MORNINGSTAR

The Future of Oil to 2050

Resilient demand will keep oil prices afloat through midcentury.

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Key Takeaways

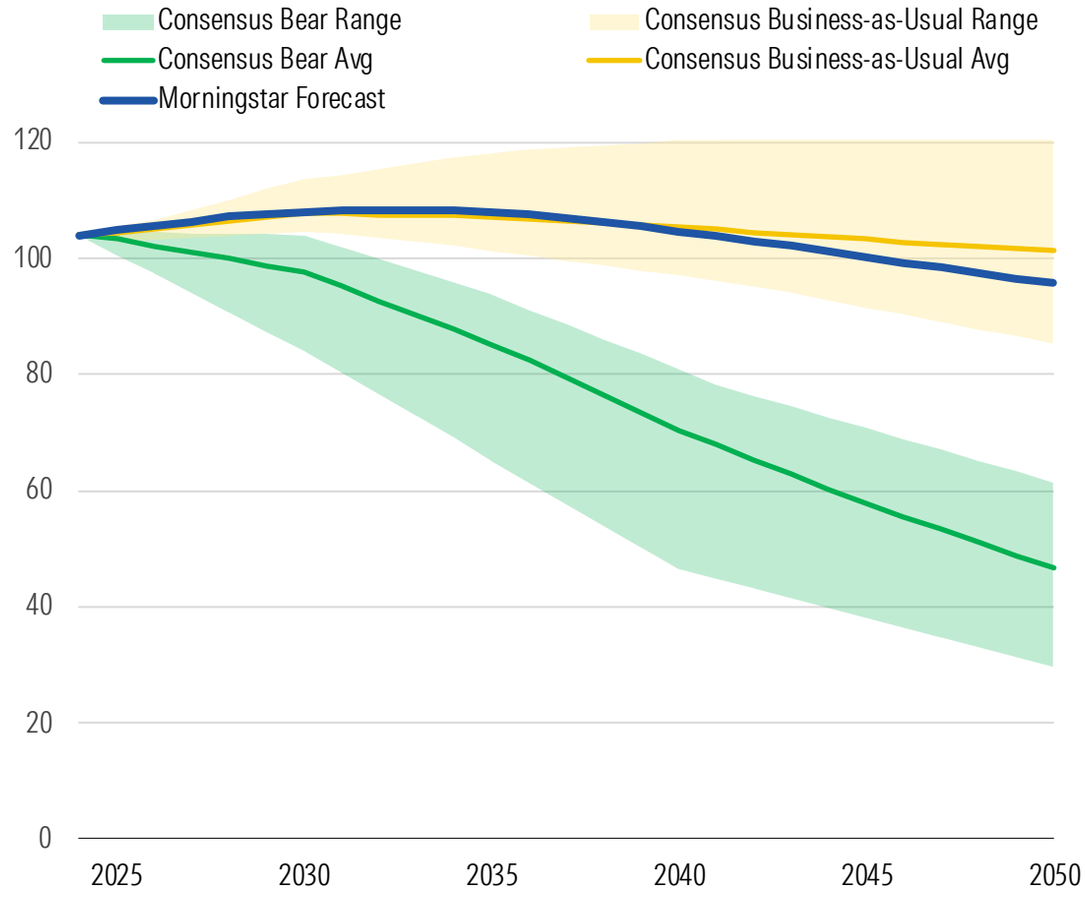
About This Report

This is an update to our 2021 report, The Future of Oil Demand. Our bullish thesis on oil demand remains essentially unchanged from that earlier report. New in this year's report is a price forecast through 2050, derived by combining our in-house demand view with Rystad's supply-side projections.

Key Takeaways

- We expect continued oil demand growth for the next five years, and we don't expect substantial declines until the second half of the 2030s. In 2050, we expect oil demand to be just 8% below 2024 levels.
- As a result of our demand outlook, we've recently upgraded our midcycle oil price to $65 per barrel from $60 (Brent). For oil producers, this resulted in fair values increasing by a low-double-digit percentage.
- We're not blindly optimistic about oil's future. We remain upbeat about electric vehicle adoption and are more optimistic than the consensus about the electrification of freight trucking. However, other sectors will find it difficult or impossible to find an equivalent to EVs that can displace oil demand.
- The aviation sector's oil demand should soar, driven by rising air travel. Clean liquid fuels to replace jet fuel will face astronomical costs.
- Petrochemical feedstock demand should surge along with plastics demand. While we expect significant growth in recycling, a host of obstacles puts a ceiling on its potential.

Oil Demand Forecast Comparison, Million Barrels per Day



Source: International Energy Agency, BP, Equinor, Shell, OPEC, Exxon, Morningstar.

Oil Forecast Summary

Resilient demand will keep oil prices afloat through the midcentury.

No Quick Decline in Oil Demand in Sight

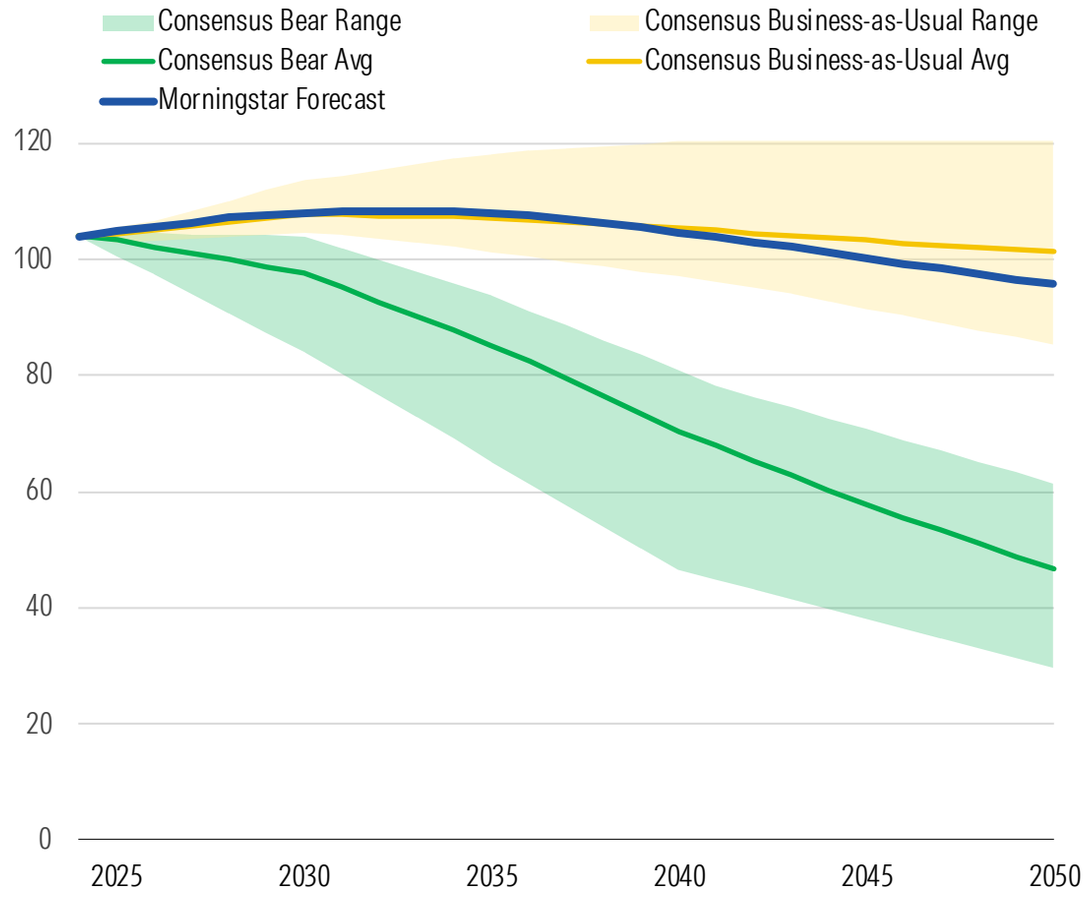
Oil Demand to Peak in 2030s but Drop 8% by 2050 Versus 2024 Levels

We believe oil demand still has five to 10 years of decent growth before plateauing in the early 2030s. Demand doesn't start declining until the late 2030s. We project oil demand to grow from 104 million barrels per day in 2024 to a peak of 108 mmbpd in 2032, then decline to 96 mmbpd in 2050. That's a cumulative 8% drop versus 2024, or 0.3% annually.

Our methodology is a bottom-up forecast that splits oil demand into 10 sectors. Each sector has unique drivers. Only some sectors are vulnerable to the replacement of oil demand by electrification. For other sectors, the available substitutes are unlikely to reach the cost parity with oil that we expect for electric vehicles. In aviation, for instance, we expect the cost of switching from oil to be entirely prohibitive.

It's difficult to pin down a consensus "base case" for oil demand, as we discussed in more detail in our 2021 report. Other forecasters present a range of scenarios, which can generally be clustered into "business-as-usual" or "bear" cases. Neither type is ideal: business-as-usual scenarios tend to be dismissive of progress in green technologies, while bear scenarios are entirely unrealistic, assuming a given emissions-reduction target and working backward from there. Ultimately, we're much closer to the typical business-as-usual than the bear case.

Oil Demand Forecast Comparison, Million Barrels per Day



Source: International Energy Agency, BP, Equinor, Shell, OPEC, Exxon, Morningstar.

We Expect Electrification of Cars and Trucks, but Strong Oil Demand Growth in Other Areas

In light-duty vehicles (25% of 2024 oil demand), we expect oil demand to fall 36% through 2050, as electric vehicles climb to 55% of the global vehicle fleet by 2050, up from 3% in 2024. Since our 2021 report, the consensus business-as-usual case has moved closer to our EV optimism.

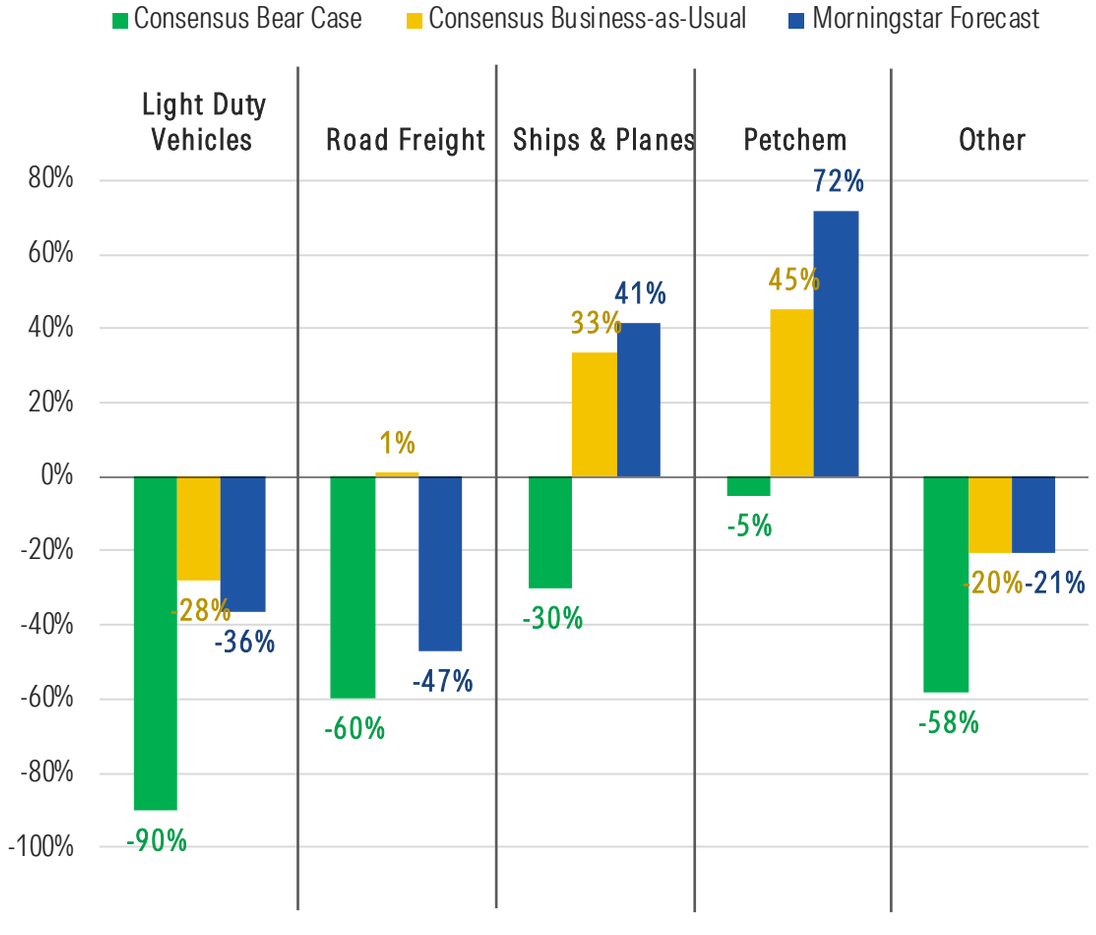
Road freight (16% of oil demand) is one sector where we're closer to the bears. We expect demand to drop 47% through 2050. The conventional wisdom is relatively pessimistic about the electrification of freight trucks, whereas we think that freight trucking is actually an ideal candidate for electrification.

For marine shipping and aviation (13% of oil demand), we expect demand to swell by 41%. We're slightly more optimistic than consensus, as we expect only modest penetration of oil substitutes. For planes, in particular, we think the costs of clean liquid fuels, derived from green hydrogen, will be prohibitive. We also expect strong activity growth and limited efficiency gains; these factors may account for why our forecast is above the consensus business-as-usual case.

In petrochemical feedstock (14% of oil demand), we expect demand to explode by 72%. We remain way above the business-as-usual average. This is despite our upbeat assumptions around recycling uptake (which will reduce demand for virgin plastics). The consensus forecasts here are generally light on detail, but they seem to imply plastics demand far below historical trends along with unrealistic assumptions around recycling.

Oil Demand Forecast Comparison by Sector, Million Barrels per Day

Percentage change in oil demand (2024-50) by sector



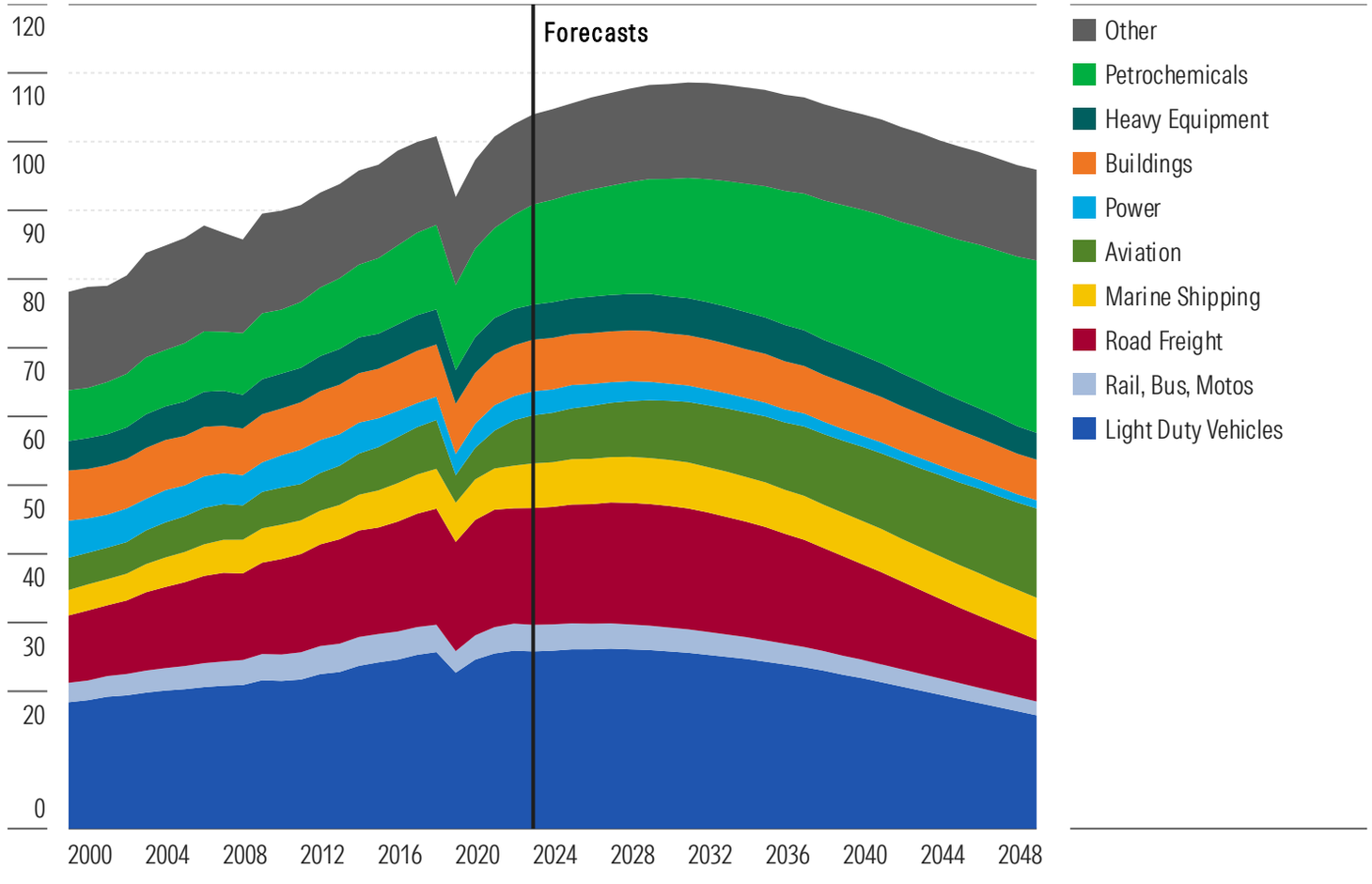
Source: International Energy Agency, BP, Equinor, Shell, OPEC, Exxon, Morningstar.

A Large Chunk of Oil Demand Is Resistant to Demand Disruption

We expect aviation, petrochemical feedstock, and "other" sectors to be highly resistant to demand disruption. These sectors accounted for 33% of oil demand in 2024, and we expect that to rise to 54% by 2050.

Oil Demand mmbpd	**2024**	*% Share*	**2050**	*% Share*
Total	**104.0**		**95.8**	
Other	13.1	*13%*	13.2	*14%*
Petrochemical Feedstock	14.6	*14%*	25.1	*26%*
Heavy Equipment	5.1	*5%*	3.9	*4%*
Buildings	7.5	*7%*	5.9	*6%*
Power	3.5	*3%*	1.2	*1%*
Aviation	7.0	*7%*	13.0	*14%*
Marine Shipping	6.5	*6%*	6.1	*6%*
Road Freight	17.0	*16%*	9.0	*9%*
Rail, Bus, Motorcycles	3.9	*4%*	2.0	*2%*
Light-Duty Vehicles	25.8	*25%*	16.5	*17%*

Oil Demand by Sector (Detailed) Million Barrels per Day



Source: IEA, Morningstar.

For All Other Sectors, Demand Should Fall in Aggregate, but Not Rapidly

For all sectors that we didn't cover on Slide 6, our oil demand expectations are, in aggregate, about in line with the typical business-as-usual case.

For heavy equipment (5% of 2024 oil demand), we expect demand to drop 24% through 2050. Electrification should be economical for heavy equipment just as it is in cars in trucks, but there are some impediments that will slow adoption. Agriculture equipment, in particular, will be a tough nut to crack.

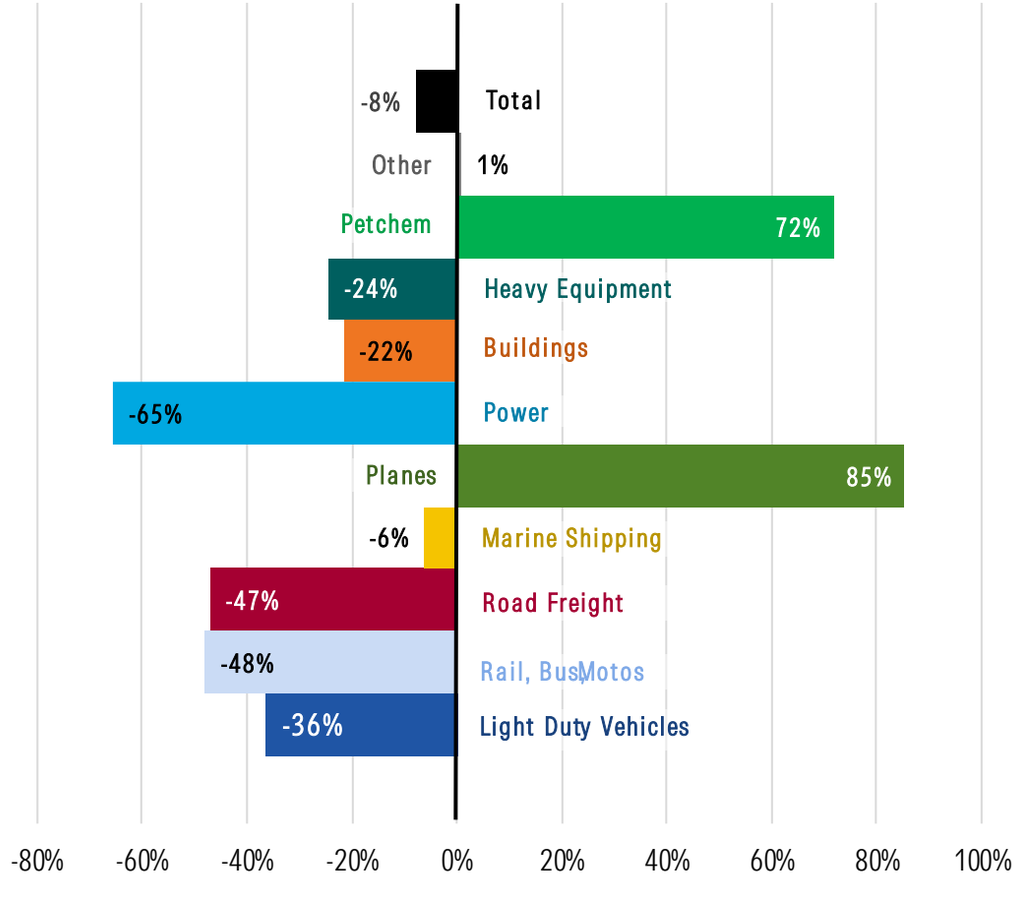
In the buildings sector (7% of oil demand), electrification of building heating will reduce oil demand, especially in advanced economies. However, the building sector's energy use is sticky, so demand won't disappear overnight.

In the power sector (3% of oil demand), demand should continue its long-term trend of steep decline, owing to very poor economics of oil-fired power generation compared with alternatives.

Electrification of rail, bus, and motorcycles (4% of oil demand) should proceed rapidly, with oil demand falling 48%.

For the "other" category (13% of oil demand), we expect demand up 1% through 2050. Many of the products in this category, such as asphalt, constitute nonenergy use of oil (it's not combusted), so decarbonization policies are much less relevant here.

Oil Demand by Sector (Detailed)



Source: IEA, Morningstar.

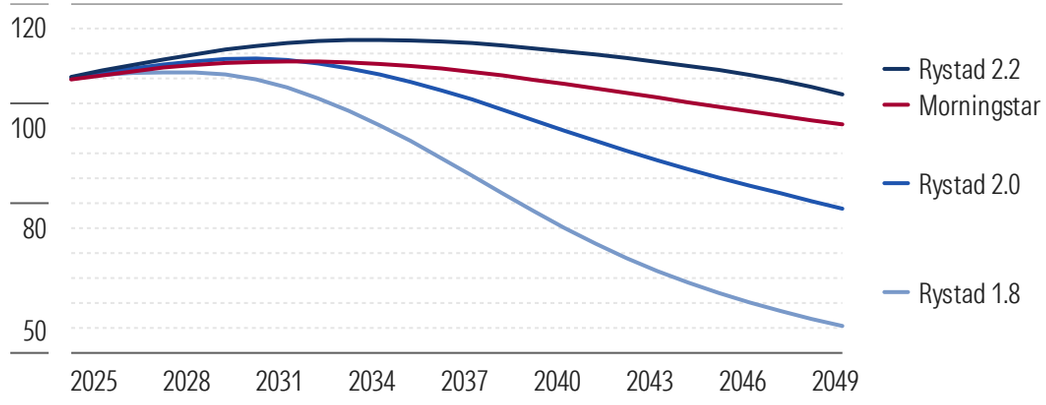
Resilient Oil Demand Will Require Ongoing Development of New, Costly Oil Projects

We project oil prices by combining our demand forecast with Rystad's supply-side views. Rystad has several scenarios for oil demand through 2050. For each of these scenarios, it uses its detailed cost-of-production model to determine the equilibrium oil price in each year. Our forecast is closest to the Rystad 2.2 scenario.[1]

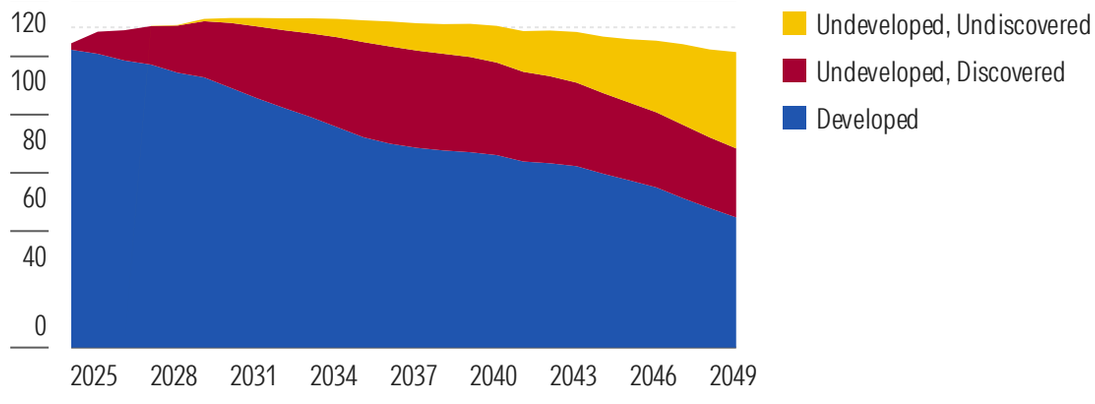
It's important to remember that oil production from existing assets is always declining. Even though we're projecting oil demand to decline after 2035, demand will hardly dry up entirely. Therefore, intensive development of new oil assets will be required to facilitate oil demand through 2050.

In the Rystad 2.2 degrees scenario, 56% of oil demand will come from undeveloped assets as of 2024. Within that, 33% of oil demand comes from assets that haven't been developed or haven't even been discovered yet. It's likely that costs in new developments will exceed those in existing assets, particularly for undiscovered resources. Rystad estimates that, among currently undiscovered assets expected to produce in 2050, around two-thirds of the volumes will consist of shale oil or deepwater projects. These supply segments are more expensive than traditional oil production.

Oil Demand: Rystad Scenarios and Morningstar Forecast, Million Barrels per Day



Oil Production in Rystad 2.2 Scenario, Million Barrels per Day



1 Corresponding to an average global temperature rise of 2.2 degrees Celsius by 2100 versus preindustrial levels.

Source: Rystad, Morningstar.

Oil Prices to Average $65 per Barrel Until 2035, but Then Soar Afterward

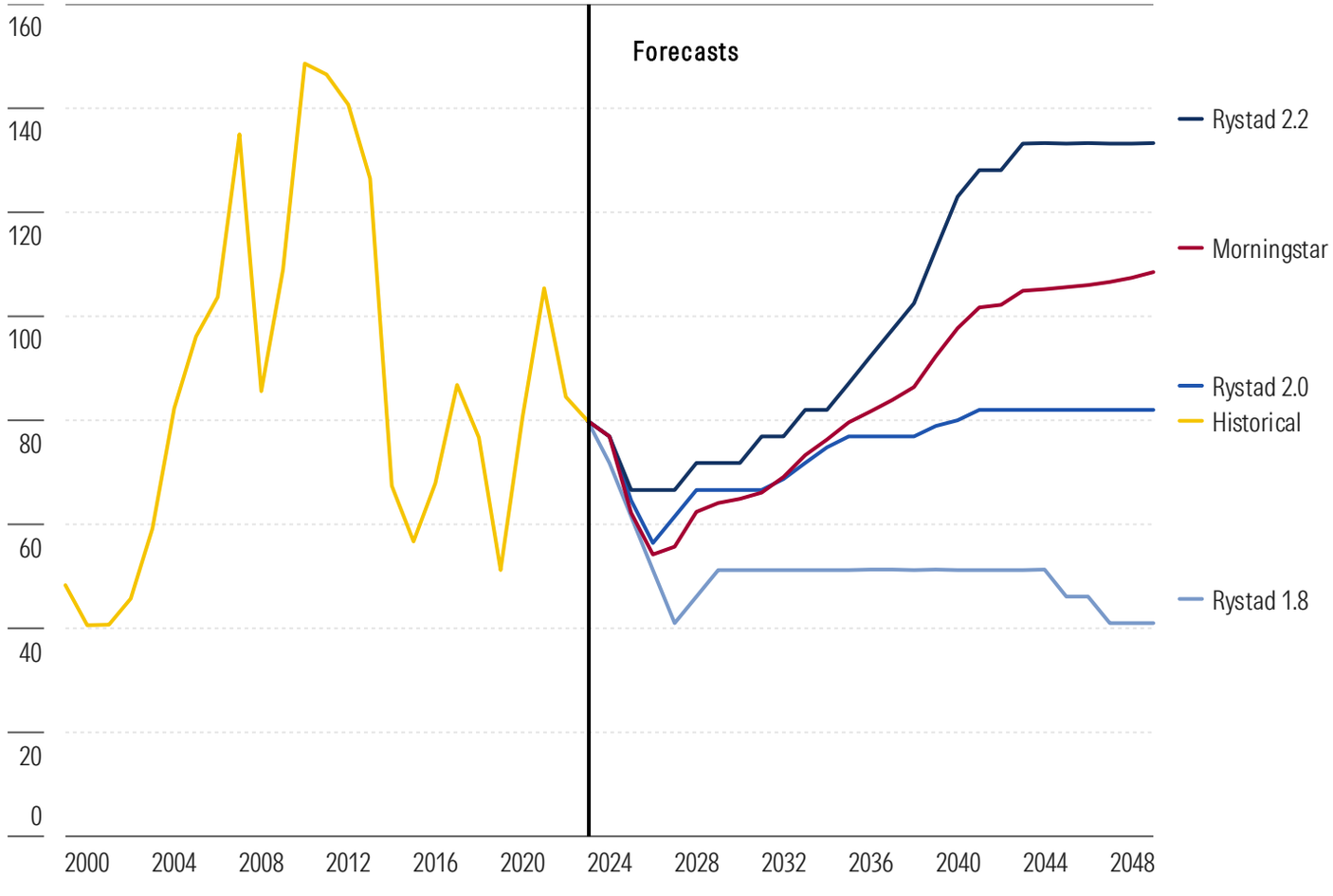
Given the need to tap a vast new supply, Rystad projects oil prices to soar in its 2.2 scenario. We agree with Rystad that it's unlikely a new supply source will emerge like US shale in the 2010s to drive a sustained major reduction in oil prices.

Our own forecast is a linear interpolation between the Rystad scenarios, based on how close our demand projection is to the production volumes in each scenario.

Over 2025-34, we expect Brent oil prices to average $65 per barrel in inflation-adjusted terms. This is close to the current Brent price at $63 as of November 2025, and a bit below the 2015-24 average real Brent price of $76. We use this 10-year average through 2034 as our midcycle price.

By the 2040s, we project oil prices to surge over $100 per barrel in real terms. For now, we're not factoring in the 2035-50 period into our midcycle price, as existing producers may not have enough inventory to reap the benefits of higher prices (and new assets will be developed at higher costs).

Real Oil Price (Brent), Dollars per Barrel



Source: Rystad, Morningstar.

Light-Duty Vehicles

EV adoption will shrink demand but not replace it entirely by 2050.

EV Adoption Will Shrink Light-Duty Vehicle Oil Demand

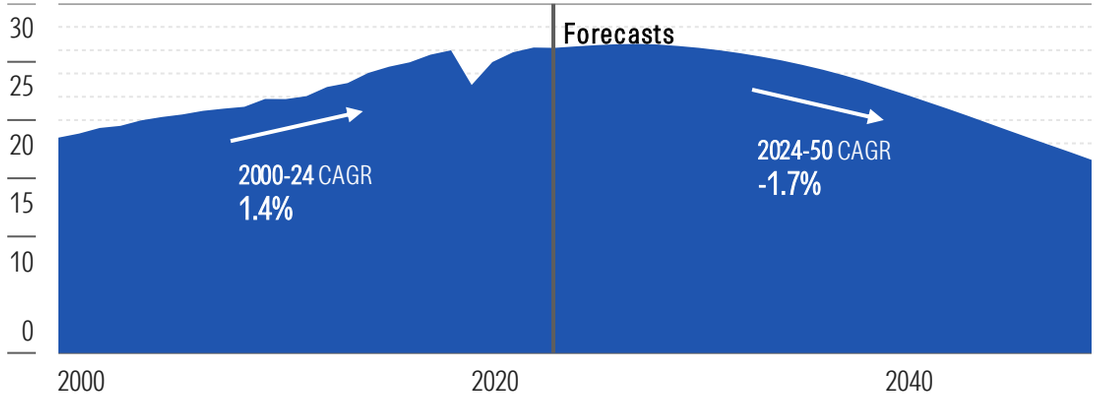
Light-Duty Vehicle Oil Demand to Drop 36% Through 2050

We expect oil demand for light-duty vehicles to drop by 36% from 2024 to 2050, or 1.7% annually, as the effect of EV adoption outweighs future growth in vehicle miles traveled. Our projected decline is a bit steeper than the consensus business-as-usual scenario, which calls for about a 25%-30% decline, probably owing to our more upbeat views on EVs (some forecasters still expect rather sluggish adoption). Still, EVs won't displace this sector of demand entirely by 2050.

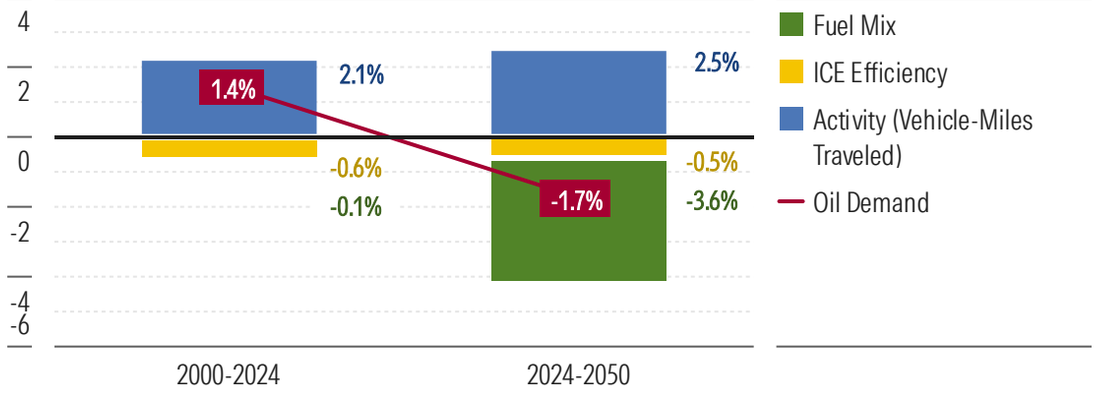
We expect vehicle miles traveled to grow 2.5% over 2024-50, slightly higher than 2.2% over 2000-24, though in line with the 2.5% posted over 2000-19 (stripping out the pandemic impact). Improvements in the fuel efficiency of internal combustion engine cars drive 0.5% in annual fuel savings, slightly lower than the 0.6% over 2000-24, owing to the exhaustion of low-hanging fruit. The effect of the fuel mix (shifting from pure ICE vehicles to EVs and plug-in hybrid electric vehicles) accounts for 3.6% of annual fuel savings.

As detailed in our March 2025 report EV Sales Will Continue to Rise, Driving Lithium Prices Higher, even though EV sales in the US and Europe stalled in 2024 following several years of rapid growth, we still see the EV transition coming. As more-affordable long-range EVs are sold in the US and Europe over the next couple of years and fast-charging networks are built, we expect EV growth to accelerate, even if subsidies fall away. This follows China's trajectory, the world's largest EV market, where EVs continue to gain market share despite federal subsidies ending at the end of 2022.

Light-Duty Vehicle Oil Demand, Million Barrels per Day



Light-Duty Vehicle Oil Demand Drivers, Percentage Compound Annual Growth Rate



Source: International Energy Agency, Morningstar.

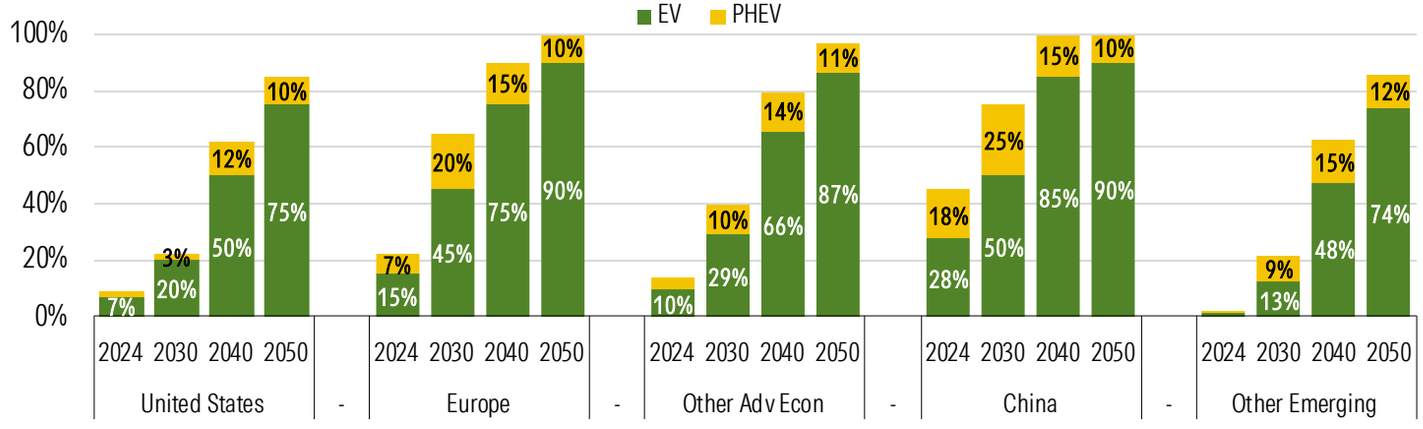
EVs Will Account for Most Vehicles Sold by 2050, but Lots of ICEs Will Remain on the Road

China and Europe are leading the way in EV adoption, and by 2040 and 2050, respectively, EVs will compose nearly all vehicles sold in these geographies (with PHEVs making up the rest).

The United States and non-China emerging economies are lagging in adoption. Electric cars, even the ones that can go long distances, are very likely to take over completely in the future because they're about to cost the same as regular cars. Also, they're building charging stations in the US and big developing countries like India. However, there is a risk that these regions will fall short of total EV adoption even by 2050.

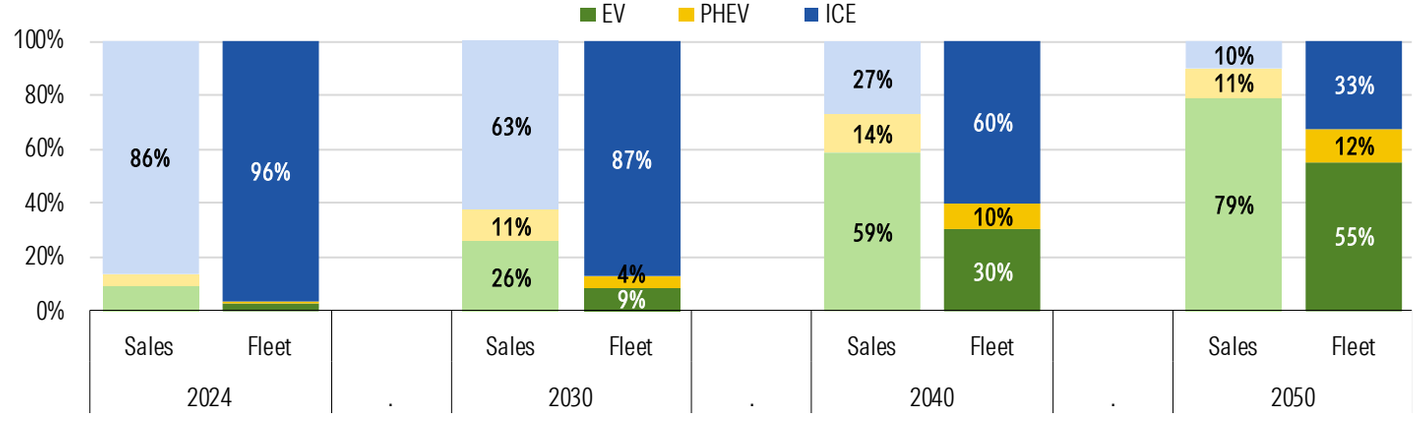
Given the long life of vehicles (15-20 years on average), we still expect that 33% of global vehicles on the road in 2050 will be pure ICEs, even as the ICE sales share falls to 10% by then.

EV and PHEV Share of Vehicle Sales (%)



Global Share of Vehicle Sales and Vehicle Fleet (%)

Weighted by Vehicle-Miles Driven



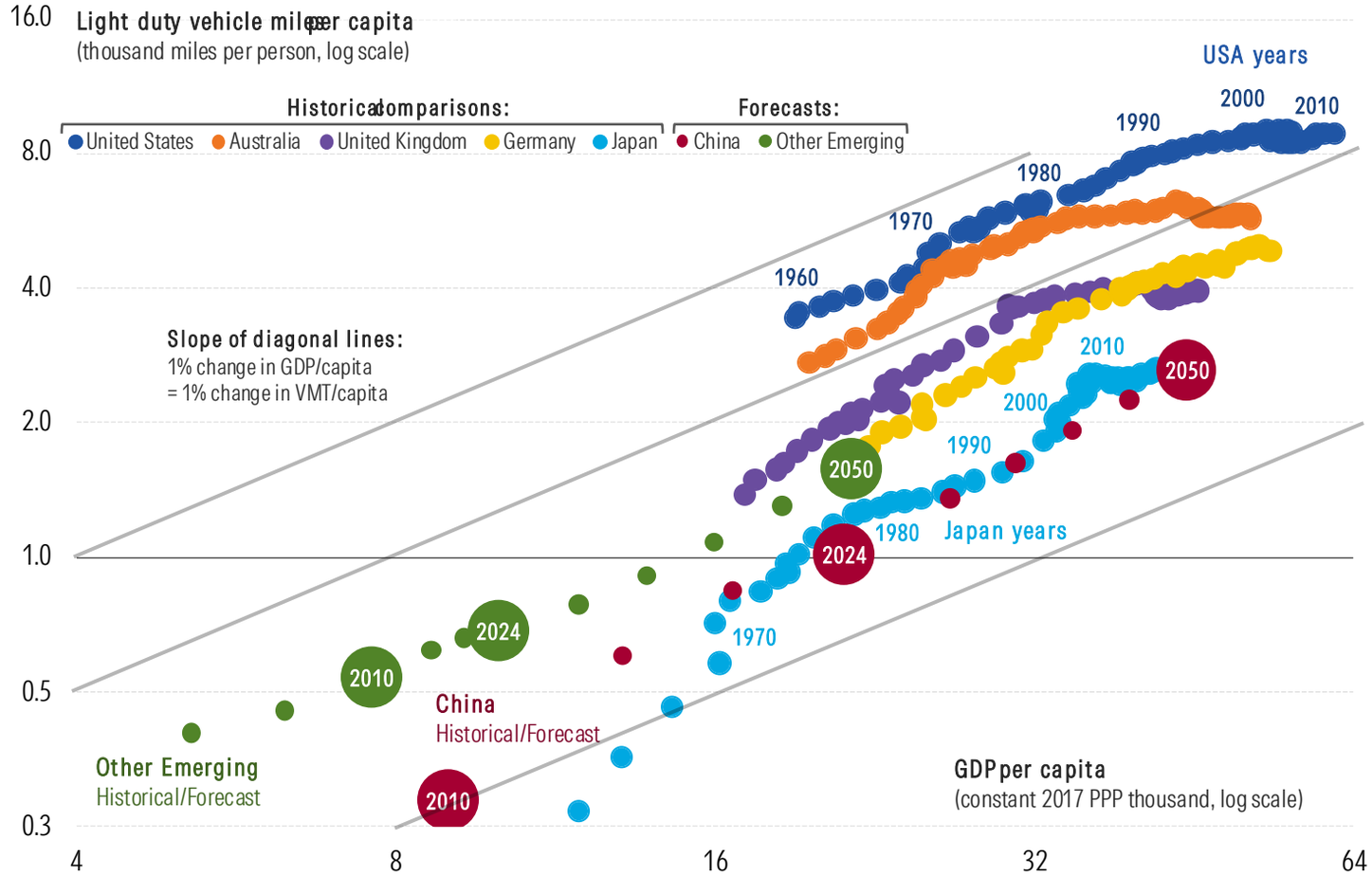
Source: International Energy Agency, Morningstar.

Emerging Economies to See Growing Vehicle Use Through 2050

In advanced economies where vehicle use is near saturation, we expect vehicle miles traveled to grow by just 0.1% per capita over 2024-50. However, we expect China's per capita VMT growth at 3.7%, and the average growth for other emerging economies at 3.3%, moderately higher than GDP per capita growth at 2.9% and 3.0%.

China is in its prime years for driving adoption, and the typical other emerging economy is entering that zone (namely, India). Historically, countries at income levels of around $10,000-$ 40,000 per capita (2017 purchasing power parity dollars) have seen vehicle travel per capita grow at least as fast as GDP per capita, and often much faster. China appears to be following Japan's trajectory, mirroring its massive public transit buildout. We expect the typical other emerging economy to trace the trajectory of continental Europe (that is, somewhere in between Japan and the more intensive vehicle use seen in English-speaking countries).

Light-Duty Vehicle Usage Versus Income Levels



Source: IMF, International Council on Clean Transportation, Morningstar.

Road Freight

We see potential mass electrification of freight trucks over the long term.

Road Freight Demand Also To Be Hit Hard by Electrification

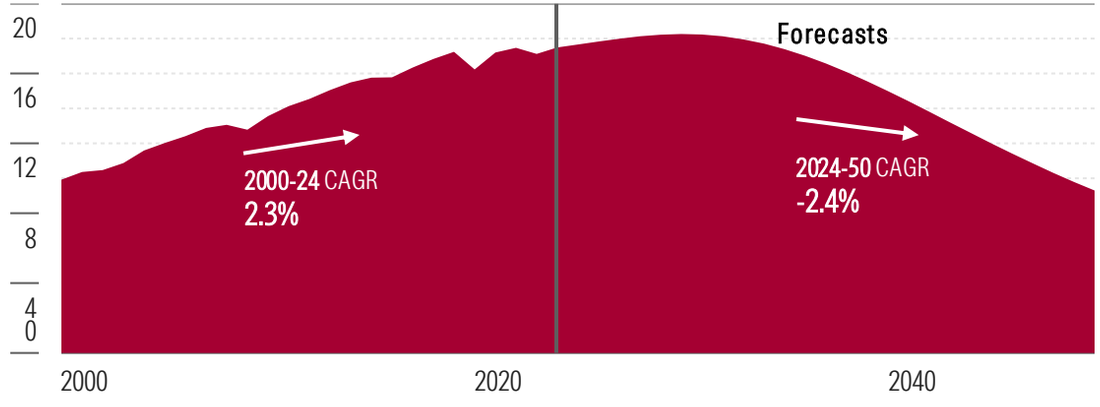
Road Freight Oil Demand to Drop 47% Through 2050

We expect oil demand for road freight to drop by 47% from 2024 to 2050, or 2.4% annually. This is the one sector where we're much more bearish on oil demand than the consensus business-as-usual scenario, which projects about flat demand. The consensus view holds that trucking is harder to electrify than passenger vehicles, but we think this is completely wrong.

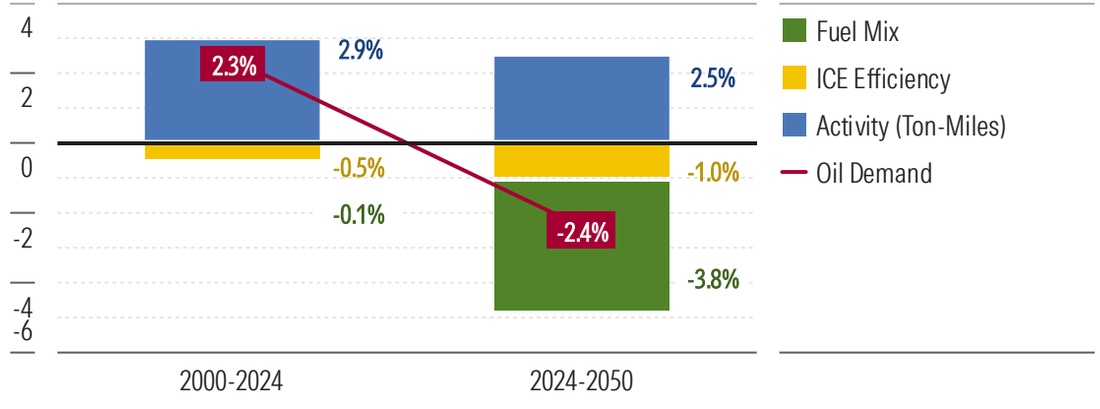
We expect road freight ton-miles carried to grow 2.5% over 2024-50, slightly lower than 2.9% over 2000-24. We expect higher efficiency of gasoline/diesel-fueled trucks to subtract 1% annually from demand, vs. 0.5% in the 2000-24 period. In contrast with light-duty vehicles, there are more opportunities for boosting fuel efficiency in trucking, which wasn't subject to fuel economy standards in major economies until the 2010s. Additionally, electrification is likely to be fastest in areas (like last-mile delivery) with the lowest fuel efficiency, which will push up the average efficiency of the remaining oil-fueled trucks on the road.

The shift in fuel mix away from gasoline/diesel trucks subtracts 3.8% annually from the sector's oil demand. In the near term, this is driven primarily by the uptake of LNG trucks in China, but in the long run, it is mainly driven by electric trucks.

Road Freight Vehicle Oil Demand, Million Barrels per Day



Road Freight Oil Demand Drivers, Percentage Compound Annual Growth Rate



Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

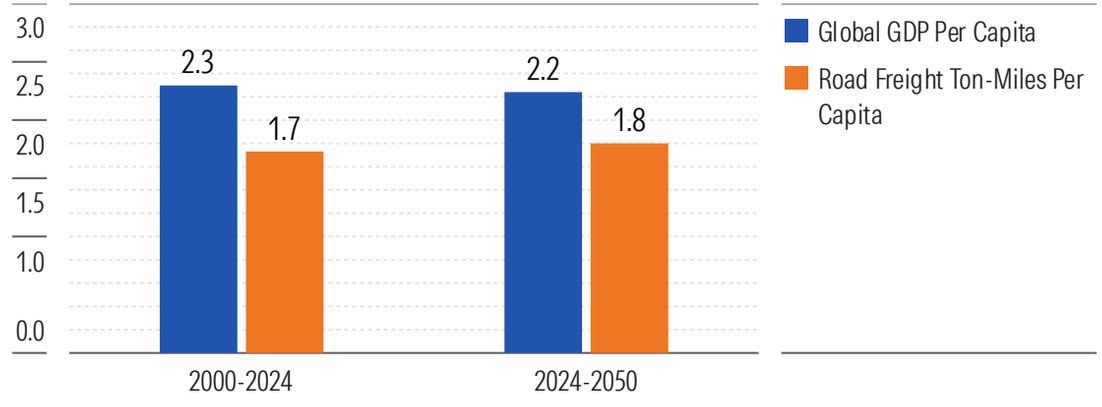
Adoption of Electric Trucks to Take Off By 2030s

Our forecast for 2.5% annual growth in road freight ton-miles is in line with typical third party forecasts, such as the IEA's Future of Trucks report. In per capita terms, we expect road freight ton-miles to grow 1.8% per year over 2024-2050, about in line with the 1.7% over 2000-2024.

We believe widespread electrification of trucking is coming. We project non-oil fueled trucks to rise from around 6% of global sales in 2024 to 16% of sales in 2030 and 81% of sales by 2025 (weighted across regions by road freight ton-miles), which in the long run is mostly composed of electric trucks. As a share of the fleet on the road, we expect the share to rise from around 1% currently to 6% in 2030 and 64% by 2050.

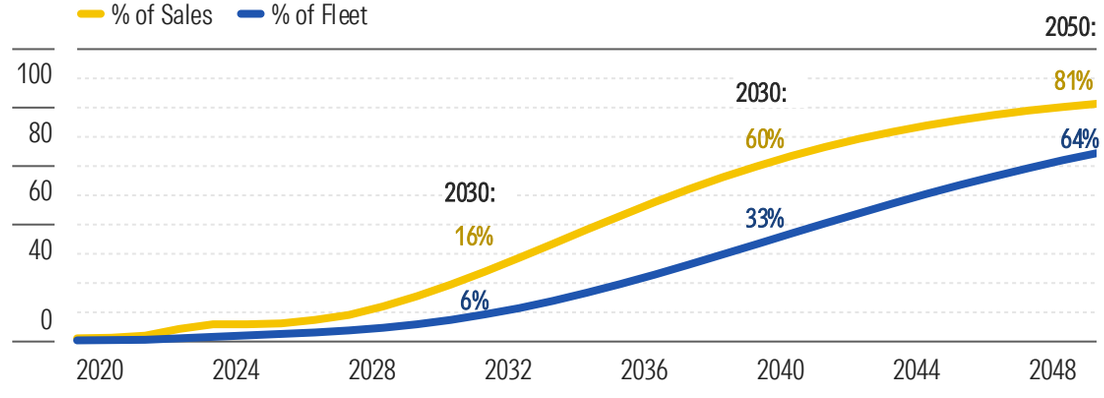
The logic of why EVs will excel for road freight is quite simple. The basic trade-off of EVs versus ICEs is this: EVs have a higher fixed cost (the battery) but a lower variable cost (cheaper fuel and maintenance). The more miles you drive, the more you reap that variable cost advantage. And freight trucks drive far more than passenger vehicles. Semi-trucks average around 95,000 annual miles in their first 10 years of use, while light-duty vehicles average only about 12,000 annual miles. Fuel comprises around 55% of the total cost of ownership for a long-haul truck, versus 10-20% for a typical passenger car. Accordingly, the fuel savings to be reaped from electrification are much greater for freight trucks than for passenger cars.

Global GDP and Road Freight Activity Per Capita, % Compound Annual Growth Rate



Global Non-Oil Fueled Freight Trucks, % Share

Weighted by Ton-Miles of Road Freight



Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

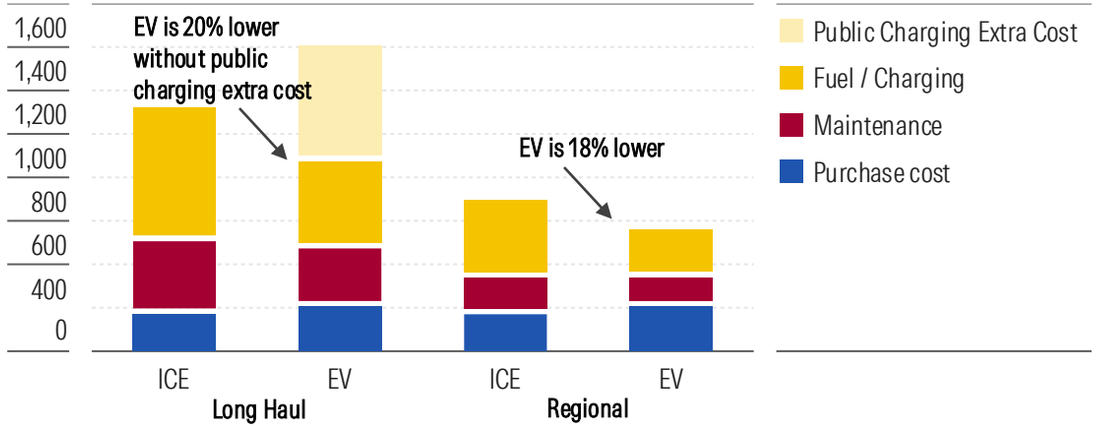
Electric Trucks Could Have a Big Cost Advantage

If the electricity price is right, the economics of electric trucks is a slam dunk. If trucks can charge using electricity prices about in line with average commercial electricity prices in the US ($ 0.14 per kWh as of August 2025, plus a $0.02 markup for charging equipment), then the total cost of ownership for an electric truck could be around 20% cheaper than an ICE (diesel) truck. However, long-haul trucks will need widespread cheap public charging. Current public charging prices (around $0.35 per kWh) put long-haul trucking at a significant cost disadvantage compared with ICE trucks.

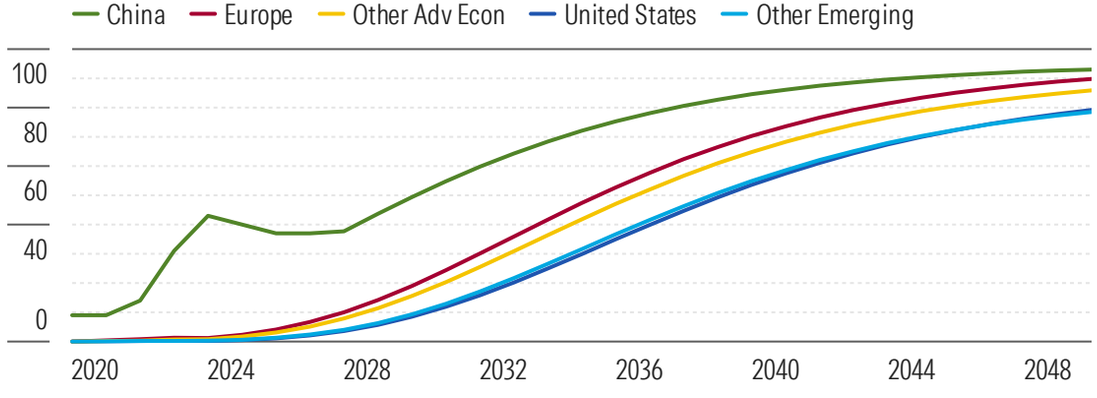
We think cheaper charging is coming, as a result of high scale and utilization of charging infrastructure, both of which will be aided by increased adoption of electric vehicles for passenger transport. Many governments are already investing heavily in charging infrastructure for electric cars, and it's likely they will do the same for electric freight trucks. However, the risk that adequate charging infrastructure isn't built is the main driver for why we don't expect EV penetration of freight trucks to reach 100% by 2050.

Over the past few years, China has already cut deeply into its trucking sector diesel demand by pushing LNG trucks up to around 30% of sales. But China's emphasis in trucking is now switching to EVs, which jumped to 13% of heavy truck sales in 2024. In the near-term, we expect enthusiasm for LNG to dim (they're only cost effective in certain low-cost natural gas regions in China), while EVs eventually cause the non-oil share of truck sales to soar in the 2030s. Europe should follow in China's footsteps, with other regions also following as electric trucking's cost effectiveness is demonstrated.

Total Cost of Ownership for Semi-Truck (10-Year)



Non-Oil Fueled Freight Trucks, % Share of Sales



Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

Greater Scale Should Reduce Charging Costs

At electricity prices paid by commercial customers in the US of $0.14 per kWh, the economics of electric trucks are very favorable. This price is a realistic scenario in the near future for trucks that can recharge overnight at their home depot, which probably includes most trucking outside of long-haul. Around 50% of US truck ton-miles comprised trips less than 250 miles in 2023, so there's plenty of room for electrification of shorter-haul while long-haul waits for cheaper charging.

We think public charging costs (around $0.35 per kWh in the US) should eventually fall dramatically, converging much closer to electricity prices for commercial customers. In general, the key to low electricity prices is scale and regularity of demand. Those attributes are why average electricity prices in the US are $0.09 per kWh for industrial customers, much lower than the $0.18 paid by residential customers. As electric vehicle infrastructure scales up, large charging stations will begin to resemble industrial customers in their demand profile. Equipment and other costs should also come down with greater scale and utilization. In much of China, we've already seen the spread of public charging costs over average electricity prices fall to $0.10 per kWh or less.

The need for utilization and scale presents a classic chicken-or-egg problem, which may require some government-led investment and coordination to overcome. Many countries are already building out extensive networks for passenger EV charging. There should be some complementarity between the infrastructure needed for charging passenger EVs and for electric semitrucks, although the latter will require separate, more powerful charging units.

Electric Truck TCO Sensitivity to Electricity and Diesel Prices

Percentage difference in TCO of electric trucks versus diesel for various price scenarios

Diesel Price $ per gal	Electricity Price $ per kWh 0.10	0.15	0.20	0.25	0.30	0.35	0.40
2.0	-13%	3%	19%	34%	50%	66%	81%
2.5	-21%	-7%	8%	22%	36%	50%	65%
3.0	-28%	-14%	-1%	12%	25%	38%	51%
3.5	-33%	-21%	-9%	3%	15%	27%	39%
4.0	-38%	-27%	-16%	-4%	7%	18%	29%
4.5	-42%	-32%	-21%	-11%	0%	10%	21%
5.0	-46%	-36%	-26%	-16%	-7%	3%	13%
5.5	-49%	-40%	-31%	-21%	-12%	-3%	6%
6.0	-52%	-43%	-34%	-26%	-17%	-8%	0%

US at commercial electricity prices

Source: IEA, Morningstar.

Ships and Planes

It is hard to replace oil for these crucial sectors.

Aviation and Marine Shipping to Contribute Solidly to Long-Run Oil Demand

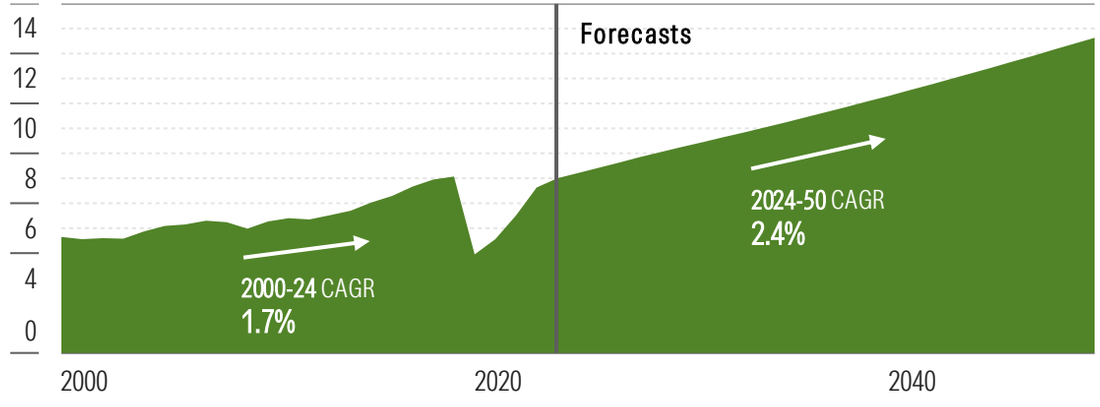
Aviation Oil Demand to Grow 85% Through 2050; Marine Shipping to Drop 6%

We expect oil demand for aviation (jet fuel) to climb by 85% from 2024 to 2050, or 2.4% annually, driven by robust growth in air traffic and minimal substitution into nonoil fuels. We expect oil demand for marine shipping to shrink just 6% (0.2% annually), with modest substitution from oil into LNG and alternative fuels. Collectively, we project demand for these two sectors to grow by 41%, slightly above the typical business-as-usual consensus scenario, which projects 30%-35% growth.

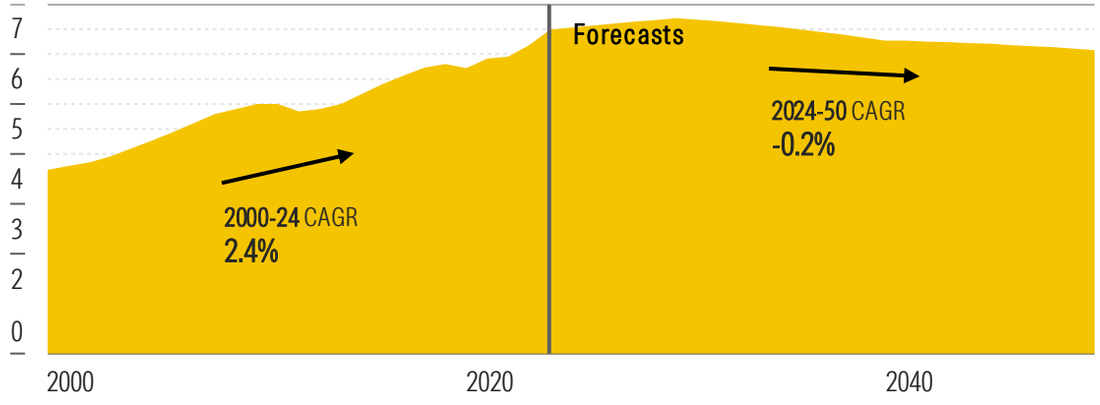
Both of these sectors are essentially impossible to electrify (excluding air taxis, which are a new market and don't compete with current air travel). The key to this is the "fuel fraction," as discussed on Pages 21-22 of our November 2021 Observer, The Future of Oil Demand—Reports of Its Death Have Been Greatly Exaggerated. An oceangoing freight ship already carries 10% of its weight in fuel, and planes carry 15%-25%, compared with about 3% for a typical car or long-haul freight truck. Even with drastic improvements, batteries won't come close to the energy density of liquid fuels, so they're untenable from a techno-economic perspective.

Instead of batteries, these sectors will need clean synthetic liquid fuels to decarbonize at scale. These prospective fuels will almost certainly be derived from "green hydrogen," that is, hydrogen produced via electrolysis with zero-carbon electricity. We're extremely skeptical that costs will come down enough for green hydrogen and other technologies needed for these clean liquid fuels. For air travel, costs will be prohibitive. For marine shipping, cost parity with oil will be elusive, but policy will probably drive some uptake.

Aviation Oil Demand, Million Barrels per Day



Marine Shipping Oil Demand, Million Barrels per Day



Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

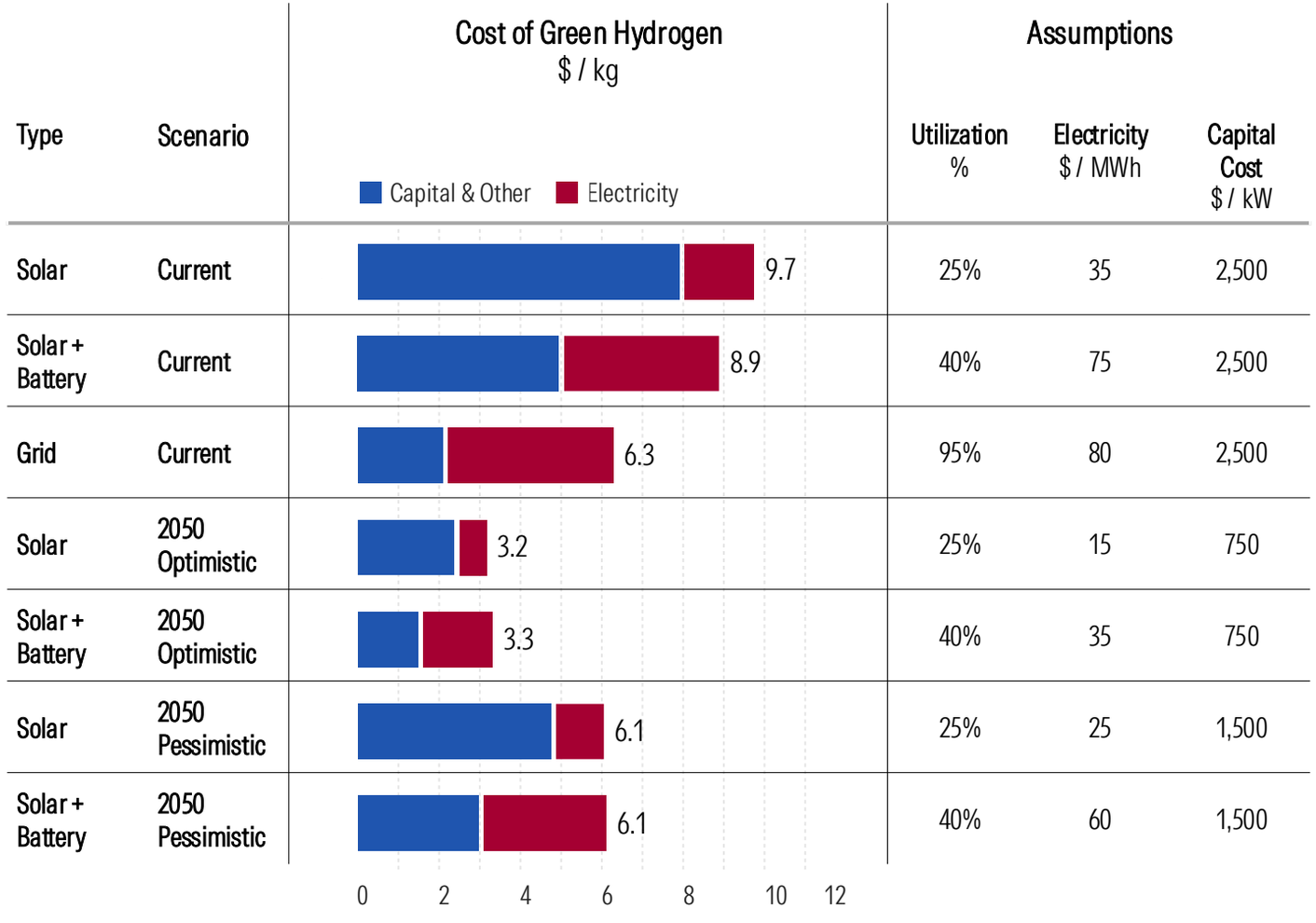
Green Hydrogen Unlikely to Get Cheap Enough for Mass Adoption by Ships and Planes

For green hydrogen and its derivative fuels to become cost-competitive with conventional fuels for ships and planes, green hydrogen production costs will need to fall to at least $2 per kilogram.

Only a couple of large-scale green hydrogen projects have come online over the past year or so. Data is scarce, but based on detailed analysis of actual projects (for example, Fletcher 2025), current costs for green hydrogen are very high, much higher than initial estimates when the hype around green hydrogen exploded in 2020-21.

The current cost for a prospective US grid-connected project could be around $6 per kilogram. Eschewing the grid to connect directly to a renewable source like solar wouldn't help, despite the lower electricity costs. That's because renewables' high intermittency means low utilization of the electrolyzer and associated plant, which dramatically inflates the capital cost. Even with extremely optimistic assumptions for reduction in solar costs and green hydrogen capital costs, we estimate the total production cost may drop to only $3 per kilogram by 2050.

Green Hydrogen Cost Scenarios (United States)



Type	Scenario	Utilization %	Electricity $ / MWh	Capital Cost $ / kW
Solar	Current	25%	35	2,500
Solar + Battery	Current	40%	75	2,500
Grid	Current	95%	80	2,500
Solar	2050 Optimistic	25%	15	750
Solar + Battery	2050 Optimistic	40%	35	750
Solar	2050 Pessimistic	25%	25	1,500
Solar + Battery	2050 Pessimistic	40%	60	1,500

Source: National Renewable Energy Laboratory, "Submission to CSIRO and AEMO" (Fletcher, 2025). "Evaluation of The Levelised Cost of Hydrogen" (Eble and Weeda, 2024). Morningstar.

Aviation Oil Demand Will Continue to Soar, With No Feasible Substitutes for Oil

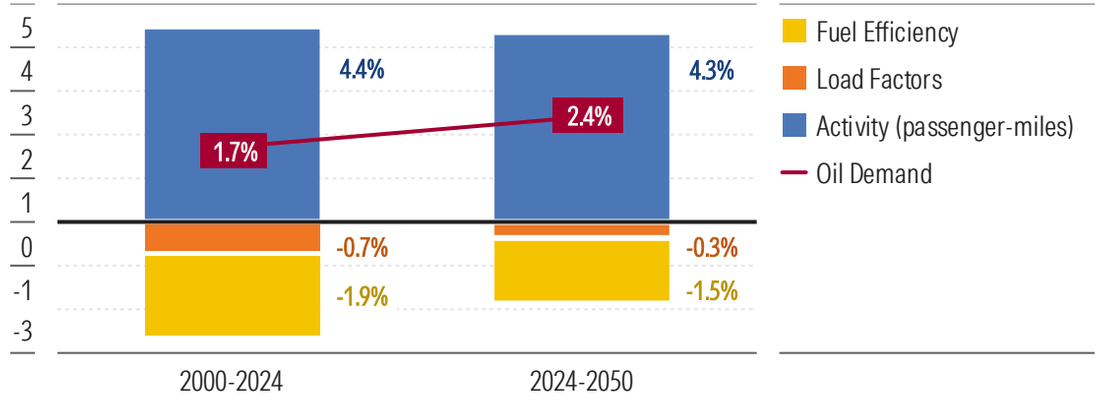
Diminishing Efficiency Gains Mean Aviation Oil Demand Accelerates

We expect aviation oil demand to increase 2.4% per year through 2050, compared with 1.7% growth over 2000-24. Passenger miles are expected to grow 4.3% annually, compared with 4.4% over 2000-24. But we expect less offset from efficiency-related factors over 2024-50 than over 2000-24. We expect negligible demand destruction from alternative fuels.[1]

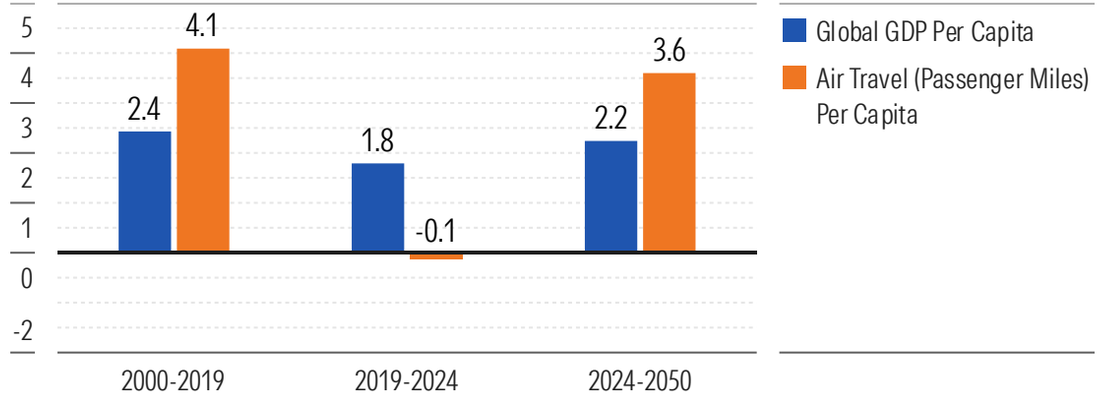
Average load factors (the percentage of seats filled) increased from 71% in 2000 to 83% in 2024, subtracting 0.7% annually from aviation oil demand. We expect load factors to increase to 90% by 2050, translating into a 0.3% annual hit to demand—it will be difficult to push much higher than this. Likewise, we expect diminishing returns in fuel efficiency, measured as fuel consumed per available seat mile. As discussed on Page 67 of our 2021 report, factors such as seat downsizing and aircraft lightweighting contributed heavily to past efficiency gains, but further gains are likely to be scarce.

Our forecast for 3.6% per capita growth in air travel passenger miles is slightly conservative, given 4.1% annual growth in the two decades before the pandemic. Per capita growth has been around 4% since 1980. Air travel remains a luxury good, with people spending a greater share of their income on it as their income level rises. On the other hand, rising oil prices in the past 10-15 years of our forecast period, along with possible carbon tax increases, could weigh on demand growth.

Aviation Oil Demand Drivers, % Compound Annual Growth Rate



Global GDP and Air Travel Per Capita, % Compound Annual Growth Rate



1 We include biofuels as a part of oil demand, so it's treated as a competing supply source, not a demand-disruptor. This is in line with IEA practice, along with the Rystad scenario we use for price projections.

Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

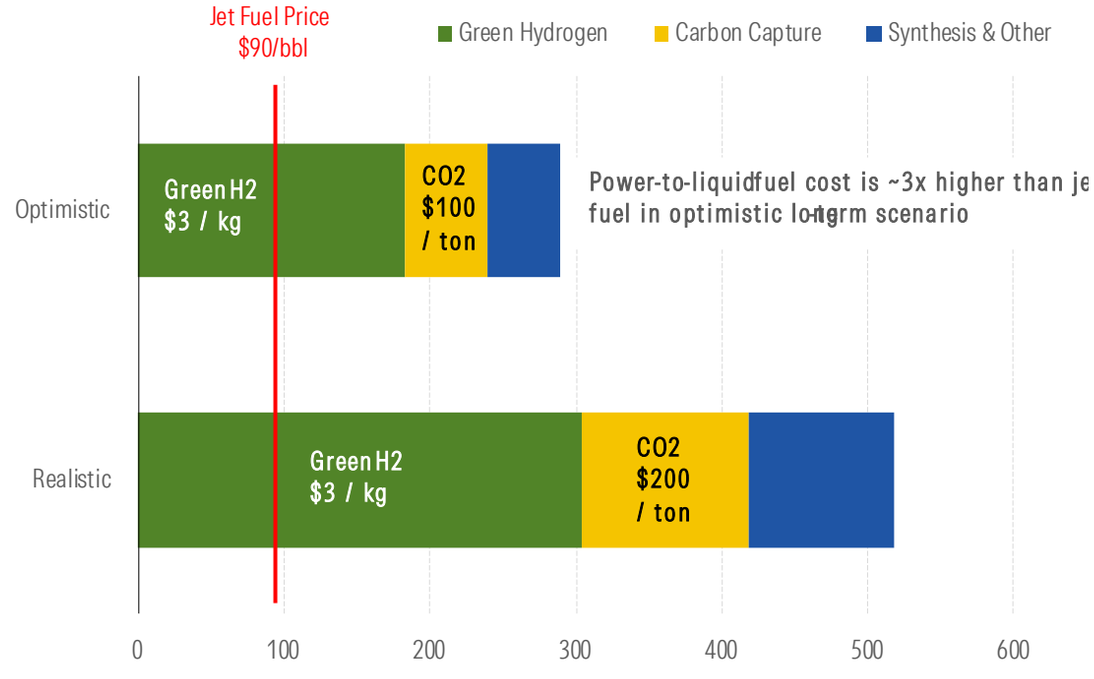
Liquid Fuels Derived From Green Hydrogen Will Be Astronomically Costly

We argued on Pages 68-69 of our 2021 report that green hydrogen would be a nonstarter for air travel, owing to high cost of hydrogen, the difficulty of adapting planes and infrastructure, and limited range. Now that Airbus has dropped plans to develop hydrogen planes by 2035, we can essentially disregard the possibility of hydrogen planes for our forecast period.

With hydrogen itself ruled out, the focus turns to "power-to-liquids," which are synthetic hydrocarbons derived from green hydrogen and captured carbon dioxide. These fuels have the requisite energy density, and could be dropped in to existing infrastructure and aircraft engines with minimal adjustments. Unfortunately, the cost for these fuels is likely to be prohibitive.

Even given (in our view) optimistic assumptions around long-run costs for green hydrogen and carbon capture, power-to-liquids are likely to remain around three times as costly as jet fuel. With more realistic assumptions, the ratio rises to over 5 times jet fuel. This would increase the cost of air travel by some 75%-150%. Moreover, it translates into a carbon abatement cost of $500-$1,000 per ton of CO_2, which is many times more costly than other emissions reductions opportunities available over the next few decades (for example, phasing out coal power costs well under $100 per ton of CO_2 in most places).

Cost Scenarios for Green Hydrogen-Derived Synthetic Fuel, $ per Barrel



Source: IEA, Morningstar.

Oil for Marine Shipping to Decline Only Slightly Despite Push for Emissions Reductions

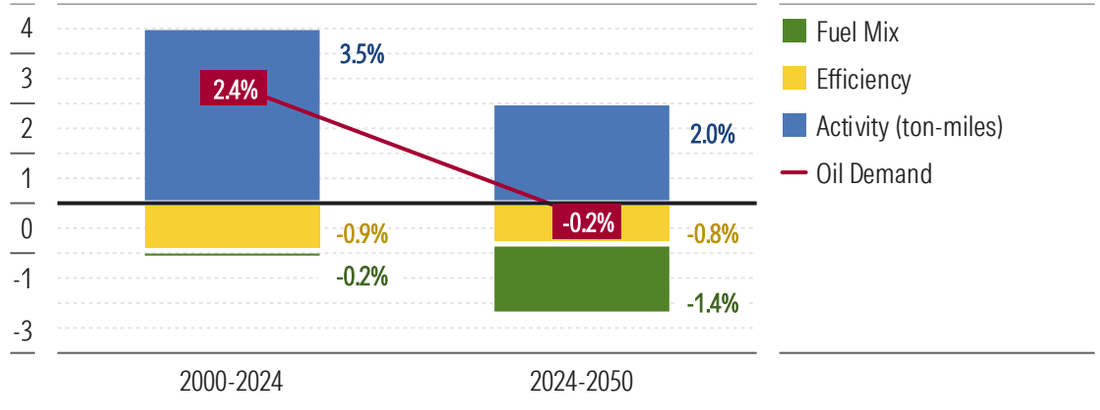
Efficiency Gains and Fuel Switching Slightly Outweigh Freight Growth

We expect marine shipping oil demand to drop an average of 0.2% per year through 2050, compared with 2.4% growth over 2000-24. Activity is expected to grow 2.0% annually in freight ton-miles. This is offset by a 0.8% annual gain in fuel efficiency for oil-fired ships, mainly due to slower steaming, which is the primary driver of yearly historical efficiency gains of 0.9%. A shift in the fuel mix from oil to LNG and green fuels like ammonia subtracts 1.4% annually from the sector's oil demand.

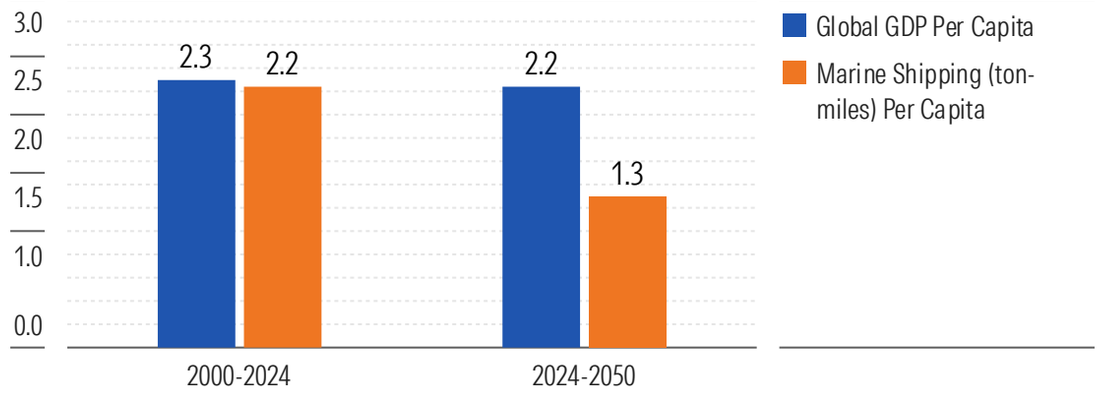
Our forecast for 2% annual growth in marine freight activity is in line with typical third-party forecasts (for example, the OECD's medium case is at 2%). It translates into per capita growth of 1.3% per year, moderately slower than per capita GDP growth at 2.3%. Over 2000-24, shipping demand benefited from expanding globalization and China's investment boom. By contrast, a likely long-term contraction of the trade share of global GDP will weigh on future marine freight growth.

In the near term, the main competitor for oil in marine shipping is LNG. LNG ships are currently at about cost parity with oil-fired ships. They emit about 20% less carbon than oil (ignoring methane slip), which allows shippers to claim they're reducing their emissions. Hence, LNG has risen to around 30% of the ship orderbook. But LNG's upside is probably mainly limited to ships with predictable routes with access to LNG bunkering. Also, if it turns out that the methane slip issue can't be fixed, that will dim enthusiasm. Thus, we assume that LNG remains about 30% of new ships delivered through 2050.

Marine Shipping Oil Demand Drivers, % Compound Annual Growth Rate



Global GDP and Marine Freight Activity per Capita, % Compound Annual Growth Rate



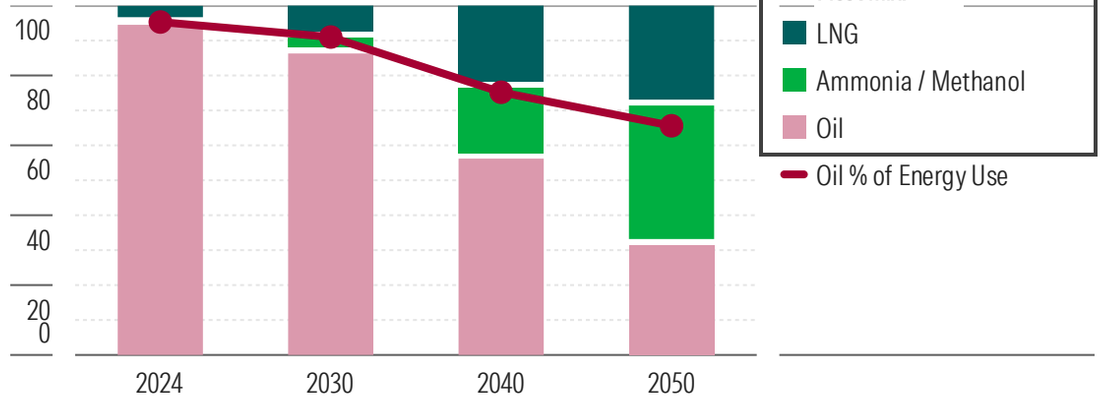
Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

Exorbitant Cost of Green Ammonia/Methanol Will Rule Out Wholesale Replacement of Oil

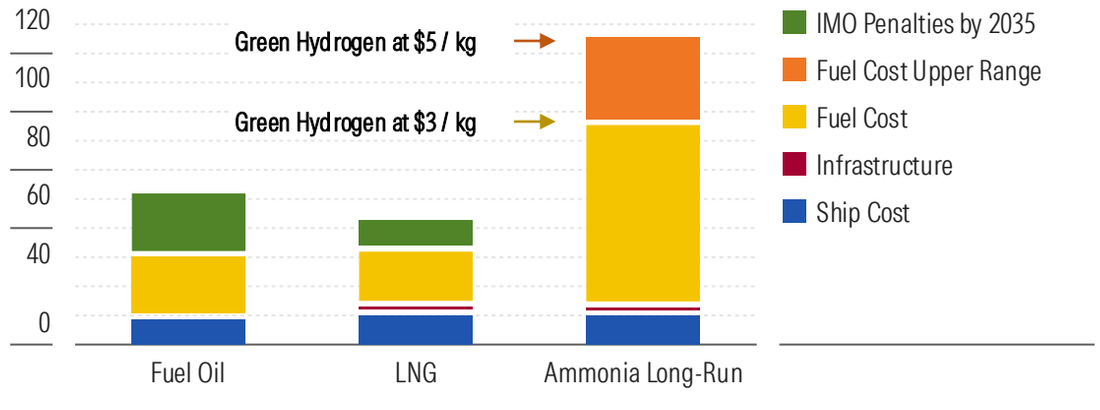
We expect oil to fall from 95% of energy use in the marine shipping sector to 66% by 2050, subtracting 1.4% annually from oil demand in the sector (the "fuel mix" effect on the prior page). This is driven by a drop in the share of ships which are only oil-fired from 95% in 2024 to 32% in 2050. However, we expect nearly all alternative-fueled ships to be "dual-fuel" (as is the case in the current orderbook), meaning they have the option to burn oil. LNG dual-fuel ships will probably burn LNG most of the time, but we think ammonia or methanol dual fuel ships will actually be burning oil upwards of 80% of the time, owing to extremely high costs for green ammonia and green methanol. If LNG ships gained the majority of share, then much more oil demand would be disrupted, but we think this is unlikely given the difficulty of building out LNG infrastructure across all shipping routes, as well as LNG's limited emissions benefits versus oil.

We estimate that, without penalties or subsidies, the total cost of ownership for an green ammonia-fueled ship will be 3-4 times higher than fuel oil. This is based on a green hydrogen cost of $3-5 per kg. Methanol is even worse due to costs of carbon capture. This would seem to rule out these fuels. However, the International Maritime Organization's proposed Net-Zero Framework will apply massive penalties to ships which don't achieve their "base" target, which seeks 32% emissions reductions per ship by 2035. The Net-Zero Framework is opposed by the US and other countries, and we think the increase in shipping costs would generate backlash. We expect a watered down version of the NZF to carry through, which shippers will cope with by burning just enough green ammonia or methanol to stay within the base target.

Marine Shipping Fleet Mix (% of DWT)



Total Cost of Ownership for Large Bulk Carrier, $/Kilogram



Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

Petrochemical Feedstock

Plastics demand to propel growth, despite greater recycling.

Plastics Demand Will Propel Petrochemical Feedstock Growth

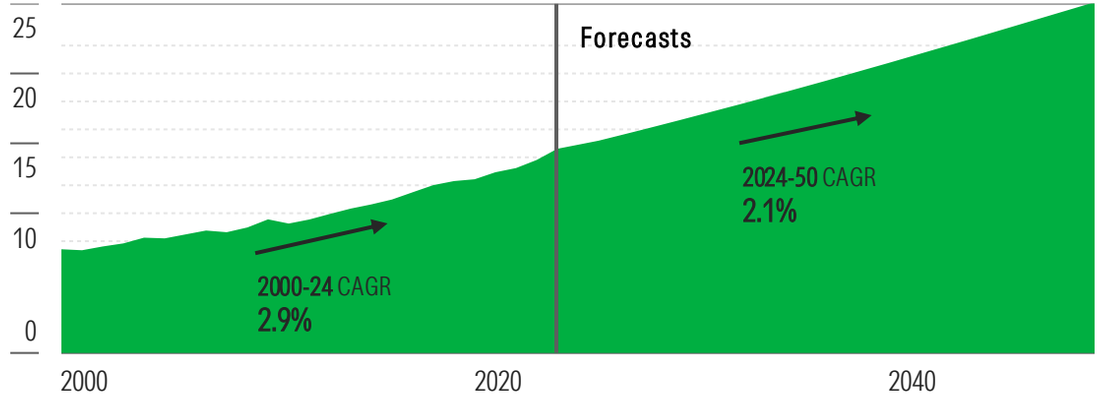
Petrochemical Feedstock Demand to Grow 72% through 2050

We expect demand for petrochemical feedstock for plastics to soar by 72% from 2024 to 2050 (2.1% annually), driven by a near-doubling of consumption of plastics (2.6% annual growth). Our forecast is optimistic compared to the typical business-as-usual consensus scenario, which projects 40-50% growth. But we're incorporating ambitious (yet still realistic) assumptions around recycling uptake, without which we'd expect demand to grow even faster.[1] See pages 73-82 of our 2021 report The Future of Oil Demand for further details on our views.

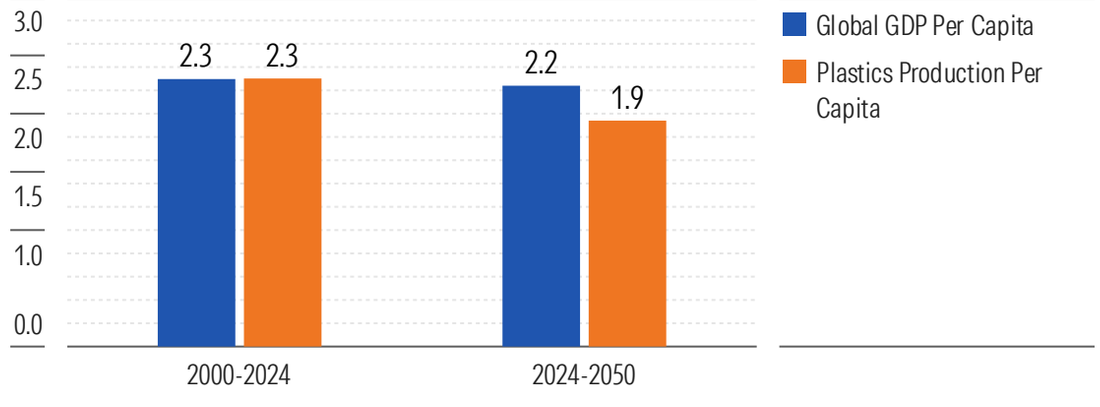
Plastics are indispensable to the modern economy. While packaging (31% of global plastic demand) is often most visible, plastic is ubiquitous in other sectors like transportation (14% of demand), textiles (10%), consumer goods (10%), and construction (17%). The average home is brimming with plastic, including siding, insulation, pipes, carpet, furniture, appliances, toys, and electronics.

Since 2000, global plastics demand per capita has grown roughly in line with GDP. Through 2050, we expect plastics demand to grow slightly slower than GDP, owing to stepped up efforts to curb use. Thus, we expect global plastics demand per capita to grow 1.9% annually through 2050, or 2.6% annually in absolute terms.

Petrochemical Feedstock Oil Demand, Million Barrels per Day



Global GDP and Plastics Demand Per Capita, % Compound Annual Growth Rate



1 Owing to lack of provided detail, we're not sure why alternative forecasts for petrochemical feedstock growth are so low, but they must be incorporating overly rosy assumptions around recycling.

Source: IEA, Organisation for Economic Co-operation and Development, IMF, Morningstar.

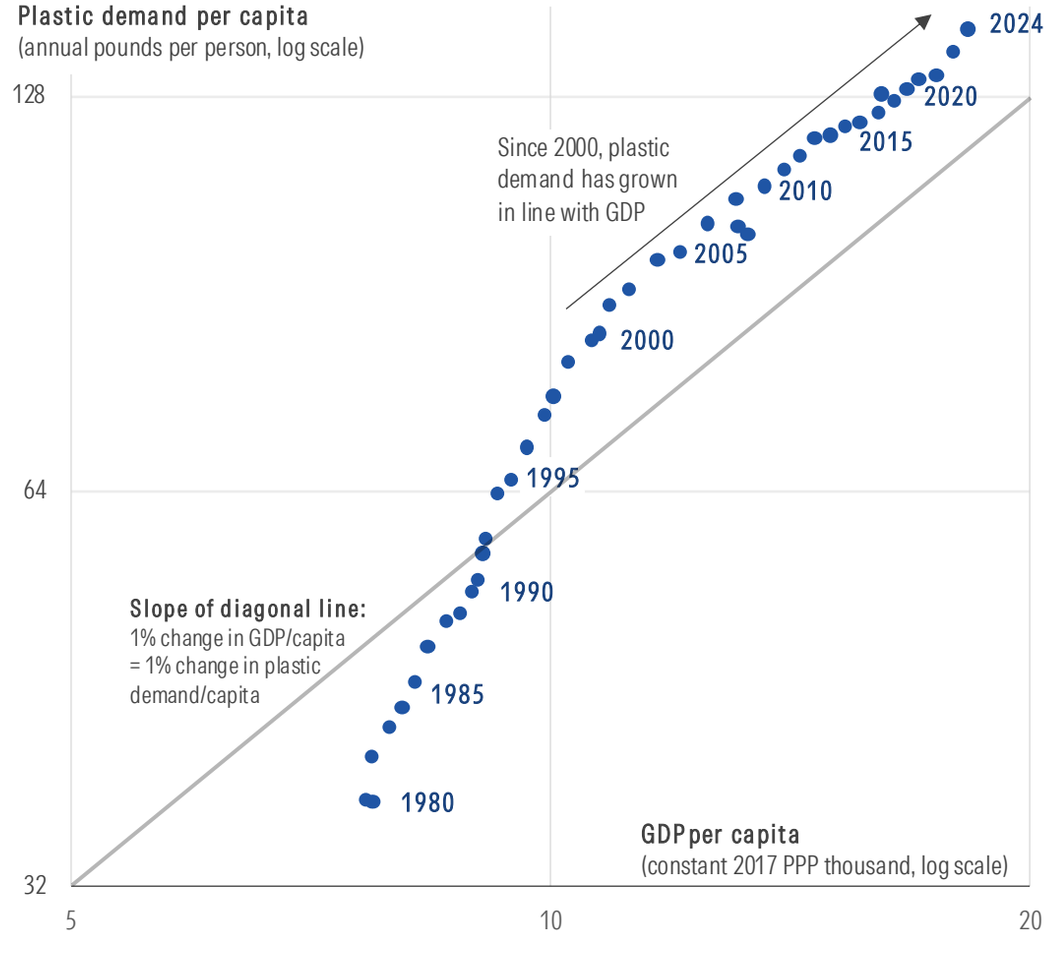
Efforts to Curb Use Will Only Modestly Dent Plastic Demand Growth

Over 1980 to 2000, plastic demand per capita was outpacing GDP per capita, probably because it was still a relatively new technology and gaining market share over other materials like glass and metals. Since 2000, plastics demand has grown steadily in line with GDP growth. We think private and governmental efforts to reduce plastics use will modestly exceed efforts seen in past years, which is why we expect plastics demand growth to fall about 30 basis points short of GDP growth.

In gauging the impact of demand reduction initiatives, we should keep in mind that such initiatives are not new. For example, the weight of the average 0.5 liter plastic water bottle has fallen by around 50% since 2000, according to the PET Resin Association. In fact, the IEA's "The Future of Petrochemicals" suggests that lightweighting of most plastic packaging may be reaching its technical limits.

Restrictions on plastic use have been limited in scope and geography. So far, these measures have had muted effect on the upward trend in global plastic use. Bans on single-use bags were widely implemented over the past decade, but enforcement was mostly limited outside of richer countries, and bags were probably only a low-single digit share of global plastic demand anyways. More recently, the EU and other polities have banned certain other single-use plastics (cutlery, straws). But for most categories of packaging, we doubt that consumers are going to be able to do without the durability and flexibility offered by plastics. Outside of packaging, plastic replacement may not even be environmentally favorable, much less technically or economically feasible.

Plastics Demand and GDP per Capita Since 1980



Source: OECD, Plastics Europe, IMF, Morningstar.

We Incorporate Ambitious Recycling Assumptions, but Petrochemical Demand Will Still Be Strong

Through 2050, we expect 2.6% annual growth in plastic demand. Because of increased recycling penetration, secondary production grows 5.3% annually, while primary plastic production grows 2.3%. Petrochemical feedstock demand grows 2.1%, slightly slower than primary plastic production owing to process improvements and uptake of bioplastics.

Our projection for continued strong growth in primary plastic production is despite our ambitious assumptions around recycling uptake. We believe private initiative and government policy will boost the share of plastic waste collected for recycling to 28% in 2050 from 16% in 2024. Technological improvement will be needed to keep recycling yields flat, as higher collection entails collecting lower-quality recyclables.

By 2050, we expect secondary plastic production to equal 17% of plastic waste produced. For comparison, the Organisation for Economic Co-operation and Development's baseline scenario puts that figure at 13%, and its "regional action" scenario (assuming aggressive new policies by OECD countries) puts it at 29%.

We believe forecasts for much higher recycling uptake than we project are unrealistic, owing to overwhelming technical and economic challenges. Indeed, the OECD's "regional action" scenario assumes a tax on primary plastics of up to 75% of production cost (a policy with scant chance of enactment), which illustrates the cost disadvantage of expanding recycling beyond its current scope.

Plastic Demand and Recycling Assumptions

Million tons (unless otherwise noted)	Morningstar Forecast		
	2024	**2050**	**% CAGR**
Plastic Demand	534	1041	2.6%
% Waste/Demand	77%	82%	
Plastic Waste	410	852	2.9%
Collection Rate	16%	28%	
Collected for Recycling	64	239	5.2%
Recycling Yield	59%	60%	
Secondary Plastic Production	37	143	5.3%
% Share of Demand	7%	14%	
% Share of Waste	9%	17%	
Primary Plastic Production	497	898	2.3%
% Share of Demand	93%	86%	
Petchem Feedstock mmbpd	14.6	25.1	2.1%

Collection Rate = Collected for Recycling/Plastic Waste
Recycling Yield = Secondary Plastic Production/Collected for Recycling

Source: Organisation for Economic Co-operation and Development, Morningstar.

Limited Supply of Suitable Recycled Plastic to Put a Lid on Recycling Growth

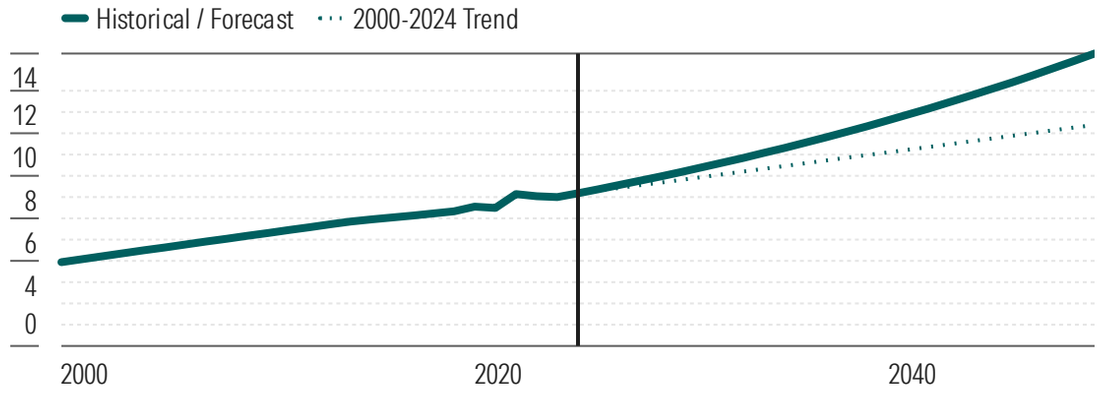
We forecast that secondary (recycled) plastic will grow from about 7% of global production in 2024 to 14% in 2050. That's faster than the 2000-2024 linear trend, which would reach just 10% by 2050.

Private and governmental efforts are boosting the demand for recycled plastic. But there is a ceiling on how far and fast recycling can grow. For one, government mandates have lacked teeth, especially outside the EU. Also, the high-profile brands with recycled-content goals account for only 5%-10 % of global plastic consumption.[1]

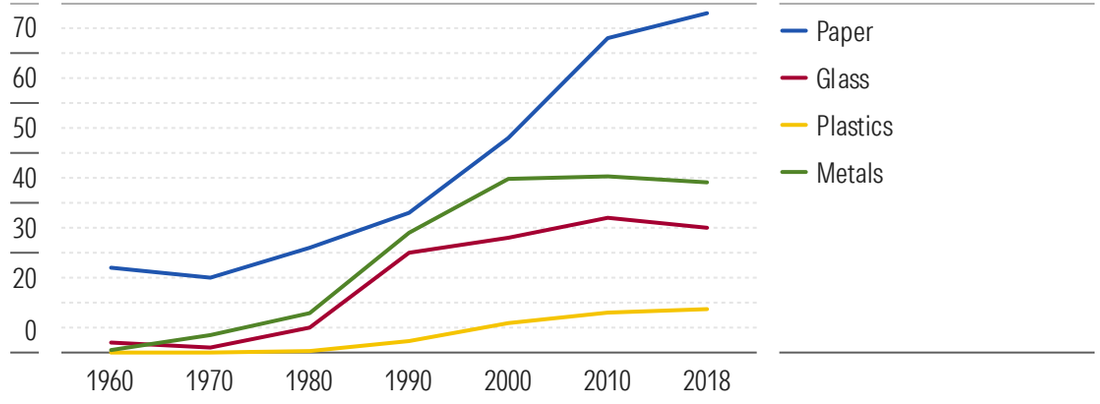
Most importantly, recycling will be limited by the supply of suitable waste plastic. Most plastic waste is not well-suited to recycling. Because plastics are used in so many different ways, they're extremely heterogeneous, which is a problem for recycling. This makes it highly unlikely that plastics will repeat the recycling successes of other materials like paper, which are much more homogeneous.

As companies have stepped up their use of recycled plastics over the past five years, prices have soared for the few types of plastic that are easier to recycle. These select recycled plastics now trade at a hefty premium to their virgin plastic equivalent. In turn, this premium has led many companies, such as Coca-Cola, to dial back their recycled-content targets.[1] In other words, recycled plastic must remain affordable if increased uptake is to persist. This is contingent on technological and operational improvement.

Secondary (Recycled), Percentage Share of Global Plastic Production



US Recycling Rate by Type of Material (%)



1 "High cost of recycled plastic pellets in Asia, US limits recycling adoption" (S&P Global)

Source: Organisation for Economic Co-operation and Development, Plastics Europe, Morningstar.

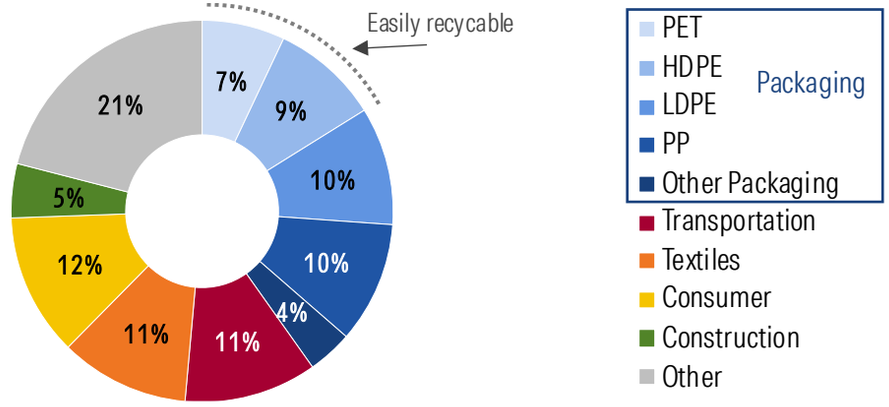
Expanding Recycling Will Require Major Technological Improvements

Today, recycling only works really well within a niche of waste plastics: PET beverage bottles and certain HDPE containers like milk jugs. These items are a subset of PET and HDPE packaging, which together compose 16% of global plastic waste. These items are homogeneous, easy to pick out of the waste stream and clean, and exist in large volumes. These favorable attributes are scarce among other types of plastics.

For plastic waste to become usable for recycled plastic, it has to be sorted and cleaned into a high-purity stream of a single type of plastic. Yet the heterogeneity of many types of plastic makes the sorting process a nightmare. This is partly why recycling rates in some rich countries like the US lag those in poorer countries, where cheaper labor makes meticulous sorting more feasible. Also, the sundry additives to plastics can be extremely difficult to extract.

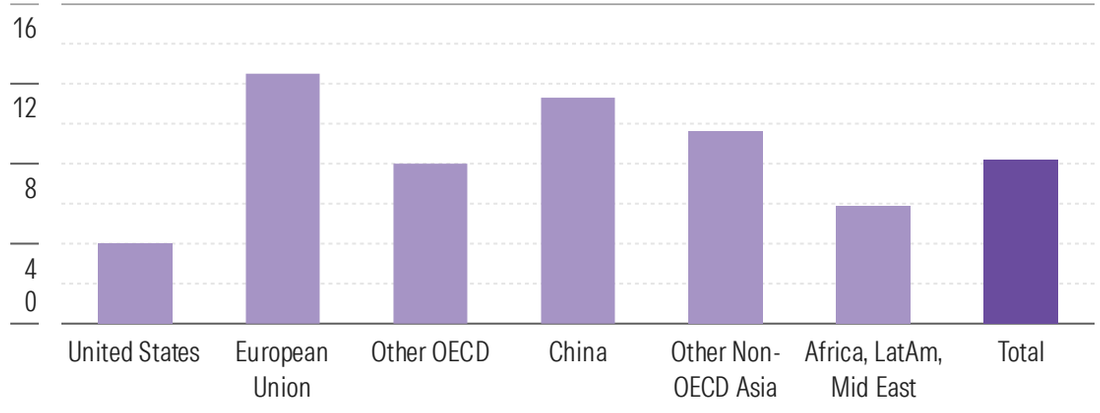
For our forecast horizon, we expect plastics recycling to remain mostly confined to packaging (40% of plastic waste). Even to expand recycling of packaging beyond its current niche, we'll need substantial efficiency gains in sortation. Companies are helping to some extent by simplifying packaging. Additional assistance will be needed from chemical recycling, which can break waste plastic into its molecular building blocks, and so is more resilient to contamination and heterogeneity. Chemical recycling is a nascent technology, accounting for just 0.1% of global plastic production currently. It's also no silver bullet. Different types of waste will require different chemistries and plant structures. Building out chemical recycling will be a multidecade process, and may never be cost effective for some types of plastic.

Plastics Waste, Percentage Share by Sector/Type of Plastic (2019)



Recycling Rate by Country (Percentage)

Secondary plastic production is divided by the total plastic waste generated.



Source: Organisation for Economic Co-operation and Development, EPA.

Other Sectors

Some other sectors to electrify; others will see steady demand.

Electrification Also to Hit Heavy Equipment and Other Land Transport

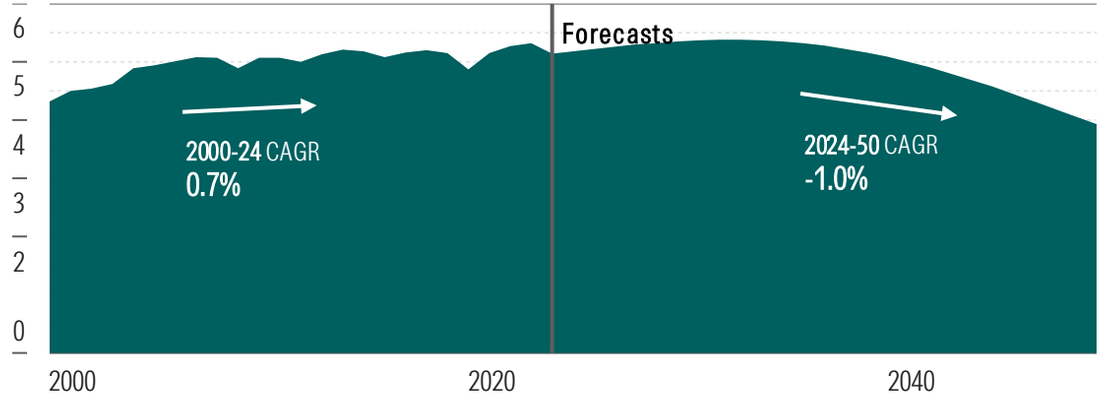
Heavy Equipment Oil Demand to Decline 24% Through 2050

We expect oil demand for heavy equipment to fall by 24% from 2024 to 2050 (1% annually), down from 0.7% annual growth over 2000-24, owing to electrification. Broadly, we expect heavy equipment to follow freight trucking in electrification with a lag. Many equipment types in mining and construction benefit from high utilization, making electrification advantageous for the same reason it is in trucking. Battery swapping or corded systems could reduce the need for huge batteries. China is leading the way in adoption, with electric models reaching 15% sales share for loaders in the first half of 2025, though electrification for most other equipment types remains around 1% or less. Agricultural equipment, which accounts for some 40% of oil demand in heavy equipment, will be more challenging to electrify owing to low utilization and underdeveloped rural electricity infrastructure.

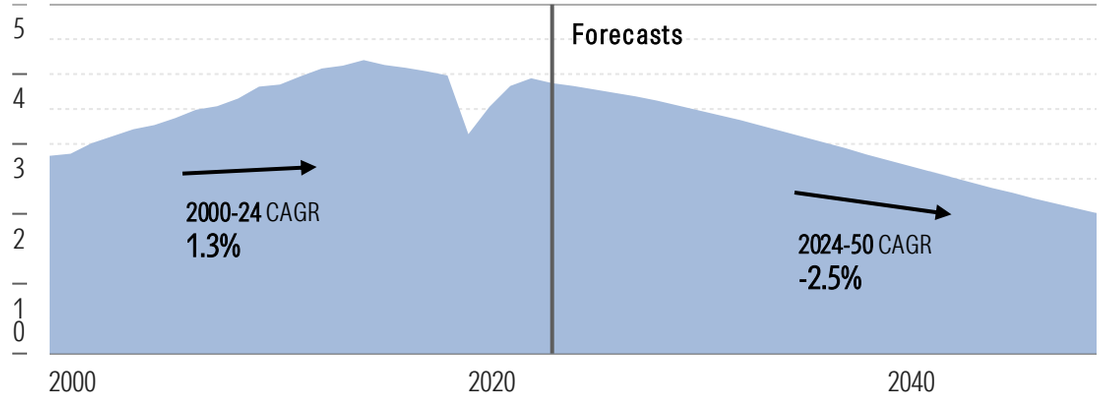
Rail, Bus, and Motorcycle Oil Demand to Decline 48% Through 2050

Like light-duty vehicles and road freight, we expect the electrification of other areas of land transport. We expect oil demand for rail, bus, and motorcycles to fall by 48% from 2024 to 2050 (2.5% annually). Here again, China is leading the way, with the sales share for electric motorcycles and buses having been over 50% for the past five years, which has caused global demand for this sector to already begin falling. Motorcycles are favorable for electrification given their small size, and buses because of their high utilization. On the other hand, while rail is already heavily electrified in Europe and China, penetration into the US and other markets may be very slow due to the required infrastructure. On net, we expect the sector's demand to fall modestly faster than light-duty vehicles.

Heavy Equipment Oil Demand, Million Barrels per Day



Rail, Bus, and Motorcycle Oil Demand, Million Barrels per Day



Source: IEA, Morningstar.

Buildings Sector Demand to Drop Gradually; Power Demand to Drop Steeply

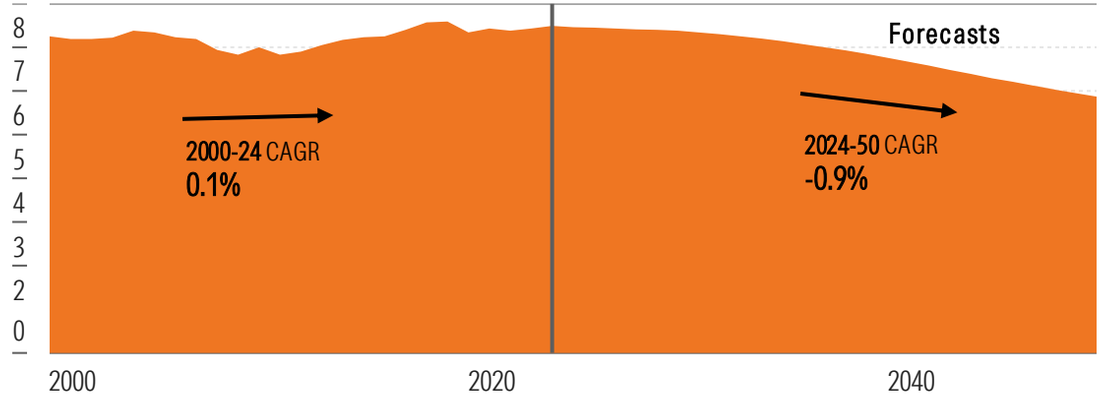
Buildings Oil Demand to Decline 22% Through 2050

We expect oil demand in the buildings sector to fall by 22% from 2024 to 2050 (0.9% annually), after growing 0.1% annually over 2000-24. About 70% of oil demand in this sector is for building heating, especially in rural areas without natural gas infrastructure. The remaining 30% is for cooking, mainly in emerging economies where electric or natural gas stoves aren't common. Developed countries are pushing hard to replace oil heating with electric heat pumps, but the pace of replacement in existing buildings is likely to remain slow. Meanwhile, oil for cooking in emerging economies should continue to grow, at least through the 2030s. Governments such as India's are encouraging switching from wood or coal to liquefied petroleum gas, as the latter produces much less indoor air pollution.

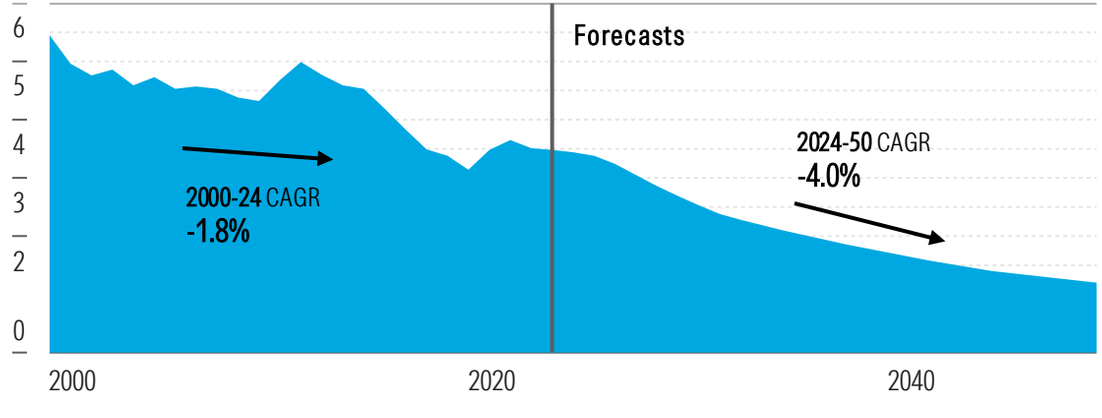
Power Oil Demand to Decline 64% Through 2050

We expect demand in the power sector to fall by 64% from 2024 to 2050 (4.0% annually), even faster than the 1.8% average decline over 2000-24. Around one-half of the sector's demand comes from the Middle East. However, Saudi Arabia and other countries are planning to ramp up alternative power sources massively to phase out oil in power generation, freeing it up for export. In most other economies, oil should also decline, owing to its higher costs relative to natural gas, not to mention the uptake of renewables. Diesel used for backup generation will persist for some time, though improvements in battery storage should eventually eat into that demand.

Buildings Oil Demand, Million Barrels per Day



Power Oil Demand, Million Barrels per Day



Source: IEA, Morningstar.

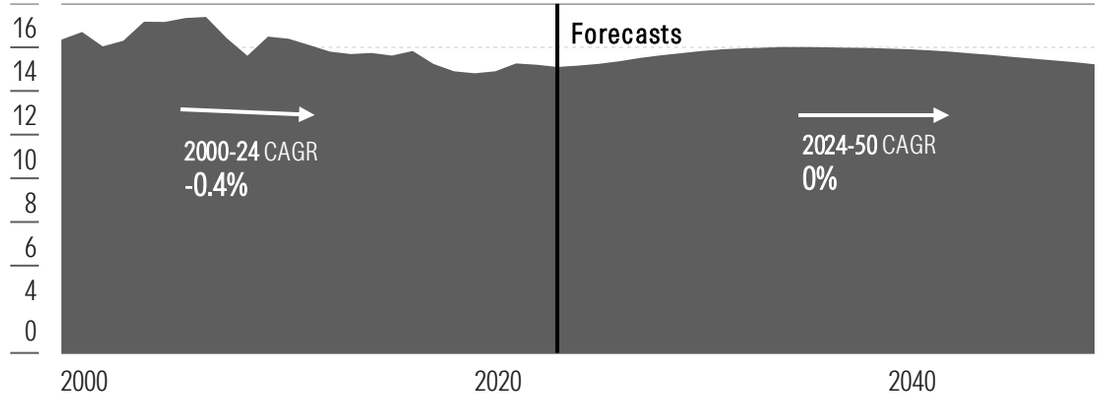
All Other Oil Demand to Be Flat Through 2050, With Industrial Fuel Oil Decline Finished Playing Out

Other Sectors' Oil Demand to Be Unchanged on Net Through 2050

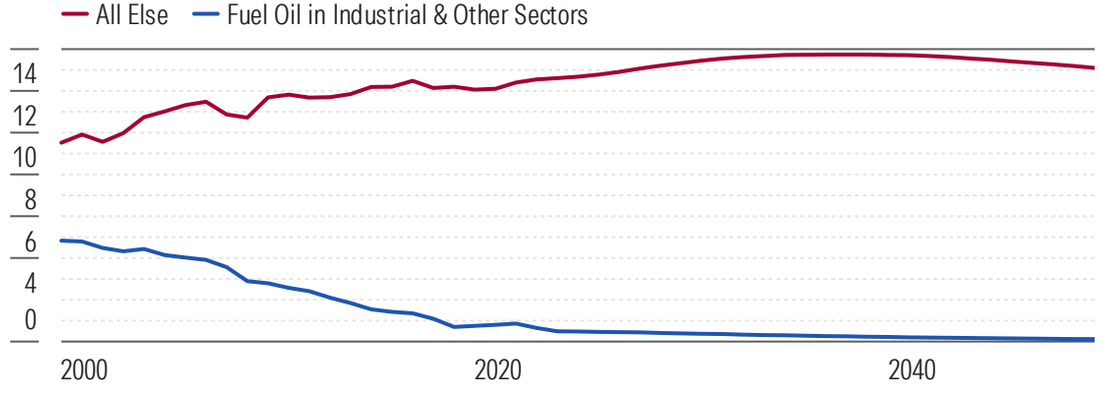
We expect other oil demand (all sectors excluding those covered so far) to be about flat over 2024-50. While this part of oil demand declined by 0.4% annually over 2000-24, this was entirely due to fuel oil in industrial and other sectors (that is, all sectors excluding marine shipping and power, which are covered above), which collapsed by over 80% from 2000 to 2024. Industrial use of fuel oil for producing heat or powering machinery has been almost entirely displaced by natural gas or electricity. But this area of demand destruction has played out almost entirely. Excluding fuel oil, other demand grew a healthy 1.2% over 2000-24.

Other oil demand is a hodgepodge of end markets and product types. One major part is asphalt (perhaps 15% of demand), which we expect to grow 2.3% from 2024 to 2050. Asphalt is an example of a nonenergy use of oil (it's used as a material rather than combusted for energy), so decarbonization policies are much less relevant here compared to other parts of oil demand. Altogether, non-energy use accounts for about 40% of the oil demand in different sectors. On the other hand, refinery gas (about 25% of demand) will eventually align with overall oil demand. And petroleum coke (perhaps 15% of demand) is a very dirty (though cheap) fuel that will likely decline steeply in demand in the 2030s and 2040s.

Other Oil Demand, Million Barrels per Day



Other Oil Demand: Fuel Oil and Excluding Fuel Oil, Million Barrels per Day



Source: IEA, Morningstar.

Appendix

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