect the evolving power landscape.**
   - A. Segment target gas markets by the sensitivity of gas in the power mix—that is, its potential to substitute coal, as well as its potential to be substituted by renewables, versus the ability to deliver cheap gas into that market to reduce the risk of stranded assets.
   - B. Promote the use of gas/clean gas to solve the problem of long-term energy storage.

3. **Maintain market share in power generation by moving into renewables where skillsets are complementary or adjacent. Examples include:**
   - A. Offshore wind.
   - B. Major capital programs in renewables of all types.

Light-duty passenger vehicles

Accenture 2050 stretch goal

71 percent reduction from 2050 business-as-usual emissions by accelerating electric vehicles, penetration to 50 percent, while also doubling internal combustion engine efficiency.

The brief

Our top levers to reduce emissions from operations in the light-duty passenger vehicle sector.

1. Get ICE fuel efficiency back on track (Clean the Core).
2. Accelerate EV total operating cost reduction (Accelerate the Transition).
3. Build out EV-supporting infrastructures and expand supply chains (Accelerate the Transition).

The light-duty passenger vehicle sector currently accounts for roughly 10 percent of global CO_2 emissions and it accounts for 23 percent of oil and gas demand.

All this sector's emissions originate from the combustion of oil and gas products. Demand for light-duty passenger vehicles will likely be influenced by two major trends over the next three decades[2].

Our business-as-usual models project that by 2050 the number of cars on the road increase by 150 percent, from 1.1 billion today to about 2.7 billion. This is aligned with forecasts that predict a doubling of total kilometers traveled to more than 20 trillion per year. The personal mobility surge will be driven largely by GDP growth in developing countries.

The business-as-usual view of this sector suggests internal combustion engine (ICE) vehicles will continue to dominate the market, increasing from about 1.1. billion vehicles today to 2.2 billion by 2050. The remaining 500 million cars will be electric vehicles (EV), largely in the OECD markets[2].

Despite this second trend having the potential to decouple new sales growth from mileage demand growth, it is clear that light-duty passenger vehicles will continue to incur significantly increased CO_2 emissions through 2050 if alternative technologies are not accelerated.

With high hopes for fuel efficiency improvements fading, there are limited opportunities for market forces to get fuel efficiency rates back on track.

Fuel efficiency is a vital component in the emissions-reduction strategy for light-duty passenger vehicles. In fact, our analysis shows that increasing efficiency from 0.7 percent per year to 2 percent would have a greater impact on the sector's emissions in 2050 than doubling the projection of EVs on the road from 500 million to one billion.

Unfortunately, the average fuel economy of light-duty vehicles increased by barely 0.7 percent in 2017, compared to a previous 10-year average of 1.8 percent per year. More than 20 countries even experienced reduced fuel economy compared to previous years[32].

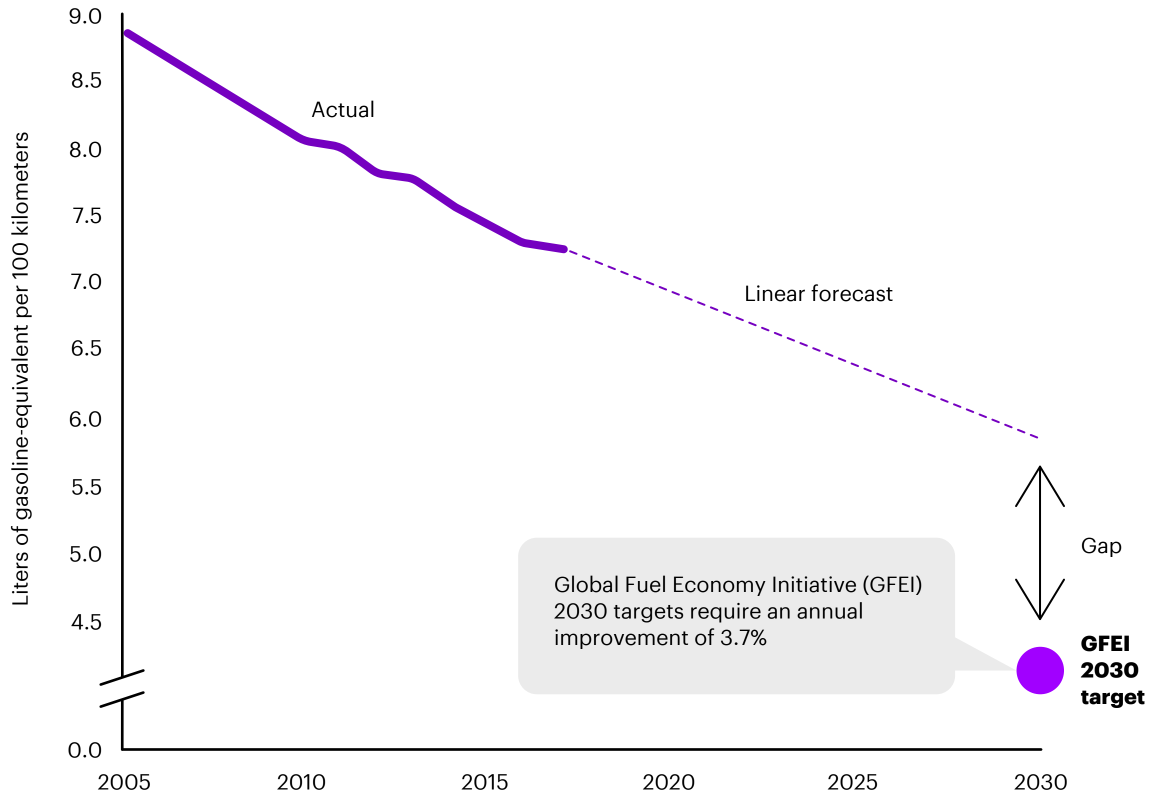
This slowdown is attributed to consumers purchasing both larger, heavier cars like SUVs and fewer diesel cars. As a result, it is highly likely that the 2030 target set by the Global Fuel Economy Initiative (the leading global partnership on fuel efficiency), requiring a 3.7 percent annual rise in efficiency, will be missed.

With EVs on the horizon, automakers have limited incentive to develop the next model of ICE vehicles and several have slowed or stopped development of next-generation ICEs in favor of electric propulsion. Outside the field of battery technologies, R&D is likely to focus on areas that benefit both ICE vehicles and EVs, such as aerodynamics, light-weighting and reduced rolling resistance.

The ball appears to be in the policymakers' court to provide the incentives needed to get the fuel-economy trend back on track. While many countries have a combination of fuel-efficiency policies in place, the major issue with existing fuel economy regulations is duration. Most are not guaranteed to last beyond a few years. The uncertainty this introduces does not spur the action required from fuel producers and retailers, automotive manufacturers and consumers.

Figure 20

Average new global fuel economy of light-duty vehicles



Source: Accenture Analysis; IEA; GFEI

Figure 21

Projected 2050 light-duty vehicles emissions (GT CO_2/yr)

# EVs on the road	Annual internal combustion engine efficiency gains: No gains	0.7% gains	1% gains	2% gains
No EV	8.2	6.6	6	4.3
500M EV	7	5.6	5.1	3.7
1Bn EV	5.5	4.4	4	2.9

Source: Accenture Analysis

The total cost of ownership of smaller electric cars has already reached parity with internal combustion engine vehicles. Larger electric cars are on course to reach parity by 2025.

Light-duty EVs will reach total cost of ownership parity with ICEs in the next five years—and leave them completely behind by 2030.

Electric vehicle costs fell by 20 percent in the four years to 2020. A further 20 percent reduction is expected by 2025 due to rapidly falling battery costs[2]. In fact, thanks to the subsidies and tax breaks offered across the OECD, the total cost of ownership of smaller EV cars and buses has already reached parity with ICEs. Larger EV cars and small-to-medium-sized vans are on course to reach parity by 2025.

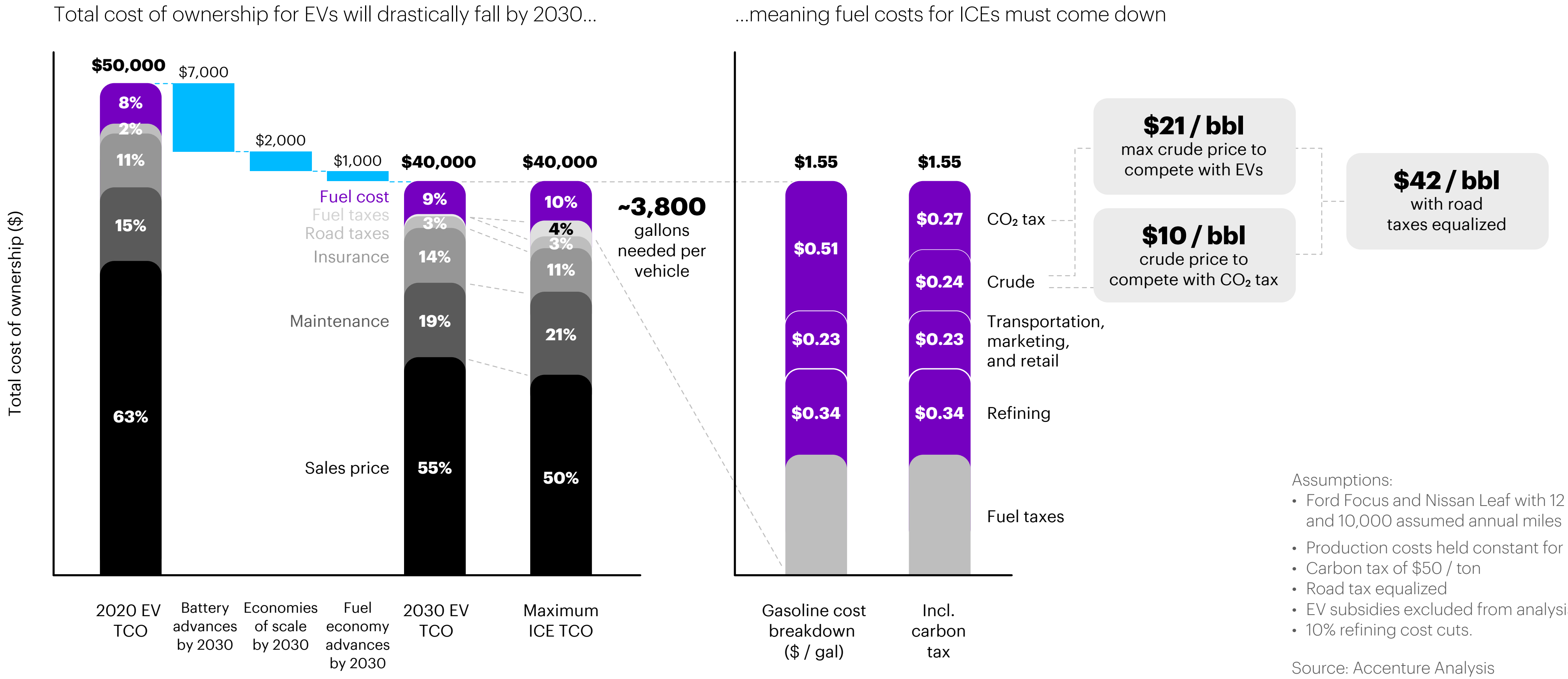
Our modeling suggests ICEs will need a crude oil price of around $40/bbl to compete on a total cost of ownership basis with EVs by 2030. This reduces to around $20/bbl if today's fuel taxes are not passed on to EV owners. Fuel producers and retailers will, therefore, need to take it upon themselves to promote greater efficiency to ward off environmental and economic pressures on the ICE.

While EVs have higher upfront costs but lower running costs than ICEs, the annual fuel costs for an EV are 40 to 50 percent lower than those for an ICE. And, because EVs have just 20 moving parts compared to 2,000+ for ICEs, servicing and maintenance cost are also lower, on average[5].

With cheap renewable power generation achieving ever-greater grid penetration, the economic and environmental case for EVs looks only set to improve year-on-year.

Figure 22

US scenario for evolving light-duty vehicle costs and impact on competitiveness of gasoline



Assumptions:

- Ford Focus and Nissan Leaf with 12 year life and 10,000 assumed annual miles
- Production costs held constant for ICEs
- Carbon tax of $50 / ton
- Road tax equalized
- EV subsidies excluded from analysis
- 10% refining cost cuts.

Source: Accenture Analysis

With economics looking increasingly favorable for electric vehicles, charging infrastructures and potential rare metal supply chain constraints become the biggest barriers to adoption.

Along with price and range anxiety, the lack of charging infrastructure is seen by many as the major barrier to the adoption of EVs. These concerns, however, appear to be receding. Modern EVs have ranges of over 300 miles on a full charge and a network of superchargers, spaced to enable almost any conceivable journey, can charge a battery to 50 percent capacity (i.e. around 150-mile range) in 20 minutes. An average daily mileage of just 30 miles in the United States, coupled with behavioral trends that show drivers now take regular breaks on longer journeys[2], suggest EVs are feasible today for all but a handful of journeys. It further suggests that the biggest barrier to EV adoption from a charging point of view is the lack of an overnight charging infrastructure for those who don't have their own garages.

A new global supply chain that connects rare metals mining, battery manufacturing and automotive manufacturing will emerge and give rise to potential supply constraints. The global annual power output of electric vehicles in GWh/year is expected to increase tenfold by 2030[33]. That will put the rare metal supply chain, which is required for battery production, under strain. Advances in battery technologies, however, are making them less rare metal intensive. They are also increasingly diversified in terms of source metals, as will be seen in the likely transition from lithium to nickel-manganese-cobalt batteries.

Implications and actions for oil and gas

With EV costs falling faster than predicted, total cost of ownership will hit parity with conventional ICE vehicles for most models in the next five years. In the short term, EV adoption rates will be determined by how fast the charging infrastructure is built, the ability to reduce range anxiety, and further cost reduction. In the medium term, rare metal and battery manufacturing constraints may come to the fore. In all cases, strong acceleration is expected over the next decade, creating a drag on oil demand growth.

Today, we have a shifting perspective on when peak oil for the light-duty vehicle sector will happen. It could be as soon as 2025. But every year, this window of uncertainty will become narrower and the timing clearer. In addition to the substitution threat from electrification, fuel retailers are also at risk of losing the associated sales from stores co-located at the pump. If more regulations are introduced to get fuel efficiency back on track, the nature of fuel retail sales volumes and product characteristics may change.

We see four discrete actions that oil and gas companies can take to accelerate decarbonization and maintain market relevance in the light-duty passenger vehicle market in the next 30 years.

1. **Accelerate the rollout of EV charging stations to existing fuel stations to capture market share before other players move in.**

2. **Double down on efficiency research, blending, branding and pricing to create differentiated fuel products, including additives that maintain engine cleanliness and performance efficiency.**

3. **Engage in the research into hydrogen fuel cell solutions for vehicles.**

4. **Promote fuel efficiency behaviors and driving practices to enhance fuel efficiency.**

Heavy-duty and commercial transportation

The following section covers heavy-duty road transportation, aviation and shipping.

Collectively heavy-duty road transportation, shipping and aviation account for around 12 percent of global CO_2 emissions, of which virtually all are from the combustion of oil and gas products.

Heavy-duty road transportation represents 17 percent of total oil demand, whereas shipping and aviation, combined, represent 12 percent[2].

While the key levers and trends within these sectors are covered separately, the implications for oil and gas are combined at the end of this section. That is because these sectors, collectively, will shape the future of middle distillate demand. Middle distillates are the portion of refined products that sit between the lighter gasoline and the heavier fuel oil (HFO). They include diesel, marine diesel oil (as an intermediary between middle distillates and HFO), extra-light fuel oil and kerosene, including jet fuel.

Within the following section, we will explore the feasibility of a number of decarbonized fuels based on their volumetric and gravimetric energy density and their emissions-reducing and economic credentials. In short, we set out to answer two questions:

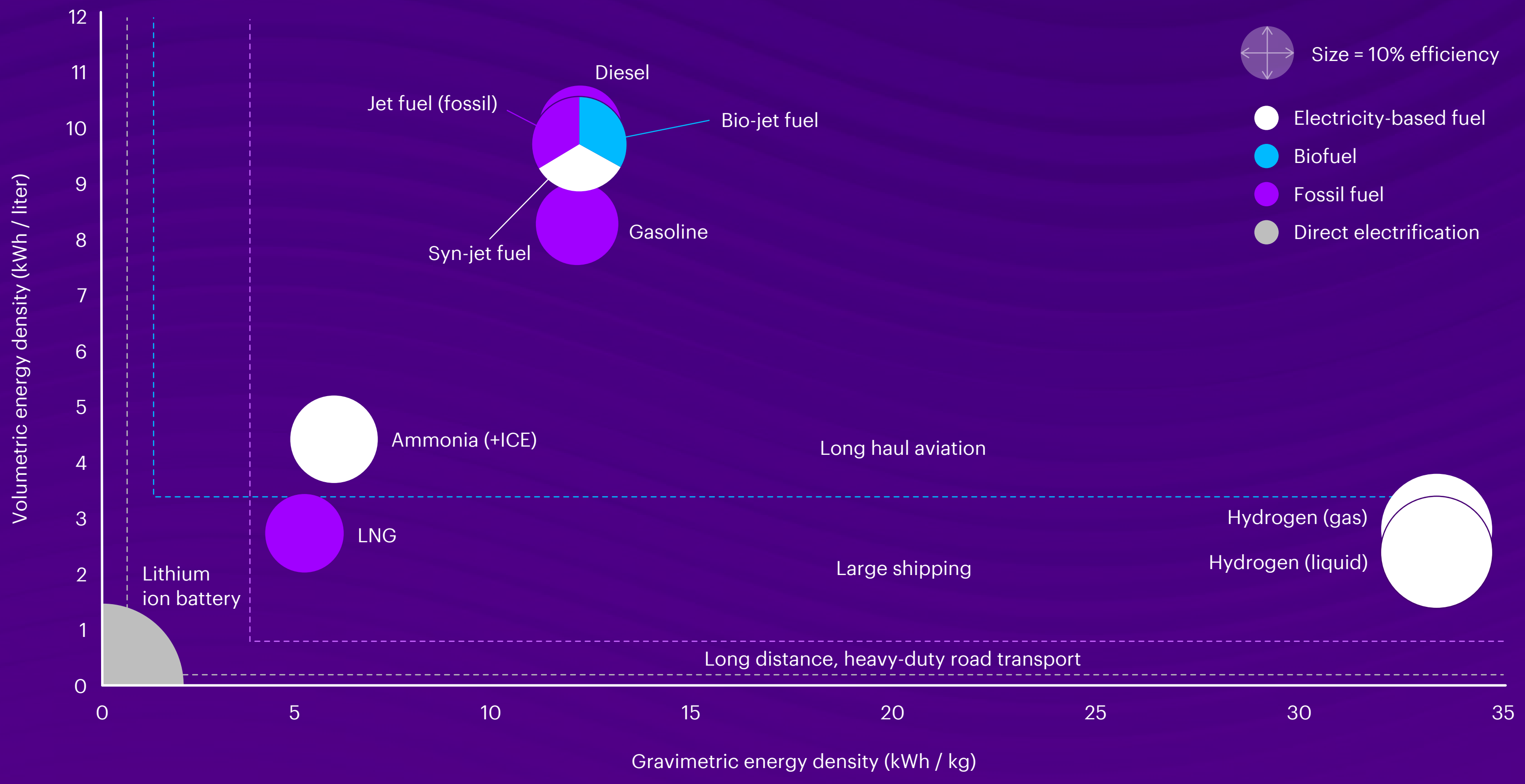
1. Do these decarbonized fuels produce enough energy for the storage volume they need, and do they produce enough energy given their weight?
2. Are they cost-competitive and carbon-reducing given today's carbon-pricing mechanisms and the carbon intensity of electricity?

To answer the first question, the different fuel sources have been plotted on these two axes with the feasible envelopes for different modes of transportation superimposed on top. This presentation provides an indication of which fuel types are suitable for each application. The size of the bubble represents the efficiency of the solution at the point of consumption.

Figure 23

Source: Accenture Analysis; Energy Transitions Commission; IEA

Technical feasibility of energy sources for transport based on volumetric and gravimetric energy density and efficiency



To answer the second question, we've plotted different fuel sources and their applications (light/heavy-duty road, shipping, aviation) on two axes:

1. Carbon pricing in $/ton required to achieve economic parity with today's incumbent solutions.
2. The electricity carbon intensity in gCO_2/kWh required to be less emitting than today's incumbent solutions.

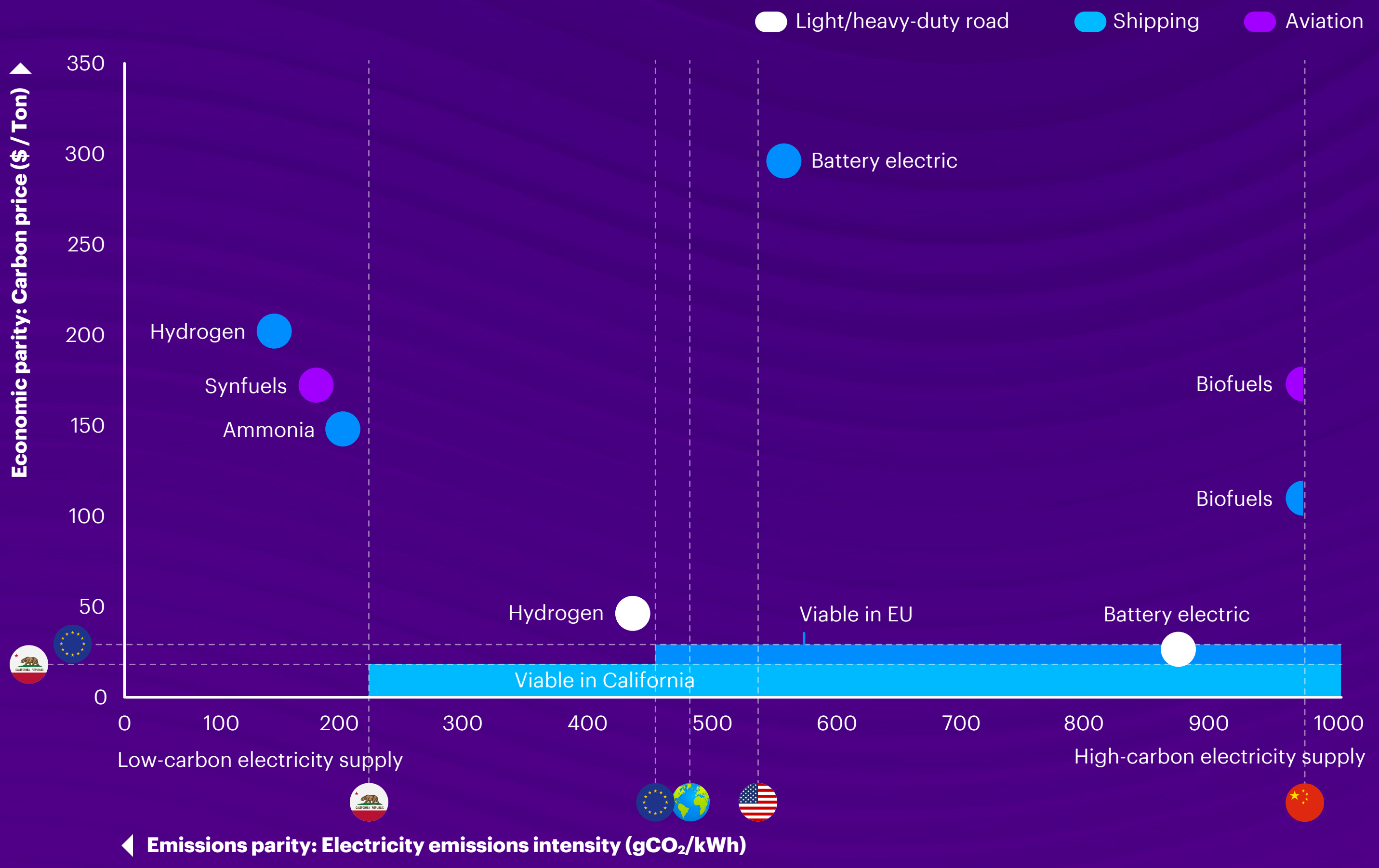
The viable envelope will, therefore, differ by geography and depending on its specific carbon price and electricity carbon intensity. The most viable solutions can be found in the bottom right, while the least viable are found in the top left. As electricity grids decarbonize over time, increased carbon pricing is introduced, and learning curves bring costs down, more of these solutions will become viable alternatives.

To illustrate this, we have shown the viable windows in California and the European Union today.

To avoid repeating the same charts multiple times, we have set out this viewpoint upfront and will refer to the conclusions as we turn the discussion to the heavy-duty transportation sector.

Figure 24

Economic and emissions parity required for clean transport fuels



Source: Accenture Analysis; IEA, Energy Transitions Commission

Heavy-duty road transportation

Accenture 2050 stretch goal

78 percent reduction from 2050 business-as-usual emissions through efficiency increases and electrification.

The brief

Our top levers to reduce emissions from operations in the heavy-duty road transportation sector.

1. Maximize operational, logistical and energy efficiency (Clean the Core).
2. Accelerate EV total cost of ownership reduction (Accelerate the Transition).
3. Increase investment in renewable fuel decarbonization pathways (Accelerate the Transition).

In a business-as-usual scenario, heavy-duty road freight volumes are expected to triple by mid-century, in part because they are strongly correlated with rising prosperity.

Growth will be concentrated in major emerging economies such as India, the ASEAN economies and Africa, whereas growth is expected to slow in mature economies such as the European Union, United States and even China.

Non-urban, long-distance traffic is forecast to grow more rapidly than short-distance traffic, say, within a city. This makes it particularly important for the heavy-duty vehicle sector to develop decarbonization options.

Demand management and energy efficiency are under-used levers today and could contribute most of the required emissions reductions in heavy-duty road transportation.

The reduction in emissions from demand management would arise from a combination of the following.

1. **Curbing traffic volumes** through better demand management, for example, routing, timing and hub optimization; platooning; co-loading and crowd-shipping; and use of high-capacity vehicles (25 percent reduction).
2. **A shift of heavy-duty freight volumes** to more carbon-efficient rail networks or inland and coastal shipping (up to 10 percent reduction).
3. **Local and national interventions** to improve driver training, limit speeds and reduce fuel consumption (5 percent reduction).

When it comes to energy efficiency, heavy-duty vehicles have stagnated in recent years and fallen behind the light-duty vehicle sector, which has a much stronger regulatory environment. Our modeling estimates that a total efficiency gain up to 40 percent is theoretically possible with improved aerodynamics and greater energy efficiency[2].

Electrification of heavy-duty road transportation is taking off.

Heavy-duty road transportation sits on the edge of feasibility limits for batteries, given their volumetric and gravimetric energy densities. But continuous advances in battery technology will likely make all but the heaviest of loads for the longest journeys feasible.

Several companies are betting big on the electrification of heavy-duty road transportation, with new models starting to hit the market and others expected through 2021. While there are still questions around the optimal charging strategy for such trucks, and production at scale has yet to begin, cost parity with ICE trucks is expected to be achieved by the end of the decade.

A switch to EVs in heavy-duty trucking is likely to be more complete than for light-duty vehicles. That's because logistics companies focus on the bottom line more than consumers do, and because fleets will be replaced en masse once cost parity is surpassed. The development of the autonomous driving capabilities of trucks could also significantly reduce operational costs by ultimately removing the need for a driver.

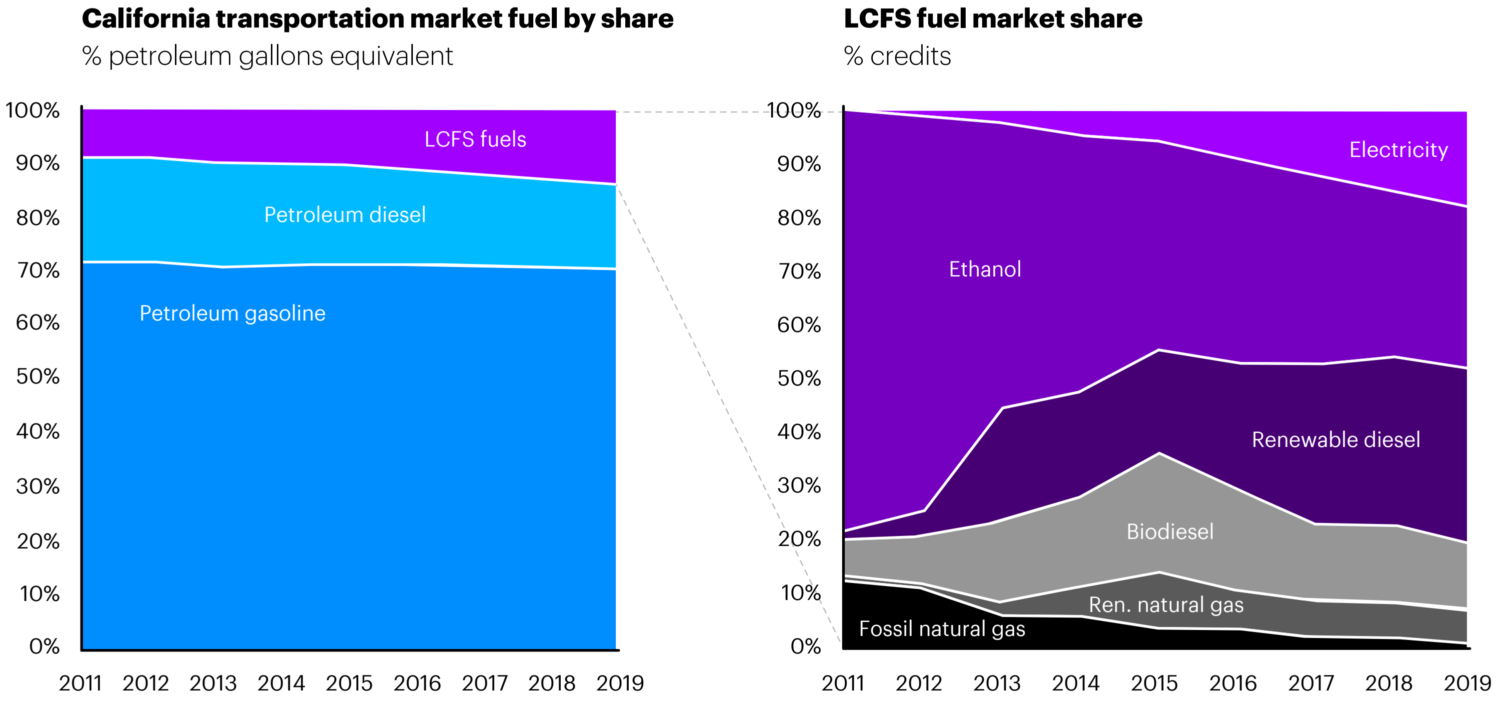
As more near-term solutions to decarbonization are emerging in this space, biodiesel, renewable diesel and renewable natural gas are also putting pressure on petroleum diesel demand.

While these solutions may be more localized and supported by generous tax credits and subsidies, their impact on petroleum diesel in select markets should not be understated. In California, petroleum diesel usage has dropped over the past decade despite an increase in heavy-duty transport miles. Refiners producing renewable diesel in the market have seen profit margins of up to 45 percent, with operating costs covered by subsidy breaks alone.

The threats to these bio-based renewable fuels posed by decreased cost of electrification, potential feedstock supply constraints as demand increases, and removal of subsidies may limit the development of this market in the mid- to long-term.

Figure 25

Localized impact of biofuels in California's incentive-driven market



Source: California Air Resources Board; Accenture Analysis

Aviation

Accenture 2050 stretch goal

63 percent reduction from 2050 business-as-usual emissions through a multi-faceted approach.

The brief

Our top levers to reduce emissions from operations in the aviation sector.

1. Maximize demand management and energy efficiency levers (Clean the Core).
2. Accelerate electrification of short-haul flights (Accelerate the Transition).
3. Reduce costs of biofuels and synfuels for long-haul flights (Extend the Frontier).

Passenger miles have increased 12-fold since 1970 and are forecast to grow by 238 percent through 2050 in a business-as-usual scenario, primarily driven by income-elastic tourism demand.

While domestic flights carry more passengers every year, international flights account for around 65 percent of passenger-miles flown. Both segments are expected to grow significantly through 2050[34].

Both passenger and freight air traffic are strongly correlated with growing global income. The largest increases in passenger air travel will be concentrated in parts of the world experiencing rapid income growth. The Asia-Pacific region is expected to account for more than 50 percent of new passengers by 2036[2].

Demand management measures could reduce 2050 business-as-usual emissions by 10 to 15 percent[2].

Demand reduction and energy efficiency improvements both play a role in reducing emissions in the aviation industry. However, both also face stiff challenges—the former, because of the high elasticity of air travel demand; the latter, because of slow fleet turnovers and a conservative approach to implementing innovations.

Our modeling suggests that up to 15 percent of emissions could be reduced through better demand-side management.

1. **Shifting short-haul passenger flights to rail**
   Successful examples include China's high-speed network, Japan's Shinkansen and the Eurostar (up to 6 percent reduction).

2. **Reducing demand for leisure travel**
   (up to 4 percent reduction).

3. **Reducing demand for business travel***
   (up to 3 percent reduction).

4. **Improving operational efficiency through better air-traffic management**
   by optimizing routing, minimizing flight waiting times and distances, etc., (up to 2 percent reduction).

The fuel efficiency of aircraft has improved by 80 percent since the 1960s, thanks to improvements in engine efficiency and aerodynamics. Additional improvements of up to 20 percent are possible before the limits of thermodynamics are reached[35].

New engine designs and use of lighter, composite materials could decrease emissions by 10 to 20 percent in the early 2020s. Additional reductions of up to 30 to 40 percent are possible by 2030 through innovations like laminar flow control and fuel cells for onboard energy. Beyond 2030, improvements are harder to foresee[36].

However, the lifespan of passenger aircraft is 25 to 30 years which, coupled with the sector's conservative approach to adopting new materials and designs, will hamper its ability to curb emissions through increased efficiency. Retrofits by carriers are, therefore, an important lever and are expected to yield a 6 to 9 percent reduction[2].

* The long-term impacts of COVID-19 on business travel are yet to be seen but could have a more significant effect on this sector than the pre-crisis estimates indicate

Short-haul electric flights are taxi-ing, ready for take-off.

Networks of electric planes are beginning to emerge in countries such as Norway for short-haul flights. The country has set ambitious goals; it anticipates having the first all-electric domestic flights in service by 2030, followed by a fully electric fleet of aircrafts by 2040. However, the short distances between airports in Norway, coupled with the ability to use smaller planes (e.g., 10-15 seats) due to limited demand, suggest that other countries with greater landmasses and population densities will struggle to replicate these goals. While more ambitious designs—such as those with more than a hundred seats and longer range—are in the works, their concept is unproven and may only be viable after 2030.

At present, the only feasible solution for long-haul flights is a decarbonized liquid hydrocarbon (i.e. a product similar to today's aviation fuel, which has net-zero emissions).

Batteries do not have the energy and gravimetric density to power long-haul flights. Hydrogen takes up too much volume. And although storing hydrogen as ammonia would reduce the fuel storage volume requirements, the jury is out on whether the solution is compatible with long-haul flights. This suggests that the only sure route to complete decarbonization of long-haul aviation is a non-fossil-fuel-based liquid hydrocarbon fuel. Such fuel would be derived either from a bioenergy source or via a "power-to-liquid" synthesis, which combines CO_2 (extracted from the air or captured at an industrial plant) with hydrogen to create synfuels.

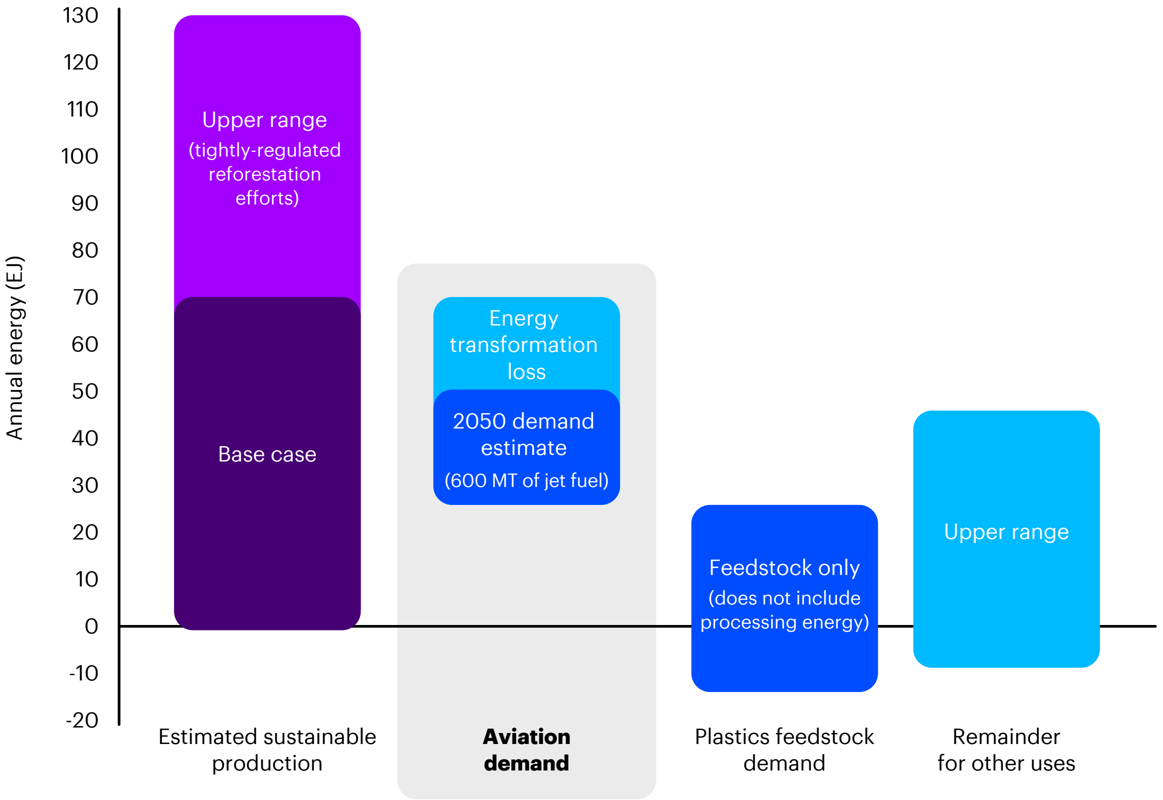
The advantage of such fuel sources is that they can be used in conjunction with existing infrastructures, which reduces the need for large capital outlays to replace assets. In the short- to medium-term, new fuel types can also be increasingly blended with jet fuel. However, the cost is prohibitively high today. Given the existing cost structure and production methods, bio-based jet fuels might cost two to three times more than traditional, fossil-based jet fuel.

Aviation will likely be one of the sectors given priority usage of a limited, sustainable biofuel supply, considering the lack of technically feasible energy alternatives in the mid-term (see sidebar and figure on page 105).

However, the current cost differential of biofuels and synfuels with fossil fuels translates into a $115 to $230 abatement cost per ton of CO_2[36], making aviation one of the costliest sectors to abate (along with heavy industry, particularly cement). In the absence of other options, this cost penalty will be the price of doing business.

Figure 26

Sustainable biomass supply estimates and priority demand in aviation



Source: Energy Transitions Commission; IEA; Accenture Analysis

A sustainable and cost-effective biofuel supply

Biomass will require strict sustainability measures to ensure it is carbon neutral over its lifecycle. The International Energy Agency's global, sustainable biomass projection is in the range of 70 to 130 exajoules (EJ)/year (10-15 EJ from municipal waste, 45-95 EJ from agricultural residues, and 15-30 EJ from wood-harvesting residues).

For biofuels to be sustainable with regard to land use, they must avoid deforestation, not impede on productive arable land (which could otherwise be used for food production) and avoid the destruction of biodiversity in the immediate area.

The cost of biofuel supply varies significantly by source and region. In some markets, biomass is economically competitive today. However, it is likely that a carbon price of around $100/ton will be required to enable biomass to fulfill its potential in the energy transition.

Unlike electricity-derived fuels, biomass cannot draw on the potential for low-cost renewable generation to bring prices down further. That means it may only be used in niche global applications (e.g., aviation and petrochemicals) or at scale in selected markets such as Brazil.

Only by participating in, and architecting, cross-sectoral actions can oil and gas companies hope to mitigate emissions across the energy system. This will be a new and valuable role for the industry to play.

Shipping

Accenture 2050 stretch goal

73 percent reduction from 2050 business-as-usual emissions through fuels-based decarbonization.

The brief

Our top levers to reduce emissions from operations in the shipping sector.

1. Implement energy efficiency measures across fragmented fleets (Clean the Core).
2. Accelerate use of LNG in shipping for near-term decarbonization (Accelerate the Transition).
3. Reduce costs of ammonia-based systems for larger vessels (Extend the Frontier).

Seaborne shipping traffic has grown continuously over recent decades, and this trend is likely to continue since international freight is strongly correlated with economic growth.

Worldwide seaborne trade has experienced a 3 percent annual growth rate since the 1970s, with most of that growth coming from the increase in the number of container ships. Projections for total freight volumes, measured in ton-kms, suggest a possible global growth of more than 240 percent by 2050, representing a 3.4 percent average annual growth rate. Passenger ship traffic represents less than 10 percent of emissions today[36].

Fragmented industry structures limit the impact of potential operational and energy efficiency measures.

Seaborne shipping is one of the lowest-emitting forms of transport per ton-km. That limits opportunities to reduce emissions by shifting to other modes of transportation. Better demand management can only reduce shipping emissions up to 4 percent[2].

An alternative is rail freight. But that move requires substantial infrastructure investments. And, in some cases, rail is a higher-emitting mode of freight transportation. Operational efficiency management (e.g., fleet management, voyage optimization, optimized speeds) could result in a 5 percent emissions reduction in fleets[36].

New ship designs should focus on improving hull shapes and materials, building larger ships to reduce drag, and reducing onboard consumption emissions—improving efficiency by 30 to 45 percent compared to today's fleets[36].

Given the long lifetime of ships, some of these technologies could be retrofitted to existing fleets, improving energy efficiency by up to 15 percent. However, the fragmented structure of the shipping industry (between owners and operators and flagging jurisdictions) reduces the potential for coordinated action and removes incentives for any one sector to make the required changes.

Use of LNG to power shipping could reduce emissions by approximately 10 percent, but only if upstream operations run with low emissions intensity[36].

While LNG is not a complete decarbonization option, it would be a viable near-term solution to emissions reduction in shipping. It sits within the envelope of potential fuels for large shipping and has energy-density properties similar to ammonia.

Upstream operations would have to significantly cut methane emissions to make the fuel as clean as possible. Electrifying the LNG process could provide additional emissions savings.

LNG carriers are already powered by LNG through steam turbines. But a new generation of dual-fuel engines capable of intaking natural gas and bunker fuel (usually heavy fuel oil) is emerging as a solution to the International Maritime Organization's (IMO) 2020 regulations aimed at tightening sulfur emissions in the shipping industry.

Ammonia is the front-runner for longer-term shipping decarbonization.

The use of biofuels, ammonia and hydrogen (the latter combusted through fuel cells or internal combustion engines) are all technically feasible for shipping.

For biofuels to be a feasible option, significant scale-up in production would be required to provide the volume of fuel needed. Given the limitations of sustainable biofuel production, they would likely need to be reserved for those sectors with the fewest abatement options. This means that sectors such as aviation and chemical industry feedstock would be prioritized ahead of shipping.

While technically feasible, hydrogen has economic challenges when it comes to shipping. Its low volumetric energy density means a large amount of monetizable cargo space needs to be sacrificed to store the fuel.

The properties of ammonia, on the other hand, make it an attractive fuel option for shipping. Ammonia has a higher volumetric energy density than hydrogen (4kWh/liter versus 2.4 to 2.8kWh/liter) and a greater gravimetric energy density than batteries (5.8kWh/kg versus 0.2kWh/kg). Additionally, ammonia is easier to store than hydrogen. It becomes liquid at minus 33ºC compared with minus 253ºC for hydrogen, making it cheaper and safer to handle. Ammonia can either be used to make electricity (using a reformer and a fuel cell) or combusted directly in an internal combustion engine. Zero-carbon ammonia can be produced with zero-carbon hydrogen and the Haber-Bosch process.

The near-ubiquitous use of ammonia for agriculture has conveniently generated a global network of ports where the chemical is traded or stored. That means the infrastructure for storing chilled ammonia as a shipping fuel already exists.

Cost and production emissions issues prevent ammonia from being feasible today[36]. Ammonia requires a carbon intensity of electricity below 200gCO_2/kWh to produce lower carbon emissions than the current fuel mix in ships. The average carbon intensity of the EU's electricity network today is currently around 450gCO_2/kWh. Also, the costs of running a ship on ammonia would be about 120 percent higher than with heavy fuel oil[36].

Some European countries are approaching the carbon intensity of electricity required for ammonia, but the global mix requires significant decarbonization. Ammonia would have to be produced in select regions or specialized plants powered by low-carbon electricity to be environmentally viable. The United Kingdom, for example, has a medium-term objective to place ammonia-powered domestic vessels in operation within the next five to 15 years.

Implications and actions for oil and gas

The implications and actions noted below refer to all heavy-duty and commercial transportation sectors.

The demand outlook for middle distillates is of great importance for the oil and gas industry. While gasoline is generally burned in passenger vehicles, which have a short-term decarbonization solution in the form of EVs, middle distillates are consumed in harder-to-abate sectors whose demand is correlated with economic growth. Those sectors are heavy-duty road transportation, shipping and aviation.

Demand for middle distillates is likely to grow faster and hold up for longer than lighter distillates such as gasoline.

This will impact refinery configurations as downstream operators attempt to retain margins from a more constricted mix of distillates.

Diesel demand in heavy-duty road transportation will be the first to plateau. But it will be held up in the shipping sector by increased diesel usage as IMO regulations force a shift away from heavy fuel oil, which is sulfur heavy, as the preferred fuel.

Gravimetric and volumetric energy density requirements limit the technically feasible alternatives for long-haul aviation and long-distance marine, making them two of the hardest sectors to abate. However, this does open up the opportunity for oil and gas companies to be part of a much-needed solution in these areas.

Within aviation, there is an opportunity to blend increased biofuel into jet fuel to create a premium, decarbonized product. A segment of the increasingly environmentally aware public would likely be willing to pay a higher airfare in exchange for its usage.

We see three discrete sets of actions that oil and gas companies can take to accelerate decarbonization and maintain market relevance in the heavy-duty and commercial transportation market.

1. **Collaborate closely with each transportation mode to co-develop solutions for hard-to-abate sectors.**

   This can be accomplished in several ways, including the following.

   A. Ramping up blending of biofuels into jet fuels to create premium, differentiated products.

   B. Taking a leading role in promoting LNG usage in shipping as a high-impact, near-term decarbonization solution that is synergistic with portfolios that have transitioned to gas (upstream and midstream operations will need to be decarbonized for greatest impact).

   C. Exploring how to economically produce and refine biofuels and synfuels (through green or blue hydrogen) combined with carbon capture.

   D. Co-designing the next generation of hardware that can be powered by fuels of the future.

2. **Prepare for refinery reconfigurations as the share of middle distillate demand grows compared to light distillates.**

3. **Explore short-term opportunities to produce high-margin renewable fuels in selected markets such as California, while hedging bets for electrification of the heavy-duty road sector in the mid-term (e.g. through deployment of charging infrastructure).**

Heavy industry

The following section covers cement, iron and steel, and chemicals.

The industrial sector accounts for around 22 percent of global CO_2 emissions, comprising iron and steel (6 percent), cement (5.6 percent) and chemicals (4 percent), with other industries such as paper and light manufacturing making up the remainder. The sector is the third biggest market for gas after power and buildings, comprising 18 percent of total gas demand[2].

Heavy industry utilizes energy-intensive processes that cannot be readily carried out with electric solutions. Within the heavy industry sector, the cement, steel, and chemical industries together contribute 6.5 GT CO_2e per year of carbon emissions[2]. Given the limited ability to electrify, coupled with the cost of alternative fuels and feedstock, emissions reduction in this sector is highly reliant on energy and materials efficiency, as well as CCUS solutions.

Cement is considered one of the most difficult sectors to decarbonize because about 55 percent of associated emissions derive from the chemical process required to produce it, rather than during the generation of the heating itself[36]. The only feasible pathway to emissions reduction today is CCUS. Another reason the heavy industry is hard to decarbonize relates to the growing demand for construction materials and plastics from the developing world. In India, for example, a country of one billion people, consumption of plastic per capita is 10 times less than that of the United States. This implies that large growth in demand may be coming from the developing world to reach parity with consumption in the OECD.

Collectively, cement, iron and steel, and chemicals account for approximately 25 percent of global coal consumption[2]. Like the power sector, this means a near-term transition to natural gas would have a high impact on decarbonization. We will explore this opportunity in the iron and steel section since this industry alone accounts for 17 percent of global coal consumption[2].

Ultimately, emissions reduction in heavy industry will be shaped by five key factors:

1. Transitioning from coal to natural gas for heavy industry heating.
2. Materials efficiency and circularity.
3. Increased energy efficiency.
4. Use of CCUS.
5. Use of low-carbon, high-heat alternative fuels and feedstocks.

Cement

Accenture 2050 stretch goal

60 percent reduction from 2050 business-as-usual emissions through demand management and decarbonized production processes.

The brief

Our top levers to reduce emissions in the cement sector.

1. Maximize demand management and circularity levers (Clean the Core).
2. Transition to decarbonized heat sources (Extend the Frontier).
3. Accelerate economic deployment of CCUS to reduce process emissions (Extend the Frontier).

We see demand for cement growing from 4.2 billion tons per year to 4.7 billion tons per year by 2050[36].

That demand growth will be driven by increased construction of buildings and infrastructure. The highest surges in demand are expected in emerging markets, which are urbanizing rapidly. China, for example, accounts for about 60 percent of cement production. This proportion will fall as China passes the peak of its construction phase. However, in other economies such as India and Africa, demand for cement is expected to triple between now and 2050.

Importantly, growth in cement demand is expected to be greatest in regions that are not likely to make significant progress on decarbonization. Cement is unique among the heavy industry sector in creating direct process emissions (accounting for 55 percent of its totals) and emissions as the product itself is manufactured.

Decarbonizing the cement sector will be a costly and lengthy endeavor. Demand management and energy efficiency levers will be essential if cement emissions are to be reduced in the near-term.

There are four main ways to reduce emissions through better demand management and circularity. When combined, these actions could reduce emissions by up to 35 percent[2].

1. **Recycling of unhydrated cement**, reprocessing of hydrated cement, and reusing concrete as aggregate could reduce emissions by around 15 percent[2].

2. **Reducing the material demand per building** by reducing over-specification, reducing construction-related waste and reusing structural elements of older buildings. In Europe, for example, this waste is estimated at 10 to 20 percent. Collectively, this could reduce emissions by about 15 percent[36].

3. **Improving the use of buildings**—adapting existing buildings to extend their lifetimes and using space more efficiently—could reduce emissions by about 5 percent.

4. **Using materials other than cement for construction**—such as timber—would also reduce emissions. However, this development could be constrained by the amount of available sustainable timber.

Using energy-efficiency levers could reduce emissions by a further 10 percent. The key levers in this space include retrofitting older plants, using a dry kiln process (which is less energy intensive than a wet kiln process), increasing the use of technologies that reduce energy intensity (such as pre-calciners and multistage cyclone heaters), and decreasing the clinker-to-cement ratio (which leads to lower energy use and emissions).

Adopting CCUS could address both the emissions produced from heat generation and process emissions.

As a single solution, CCUS could be used to decarbonize cement or for fuel switching to reduce emissions from heat production.

Cement is problematic since there are currently no viable alternatives to CCUS technologies for reducing process-related emissions released through a chemical reaction during manufacturing. While technically feasible to abate through CCUS, these process emissions are among the most expensive to abate because the CO_2 concentration of the emitted gases is very low (CCUS costs are generally proportional to CO_2 concentration of the air from which the carbon is extracted). Currently, there appears to be no pathway pointing to significant cost reduction in this area.

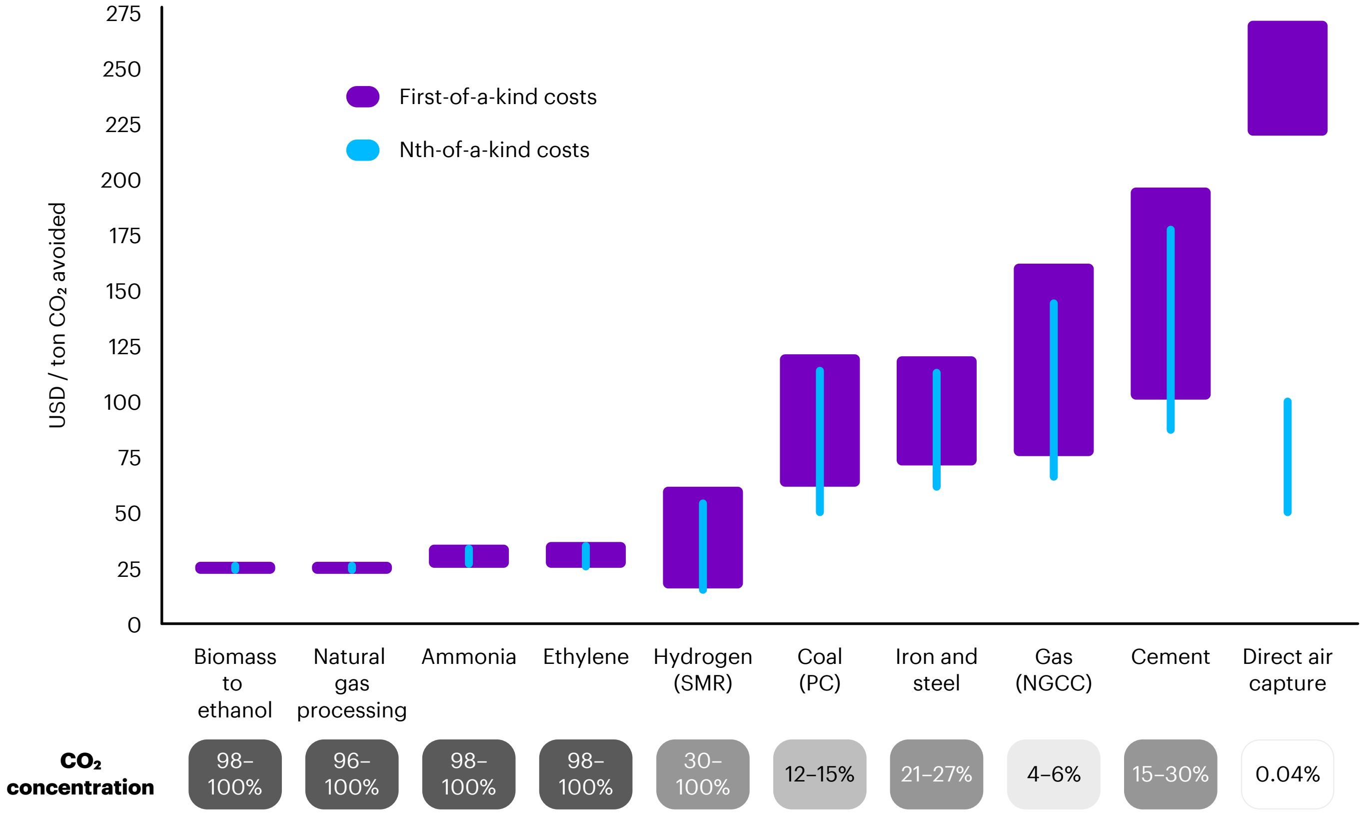
However, captured CO_2 can be used in the construction industry itself by absorbing it into concrete during the curing process. This potentially reduces the need for CO_2 storage and transport.

Additional research and development, as well as the scaling of technologies, will be required in the areas of electricity-based and hydrogen-based heat.

In theory, using electricity as a heat source for cement is possible, but further research, development and piloting of solutions would be needed before a commercial rollout would be possible. Replacing fossil fuels with hydrogen derived from clean electricity would require significant furnace redesign and lower electricity costs.

Figure 27

Global ranges for carbon avoidance costs using CCUS



Source: Energy Transitions Commission; IEA; Accenture Analysis

The outlook for CCUS

Most 2ºC scenario outlooks assume a major role for CCUS by the middle of the century, although forecasts vary considerably between from 3 to 10 GT CO_2/yr.

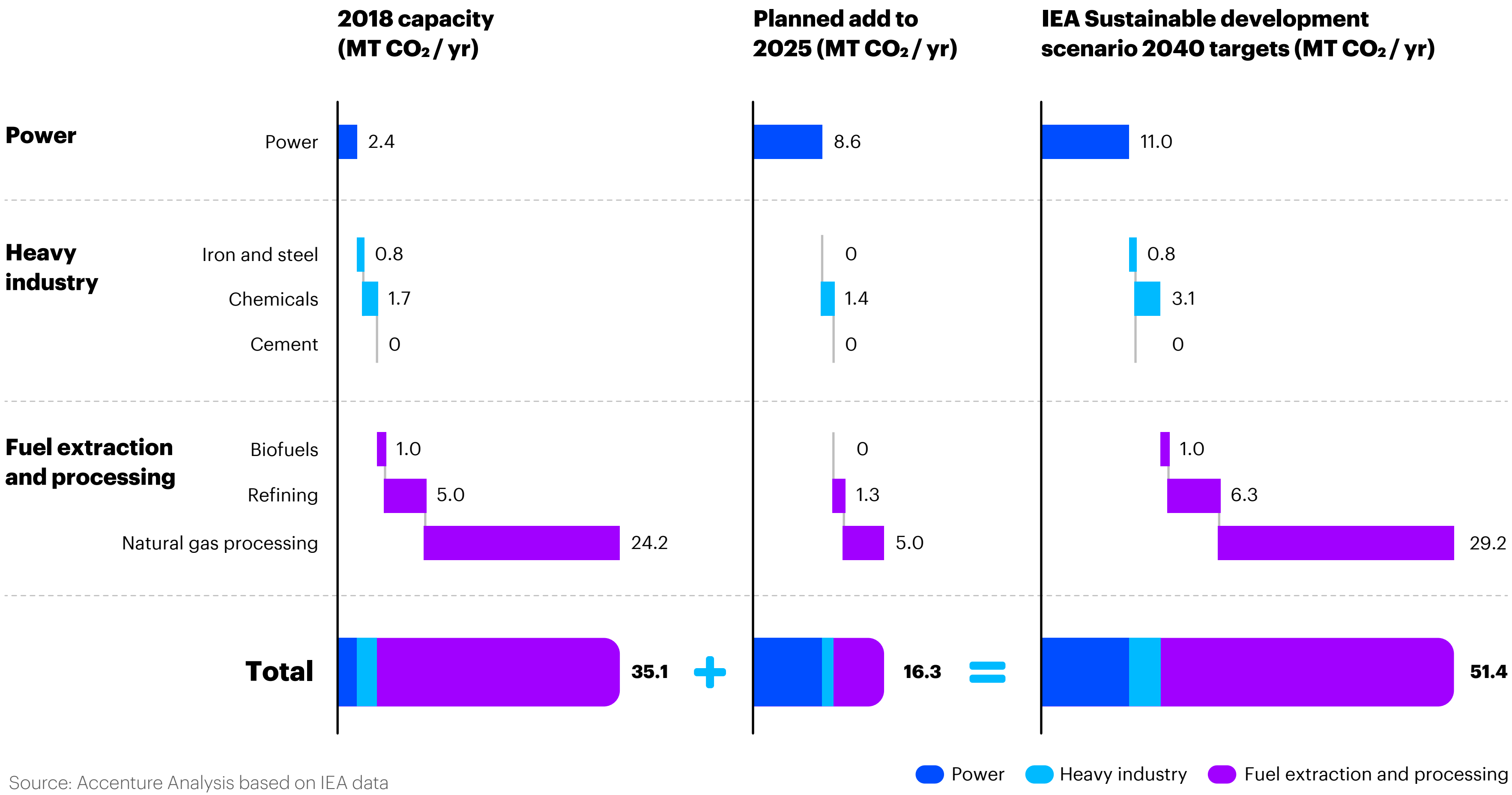
CCUS is expected to play a greater role toward the end of the century. By then, bioenergy with carbon capture and sequestration (BECCS) is projected to be available to provide net-negative emissions. Two-thirds of the Intergovernmental Panel on Climate Change (IPCC) models assume BECCS will account for more than 20 percent of primary energy by 2100.

Total capture today though, from 37 projects, amounts to a small 35 $MTCO_2$/year, about 85 to 285 times less capacity than the target ranges of 3 to 10 GT CO_2/year would imply. Looking at the development pipeline, 2025 capacity would be a little over 50 $MTCO_2$/yr. Deployment needs to accelerate significantly to be on track for these 2050 targets.

Within heavy industry, the sector most likely to be dependent on CCUS, capacity today accounts for just 2.5 $MTCO_2$/year, rising to 3.9 $MTCO_2$/year by 2025. There is notably no current or pipeline capacity for cement, for which no current alternative to abating process emissions exists.

Figure 28

2018 Global CCUS capacity and planned additions to 2025, by industry



Source: Accenture Analysis based on IEA data

Iron and steel

Accenture 2050 stretch goal

94 percent reduction from 2050 business-as-usual emissions through reduction in coal usage and transition to increased electric arc furnace production.

The brief

Our top levers to reduce emissions from the iron and steel sector.

1. Maximize demand management and circularity levers (Clean the Core).
2. Accelerate transition from basic oxygen blast furnace to electric arc furnace (Accelerate the Transition).
3. Transition from coal to decarbonized heating sources including natural gas in the near-term (Extend the Frontier).

Global steel production is forecast to grow by 30 percent between now and 2050—from 1.6 GT per year[36] to 2.2 GT per year, driven by increased demand for buildings, infrastructure and vehicles.

Two major trends will define the emissions profile of this growth.

1. **The switch from ore-based to scrap-based production** as existing steel stock grows and as more demand is met through recycling.
2. **The move from blast furnaces (BF-BOF) to electric arc furnaces (EAF)** as a result of more scrap-based production.

Overall, the iron and steel sector has several viable pathways to decarbonization and is not considered as hard to abate as cement.

Increased use of recycled steel in electric arc furnaces could reduce sector emissions by 20 percent by 2050[36].

Ore-based production is expected to remain steady as a reduction in demand from China will be offset by increases in emerging markets. The use of EAF in scrap-based steel production, produces just 0.4 tons of CO_2 per ton of steel. That compares to 2.3 tons for BF-BOF and 1.1 tons for the direct reduced iron-electric arc furnace (DRI-EAF) process, an alternative process for producing new steel[36].

As the global stock of steel increases, and infrastructure ages, the proportion of scrap-based steel production should grow. A reduction in ore-based steel production through increased recycling and materials circularity could result in up to a 20 percent emissions reduction by 2050.

Reductions in end-use demand and economical energy efficiency improvements could reduce steel emissions by a further 15 percent[36].

Two principal levers can reduce total steel demand. The first is the design of more efficient products that require less steel to perform the same job—such as lightweight automobiles. Globally, and across all sectors, product efficiency could account for a 15 percent decline in steel demand by 2050. The second demand-side lever is a reduction in steel demand through an increase in shared mobility services. This could have a tremendous potential impact, but it is too early to quantify with accuracy.

There is significant untapped potential to increase the energy efficiency of steel production without needing to make fundamental changes to the process. For example, coke dry quenching is a heat recovery system that can reduce energy consumption by up to 40 percent. The reuse of production gases for power generation (hot water, steam, electricity)—which can either be fed back into the steel production process or the broader grid—could increase efficiency by up to 35 percent[2].

Both these approaches appear to be economically favorable, but implementation is challenged by the large capital expenditure required and pressure on margins in a highly competitive industry.

There are two promising routes to full decarbonization of the steel industry: processing iron ore by electrolysis and expanding the role of hydrogen as a reducing agent in BF-BOF production.

The iron and steel industry is responsible for 17 percent of the emissions from the use of coal as an energy source, second only to power generation[36]. Switching from coal to natural gas for the direct reduced iron-electric arc furnace (DRI-EAF) process could reduce carbon emissions by 1.2 tons per ton of steel. This represents a more than 50 percent reduction and is a critical near-term lever for the decarbonization of the sector.

The reduction of iron ore by direct electrolysis (similar to the aluminum manufacturing process) and the use of hydrogen as a partial substitution to coking coal reduction in blast furnace to basic oxygen furnace production could have a significant impact on decarbonization in economies with lower stocks of scrap steel in circulation.

Chemicals

Accenture 2050 stretch goal

78 percent emissions from 2050 business-as-usual emissions through the promotion of the circularity and decarbonized heat sources.

The brief

Our top levers to reduce emissions in the chemical sector.

1. Promote circularity to reduce demand (Clean the Core).
2. Accelerate use of electricity and hydrogen-based fuels (Extend the Frontier).
3. Transition to biofuel-based feedstock for the chemical sector (Extend the Frontier).

The chemical industry accounts for 14 percent of petroleum demand today; this share is expected to increase as the demand for plastics increases and as oil transportation demand growth slows and eventually declines.

Petrochemicals are likely to account for over a third of the growth in oil demand to 2030, and nearly half to 2050[36].

Within the chemical sector, 60 percent of direct emissions come from just three sources: ammonia (30 percent), ethylene (16 percent), and methanol (14 percent). Methanol is the fastest-growing chemical segment. It has multiple applications as the base for formaldehyde and fuel additives, as well as an intermediate product for plastic production[2].

The demand for ammonia, the basis of synthetic fertilizers, has leveled off in recent years. But it is forecast to increase evenly across the globe to 2050. Also, ammonia may become a clean transportation solution in the shipping sector, further increasing the importance of reducing emissions from its production.

Substantial efforts to increase recycling and curb single-use plastic in the OECD will be offset by growing demand in emerging economies. Plastic usage correlates with income. Per capita demand for plastics is almost 20 times higher in South Korea and Canada than in Africa, and 10 times higher than in India.

Beyond the carbon emissions associated with their production, plastics cause multiple environmental issues, including the accumulation of microplastics in the ocean. Total emissions from the chemical sector in 2050 will depend significantly on the lifetime of the plastics produced and whether incineration is a preferred disposal method to landfill.

The use of virgin plastics could be reduced by more than 50 percent by 2050 through material efficiency, the substitution of hydrocarbon-based monomers, greater reuse, and increased mechanical and chemical recycling.

Improving materials efficiency in products by limiting over-specifications of packaging, extending product life, and product sharing (e.g. carsharing) would result in a more intensive use per unit of plastic and could reduce demand by 35 percent from the automotive and building sectors alone. That would translate to a 15 percent reduction in overall chemical demand.

Reducing the use of plastic-based products by banning single-use plastic is another powerful lever. For example, in the United Kingdom, banning just seven common items from straws to earbuds would reduce plastic consumption by 13 percent.

The potential of recycling to cut emissions is high and could lead to as much as 20 times less CO_2 emissions per ton of plastic. But the extent of recycling around the world is generally low and is mainly mechanical-based—involving processes such as grinding, washing, separating, drying, regranulating and compounding. The percentage of total plastics recycled today is estimated at as little as 10 percent[36].

There needs to be an increase in chemical recycling, which can return post-use plastics to their basic chemical building blocks, increase the versatility of their reuse and require less virgin plastic. The chemical approach is only a small percentage of overall recycling treatments today. Changing that situation will require large cost cuts, more significant efforts to ensure that waste plastics can be made into new monomers rather than simply fuel, and clean, high-heat energy for the process.

As in other heavy industry sectors, zero-carbon heat generation is required to fully decarbonize petrochemicals with hydrogen-based and direct electrical heating going head-to-head with CCUS. Decarbonization of heat generation will be required for complete emissions reduction. The preferred method will likely depend on local carbon markets, storage availability and local electricity prices. Hydrogen could be competitive at today's electricity prices and a carbon price of \$75/tCO_2, whereas direct electrification is cheaper than carbon capture and storage at electricity prices of under \$25/Mwh. In some regions, renewables prices have already reached this level[36].

Decarbonization of feedstocks has a priority claim on the limited, sustainable biofuel supply.

Decarbonization of feedstock using biomass fuel would reduce end-life emissions of plastic. Given the lack of suitable feedstock alternatives that are free of fossil fuels, biomass for chemical feedstock will be a priority usage (as for the aviation industry). Plastics may eventually be made from zero-carbon electrochemical processes, given the availability of low-cost, carbon-free electricity. However, these techniques are currently at an early R&D stage. A thorough assessment of the viability of using such a large amount of electricity for electrochemical processes is needed.

Implications and actions for oil and gas companies

The implications and actions noted below relate to all heavy industry sectors.

Heavy industry is one of the harder-to-abate sectors of the economy. There is a real opportunity for the oil and gas industry to help define much-needed solutions. For example, extensive CCUS deployment is required in heavy industry. It is a technology for which oil and gas companies are the lead adopters today.

There is a large opportunity to drive highly emitting coal out of heavy industry by increasing natural gas use. However, as with the power sector, this will likely require a step-change in landed LNG costs in key countries like China.

A longer-term opportunity in which the oil and gas industry can take the lead is in the identification of hydrocarbon replacements for both feedstock (for petrochemicals) and fuels (for all heavy industries) in a decarbonized world. For example, hydrogen, could be a cost-efficient alternative to direct electrification or the use of fossil fuels along with CCUS for cement heating. For example, hydrogen could be an alternative to direct electrification or the use of fossil fuels along with CCUS for cement heating. In the iron and steel industry, hydrogen can be used as a reduction agent and a heat source. In the chemical industry, hydrogen is an input to the Haber-Bosch process (an artificial nitrogen fixation process) that could potentially be used as a heat source in the petrochemical sectors. However, given the multiple conversion losses for creating and combusting hydrogen, its economic viability is likely to remain challenged compared to other pathways.

Finally, integrated oil and gas companies with petrochemical portfolios have an opportunity to redefine their role from manufacturing and selling plastic products to managing the full lifecycle of plastic demand. This would extend their role to include the gathering and recycling of products for reuse.

We see three discrete sets of actions that oil and gas companies can take to accelerate decarbonization and maintain market relevance in the heavy industry sector in the next 30 years.

1. **Collaborate closely with each industry sector to co-develop solutions for hard-to-abate areas of emissions.**

   A. Explore how to economically produce, and refine biofuels and synfuels (through green or blue hydrogen combined with carbon capture) for the creation of premium plastic products.

   B. Use the industry as a test space for the hydrogen economy, given the relative competitiveness of hydrogen versus other decarbonization routes to high-temperature, high-volume heat.

   C. Reimagine the plastics value chain and relationships with customers; create circularity by moving to a services-based model.

2. **Leverage CCUS expertise for heavy industry and use captured carbon for EOR or syngas creation, in addition to monetizing both transport networks and storage in depleted reservoirs.**

3. **Enhance the competitiveness of LNG to drive coal out of heavy industry as a heat source.**

4. **Participate in the research agenda to accelerate the adoption of low-emission processes, such as alkali-activated cement.**

5. **Actively engage the customer to adopt energy efficiency and energy management solutions that lower their waste energy and emissions intensity.**

Commercial and residential buildings

Accenture 2050 stretch goal

72 percent reduction from 2050 business-as-usual emissions through high-efficiency buildings and the shift to electricity-based heating.

The brief

Our top levers to reduce emissions in the building sector.

1. Enhance building design to be energy efficient (Clean the Core).
2. Accelerate penetration of smart devices for demand-side management (Clean the Core).
3. Transition from gas to electric heat pumps (Accelerate the Transition).

Buildings account for around 9 percent of global CO_2 demand, split roughly 60/40 between residential and commercial buildings.

Collectively, buildings represent the second largest market for gas, comprising 20 percent of total demand[2].

Energy use in the commercial and residential buildings sector has increased steadily since 2000, at an annual average growth rate of around 1.1 percent. Usage grew from 2,820 Mtoe in 2010 to around 3,060 Mtoe in 2018, accounting for 20 percent of global delivered energy consumption in 2018. Direct emissions from buildings increased to a little more than 3 GT CO_2 in 2018, up slightly from previous years when direct emissions were under 3 GT CO_2. In our 2050 business-as-usual scenario, emissions will edge up to 3.8 GT CO_2/year.

It is projected that global energy consumption in buildings will grow by 1.3 percent on average per year from 2018 to 2050[37]. In non-OECD countries, consumption is expected to grow by more than 2 percent per year, or about five times the rate of OECD countries.

This growth in energy use is driven principally by the following trends.

1. **Increases in the area of floor space used**, which have grown by around 65 percent since 2000[38].
2. **Population growth of two billion people** and the rising standard of living in non-OECD countries.
3. **Rapidly growing demand for energy-consuming equipment and services in buildings**, particularly in emerging economies.
4. **Extreme weather patterns**, which increases the demand for heating and cooling equipment.

Given projections for large expansions in floor space demand in populous regions such as India and Africa, enhanced building design will be an important way to contain emissions. Renovation-based efficiency must account for broader emission impacts in other geographies.

In developing countries—especially in Africa and Asia, where building growth will be rapid—enhanced building design will be especially important. The floor area in India is expected to double by 2035[39]. Yet, only part of the sector is subject to mandatory building energy codes. The impact of such growth in floor space usage can be mitigated by using more effective layouts, natural light and ventilation, green roofs, better insulation and windows, and lower-carbon, recycled construction materials.

In OECD countries, where 65 percent of total expected building stock in 2060 is already built, energy renovations of existing buildings will be key to reducing emissions. These renovations need to deliver 50 to 70 percent energy intensity improvements. Moving to high-performance, low-carbon or near-zero emissions buildings is a priority for the next 20 years[2]. Some caution about deep renovations must be exercised here, however, as the risk of simply passing emissions from buildings to other sectors such as construction and heavy industry is high.

Adopting smart, connected devices in buildings can significantly reduce energy usage demand and energy usage peaks without impacting lifestyle.

The adoption of smart devices could help drive behaviors that use less energy. Behavior change can also be accomplished through awareness campaigns, gamification techniques, and by enabling people to compare their energy usage with their neighbors.

The use of integrated, connected systems has a large impact. An upgrade to a single component or isolated system such as smart heating can result in energy savings of 5 to 15 percent and a smart building upgrade with integrated systems can achieve 30 to 50 percent savings in existing, inefficient buildings[2]. Smart, connected devices and systems may include the following.

1. Heating, cooling and ventilation, which limit energy consumption in unoccupied zones.
2. Advanced controls and sensors to optimize lighting.
3. Plug loads, auto-controlled receptacles and power strips that rely on time scheduling, motion sensing, or load detection to turn power off when equipment is not being used.
4. Window shading with electrochromic switchable windows.
5. Automated system optimization, which uses real-time feedback to collect and analyze building systems' operational and energy performance data to make anticipatory changes in operations based on weather patterns, occupancy numbers, etc.
6. Mobile apps and real-time reporting to help control energy usage and influence behavioral change.

As the electricity grid becomes more decarbonized, the emissions advantages of heat pumps over natural gas will grow.

The largest direct use of fossil fuels in buildings is heating. Electricity-based heat pumps now represent a viable pathway to abating these emissions. The decarbonization of the electricity sector, coupled with an efficiency two to four times greater than that of natural gas heating, means that heat pumps can potentially reduce building emissions by up to 50 percent[2].

Implications and actions for oil and gas companies

In the short-term, the oil and gas industry's ability to impact the decarbonization of the commercial and residential buildings sector is limited to decarbonization of the natural gas value chain. Beyond this, oil and gas companies can lead by example. In an industry characterized by large workforces and significant office footprints, oil and gas businesses can deploy energy-efficient programs across their locations and leverage their digital expertise to explore energy usage optimization.

Over the longer term, the oil and gas industry can help transform the building sector in a more significant way. How? By offering alternative clean power options such as renewables and hydrogen to commercial and (to an extent) residential buildings when connecting to the grid is not an option or even desired. One avenue involves partnering with key industry clusters to offer integrated suites of clean energy solutions to power both the operations and the buildings.

We see three discrete sets of actions that oil and gas companies can take to accelerate decarbonization and maintain market relevance in the commercial and residential buildings sector in the next 30 years.

1. **Identify opportunities for oil and gas in repurposing existing buildings and designing new buildings** for energy efficiency. The starting point for this involves enhancing the energy efficiency of all owned infrastructure and facilities.

2. **Take a lead role in scaling new fuels (e.g. hydrogen) and cleaning existing fuels (e.g. decarbonized natural gas)** that will be used in buildings of the future.

3. **Move close to the end customer** and take a much more expansive role in energy management services and potentially car-to-grid charging and storage solutions.

Through the 2020s, value and investment are poised to migrate away from oil and gas companies' core business, toward electricity-linked energy.

Near-term priorities will be focused on transforming today's core portfolio, while also creating optionality to win in adjacent sectors. The Decarbonization Transition won't be as effective—or may not happen at all—if oil and gas companies don't play an active role in developing solutions for their customers in those sectors.

That means more than investing. It means innovating and collaborating with partners to make the transition to a low- or no-emission future a reality. Cross-sector R&D teams can, for example, work together to identify potential uses for hydrogen with biofuels in the aviation industry. Or oil and gas companies might join up with utilities to extend the traditional value chain to cross-sector offerings like mobility-as-a-service solutions. In these and countless other ways, oil and gas companies will be actively architecting and creating the low-carbon opportunities in which they can invest—and through which they can grow.

Accenture Decarbonization Scenarios

The Accenture global decarbonization model was constructed using a four-step approach.

1. We first established the emissions base case (emissions today) for each demand sector using accredited governmental and NGO sources.
2. We then projected BAU emissions to 2050 by combining the expected increase in sector demand with the expected emissions abatement on current trajectories.
3. As a next step, we identified, by demand sector, the emissions reduction levers and their potential if fully implemented.
4. Finally we projected a percentage reduction achieved by lever according to the remaining business-as-usual emissions it would impact (near-term levers will have a larger percentage impact than those that come later and have a reduced base to impact) and the extent to which we will be successful in fully implementing each lever by 2050.

Glossary

Term	Definition
2DC guideline	One of the key guidelines formulated during the Paris Agreement, which called for an assessment of the impact on a company's portfolio and business strategy of policies and restrictions consistent with achieving the globally agreed upon target to limit global average temperature rise to no more than 2°C above preindustrial levels.
5G	Refers to the 5th generation mobile network. It is a new global wireless standard that is designed to connect everyone and everything, including machines, objects and devices. Advantages of 5G include higher peak data speeds, ultra low latency, massive network capacity and increased availability.
Asset-light business model	A business model where the company owns relatively fewer capital assets than is required to run its operations. This is achieved by outsourcing the capital requirements by way of operating leases or other pay-per-use service models.
BAU	Business-as-usual
Bio-energy with carbon capture & sequestration (BECCS)	A carbon removal technique that includes two technologies. First, biomass is converted into heat, electricity or liquid / gas fuel and, subsequently, the carbon emissions from this conversion are captured and stored or utilized in other long-lasting products. BECCS can thus serve to reduce the overall CO_2 concentration in the atmosphere.

Term	Definition
Biodiesel	Biodiesel is a form of diesel fuel derived from plants or animals and consists of long-chain fatty acid esters. It is a renewable, biodegradable fuel produced from vegetable oils, animal fats, etc.
Biofuel	A type of renewable energy source derived from microbial, plant or animal materials. Examples include ethanol (derived from corn or sugarcane), biodiesel (derived from vegetable oils, animal fats, etc.), green diesel (derived from algae, etc.) and biogas (methane derived from animal excretions, etc.).
Biomethane	Also known as "renewable natural gas," it refers to methane produced either by "upgrading" biogas (a process that removes any CO_2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation.
Biomethanol	Biomethanol is typically generated through a thermochemical reaction. The feedstocks for the process can be any type of concentrated carbonaceous materials (i.e. biomass, solid waste, coal, etc.). The process entails converting feedstock into biogas through gasification and the synthesis of methanol.
Black start service applications	Black start is the procedure used to restore power in the event of a total or partial shutdown of the electricity transmission system without relying on any external electric power source.
Blue hydrogen	Hydrogen produced by steam methane reformation, where the emissions are curtailed using carbon capture and storage.
Carbon budget	The overall quantity of CO_2 and other greenhouse gases that the world, country or company can emit without risking an average global temperature increase beyond 2ºC. It can also refer to the quantity of CO_2 or greenhouses gases that a country, company or organization has agreed is the maximum it will produce in a given time period.

Term	Definition
Carbon net neutrality	Carbon neutrality means every ton of CO_2 that is emitted is compensated with an equivalent amount of CO_2 which is removed.
Carbon offsets	A reduction in emissions of CO_2 or other greenhouse gases made in order to compensate for emissions made elsewhere.
CCUS	Carbon capture, utilization and storage (or CCUS) is a critical emissions reduction technology that can be applied across the value chain. CCUS systems capture CO_2 from power plants or industrial processes and either use it as a raw material in the production of other fuels or permanently store it in deep underground geological formations.
Circular economy	An industrial system that hinges on a shift towards renewable energy, eliminates the usage of toxic chemicals, and eliminates waste through enhanced design of materials, products, systems and processes.
CNG	Compressed natural gas (or CNG) is gas compressed to a pressure of 200+ bars. It is used in cars and other light commercial vehicles as a fuel and produces lower emissions compared to diesel- or petrol-fired internal combustion engines.
Connected Autonomous Shared Electric (CASE)	CASE refers to new areas of "connected" cars, "autonomous / automated" driving, "shared" and "electric." Technological advances in these areas are disrupting the automotive industry.
Crowd shipping	A novel shipping concept where logistics operations are carried out by crowd sourcing and existing resources such as vehicle capacity and drivers, thereby offering potential for economic, social and environmental benefits.

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