WHEN TRUST MATTERS

Energy Transition Outlook 2023

TRANSPORT IN TRANSITION EXECUTIVE SUMMARY

A deep dive into fuels, electricity, and infrastructure

FOREWORD

Our global transport system is already responsible for a quarter of global greenhouse gas (GHG) emissions. In the next three decades, the global vehicle fleet will grow from 1.2 billion to 2 billion vehicles, passenger flights will increase by 130%, and cargo tonne-miles at sea will expand by 35%. Can we accommodate that growth while reducing emissions? The short answer is that much of transportation will decarbonize, and emissions *will* reduce by some 40% by mid-century. But by then the relative contribution of transport to global emissions will have risen to one third, implying that the sector needs to tackle decarbonization with a much greater sense of urgency.

This fuel-centric forecast sets out our best estimates on the availability, costs, policy drivers, and likely uptake of decarbonization options. At the same time, we measure and forecast the decline of fossil fuel sources. We find, for example, that oil demand in transport will halve between now and 2050.

Decarbonizing transport is ultimately a fuel challenge. Transport emissions are distributed through the exhaust systems of over a billion vehicles, aircraft, and ships. These emissions cannot be captured to any meaningful degree and, in addition to CO_2, they invariably include other powerful GHGs and health-damaging particulate matter.

Electricity will, without doubt, be the main decarbonization route for transport – powering nearly 80% of the world's vehicle fleet by 2050. Recent advances in battery densities and electric motor technology suggest that electricity will make inroads into subsectors previously thought to be hard-to-electrify – like long-haul heavy trucking, and to some extent short-haul aviation.

There remain, however, very large transport subsectors that cannot feasibly electrify. Aviation is under enormous public and regulatory pressure to decarbonize. Biogenic sustainable aviation fuel will need to be produced in vast quantities but must be sourced sustainably. Hence, it will remain very costly, at least for the next 10 years, as will e-fuels that are energy-intensive to produce and rely on the widespread availability of green hydrogen that will only scale from the mid-2030s. These higher costs will need to be absorbed into the industry's value chains and socialized through higher tariffs and taxes.

In this decarbonization journey, collaboration will be the new fuel.

First mover advantages are already apparent for airlines and transport companies working with those customers willing to pay a premium to reduce their scope 3 emissions. Ultimately, however, the decarbonization at scale will require an unprecedented public-private partnership across national borders and multilateral agreement on new standards. Movement in this direction is already taking root, for example, through the World Economic Forum's Clean Skies for Tomorrow initiative.

Similar, joined-up thinking and transnational public-private commitment is needed for the decarbonization of the maritime industry, where large-scale implementation of energy efficiency measures are needed and huge amounts of carbon-neutral fuels, like biofuels and hydrogen-based fuels.

The many plans and pacts that are forming around green shipping corridors need to be actuated and scaled. Governments will need to formulate and implement plans to make their ports as attractive as possible to decarbonized shipping, while removing incentives for fossil-fuelled shipping by placing a sufficiently high price on emissions.

Key to this transition is a sense of perspective. By this I mean a science-based view on techno-economics of each fuel source. That includes a clear-eyed view on the well-to-wake efficiency of fuels and their accompanying emissions, as well as close attention to demand and supply dynamics. For example, in an ideal world, e-fuels might be the most convenient drop-in source. However, as we detail in this report, surplus renewable power and electrolyser capacity will not be available at scale for well over a decade; even then, large energy losses in the manufacture of e-fuels will have to be considered.

I hope that this report, grounded as it is in DNV's *Energy Transition Outlook* model, helps our customers and their stakeholders establish that sense of perspective and collaborate even more meaningfully to tackle the transition to a decarbonized transport future. Too much is at stake to allow for either hesitation or wishful thinking.

As ever, I look forward to your feedback.

Remi Eriksen

Group President and CEO

DNV

HIGHLIGHTS

- Transport has a severe **emissions** challenge. Its share of overall emissions grows from 25% today to 30% by 2050.
- The central difficulty for transport is that much of it will remain **fossil fuel-dependent,** even though electricity will revolutionize the road transport (78% of which will be electric by 2050).
- **Transport services** will grow significantly in the next 30 years (roughly double the number of road vehicles, 130% growth in airline passenger trips, and a 35% growth in cargo tonne-miles in shipping), but overall energy demand from transport grows only slightly from 105 EJ/yr in 2020 to 114 EJ/yr in 2050 mainly because of the **efficiencies associated with the electrification** of road transport.
- Forward-thinking national transport **policies** are critical to country-level and regional competitiveness in a decarbonizing and increasingly connected world.
- The **route to decarbonization is clear:** electrify what can be electrified; what cannot be electrified in the near term should be switched to sustainable advanced biofuels; and prepare for hydrogen-based new fuels to scale through local and regional ecosystems to a global ecosystem from 2035.
- What electrifies will be **cheaper,** but hydrogen and sustainable biofuels cannot compete cost-wise with oil and thus need different policy levers to scale.

Fossil Fuels

Oil demand halves by 2050, but fossil fuels have staying power in aviation and maritime, and in road transport in regions with insufficient electric infrastructure

- Reduction of oil is strongest in road transport - from 85 EJ today to 42 EJ in 2050, reducing its share from 91% to 57%
- Oil use in aviation is virtually flat to 2050; growth in air transport is covered by biofuels and e-fuels
- Oil benefits from high energy density and an established infrastructure, and only electricity outperforms fossil fuels on costs, owing to its superior efficiency

Electricity

Electricity will revolutionize road transport and is also gaining share in subsectors previously thought to be hard-to-electrify, like heavy trucking and short-haul aviation

- Electricity's share in transport will grow from 1% today to 4% in 2030 and will be 23% in 2050
- In 2050, electricity meets one third of energy demand in road transport, but powers nearly 80% of the global vehicle fleet
- Electricity powers just 2% of aviation and 4% of maritime transport by 2050

An all-electric refuse truck. Image: courtesy Volvo Trucks.

Biofuels

Biofuel is a ready-now drop-in fuel, but the challenge is to make it sustainable

- There is already intense competition for sustainable feedstock for advanced biofuels for **aviation and shipping**
- First-generation biofuel will be displaced by electricity in road transport
- Regulation and consumer-driven demand will push advanced biofuel development (i.e. from waste streams) and uptake. By 2050, it could cover a quarter of aviation energy demand and possibly a fifth of maritime energy demand

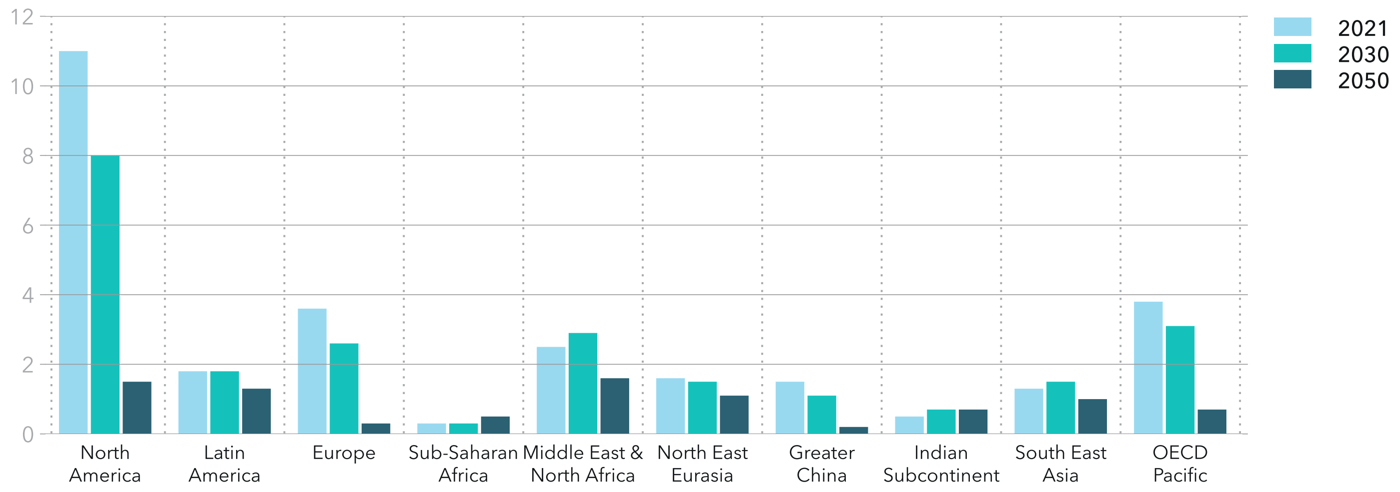
Hydrogen+

Hydrogen and e-fuels are **energy intensive** to produce and will scale in maritime and aviation only from the mid-2030s

- Renewable energy should be prioritized for direct use of electricity in the near term until sufficient surplus is available for hydrogen production at scale
- Use of e-fuel in aviation will start this decade, growing to a 13% share of the aviation fuel mix in 2050
- In maritime, where decarbonization alternatives for long-distance shipping are limited, hydrogen-based fuels (such as ammonia and methanol) could represent 50% of the fuel mix by 2050
- Hydrogen will be important for the heaviest long-distance road segments, but even there is already being challenged by electricity

FIGURE 1: OIL DEMAND PER CAPITA FOR ROAD TRANSPORT

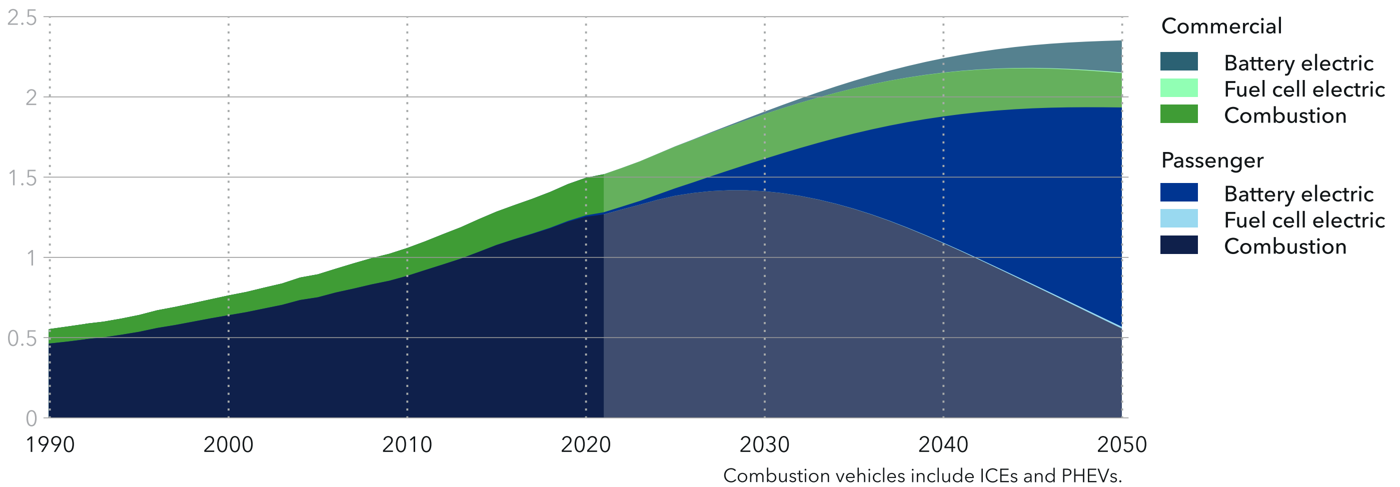
Units: barrel/yr



Due to the rapid replacement of combustion vehicles by more efficient EVs, oil demand per capita in North America, Europe, Greater China, and OECD Pacific falls by well over 80% by 2050. In contrast, across the Indian Subcontinent and Sub-Saharan Africa, transport oil demand per capita increases by over 50% to 2050 due to the lack of sufficient infrastructure for widespread EV adoption.

FIGURE 2: WORLD NUMBER OF ROAD VEHICLES BY TYPE AND DRIVETRAIN

Units: Billion vehicles

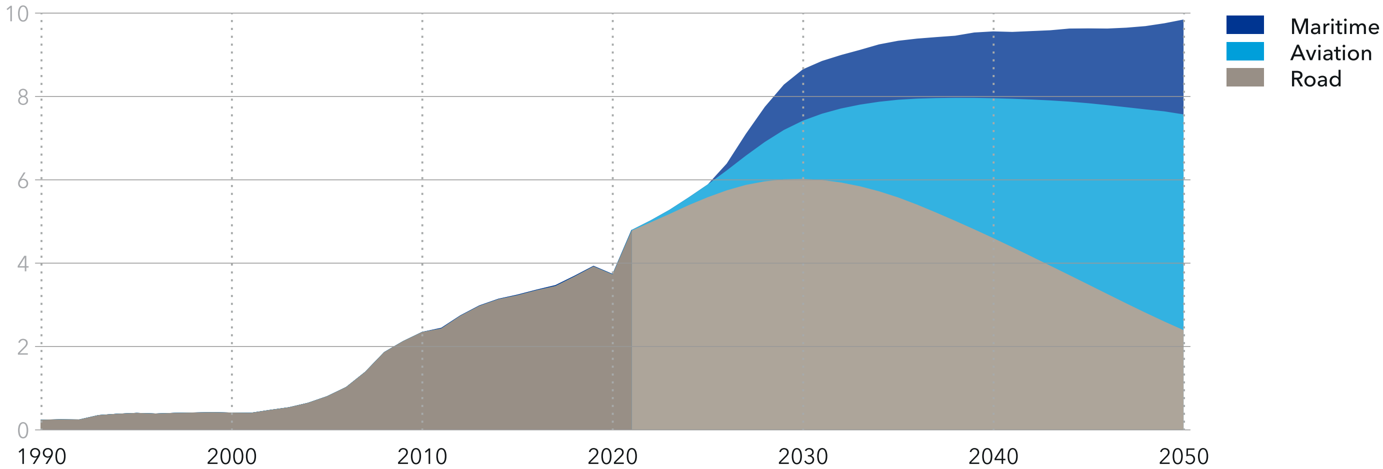


Combustion vehicles include ICEs and PHEVs.
Historical data source: Marklines (2022), IEA EV Outlook (2022), EV Volumes (2022)

The global passenger vehicle fleet expands from 1.2 billion cars today to slightly below 2 billion in 2050, with the combustion vehicle share falling precipitously from 97% to less than 30% by mid-century. At the same time, electricity is one third of energy demand in road transport, but powers nearly 80% of the global vehicle fleet.

FIGURE 3: WORLD BIOENERGY USE IN TRANSPORT

Units: EJ/yr

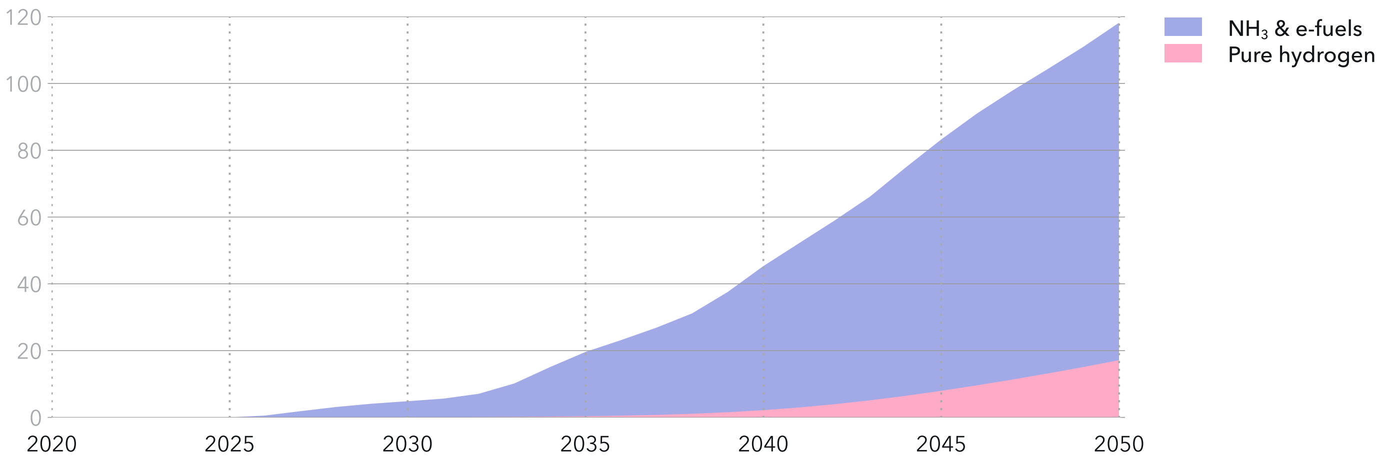


Historical data source: IEA WEB (2022)

Today`s biofuel production is dominated by first-generation biofuels – mainly biodiesel and ethanol. Electrification of road transport will reduce their use significantly. The coming decade will see advanced biofuels used at scale in aviation and maritime, where the main challenge is to secure sustainable feedstock.

FIGURE 4: WORLD DEMAND FOR HYDROGEN AND ITS DERIVATIVES IN TRANSPORT

Units: MtH_2/yr



Hydrogen, and its derivatives such as ammonia, methanol, and e-kerosene, is the prime contender in hard-to-electrify transport sectors. But these new fuels are contenders-in-training and will not be available at scale until well into the 2030s. Before then, biofuel will play an important role.

OVERVIEW

The transition in transport energy demand is by far the most dynamic among the energy demand sectors. DNV has quantified this consistently in our annual *Energy Transition Outlook*. This year, with this report, we take a deeper dive into the very large shifts in electrification, infrastructure, and fuel use that are set to take place in transport over the next three decades.

Broadly speaking, we find that electrification of transport leads to a dramatic fall in operating costs which will increasingly offset associated capital spending. In contrast, those sectors reliant on synthetic electrofuels (e-fuels) and biofuels or hydrogen for decarbonization face higher operating and capital costs that need to be absorbed into wider value chains and incentivized by wise policy choices.

Why we need to look at transport – now

Global GDP will more than double by 2050, with much of that value creation facilitated by growing volumes and increased efficiencies in the transportation of freight and people. The correlation between GDP growth and more and better transport is well-established (Gao et al., 2016; Choi, J.H., 2023). The higher the level of economic activity, the greater the need for effective transport. The contribution of transport to economic development is obvious: it creates jobs, promotes access to healthcare and education, and acts as an important source of government revenue. Less well-known is the fact that as transport decarbonizes in an era of rapid digitalization, it will become much more efficient as an economic factor of production of goods and services. As we detail in this report, while transport services will grow significantly in the next 30 years, overall energy demand in the transport sector will only expand from 105 EJ/yr in 2020 to 114 EJ/yr in 2050. Along the way, transport emissions will fall substantially, but will be far off course for net-zero by 2050.

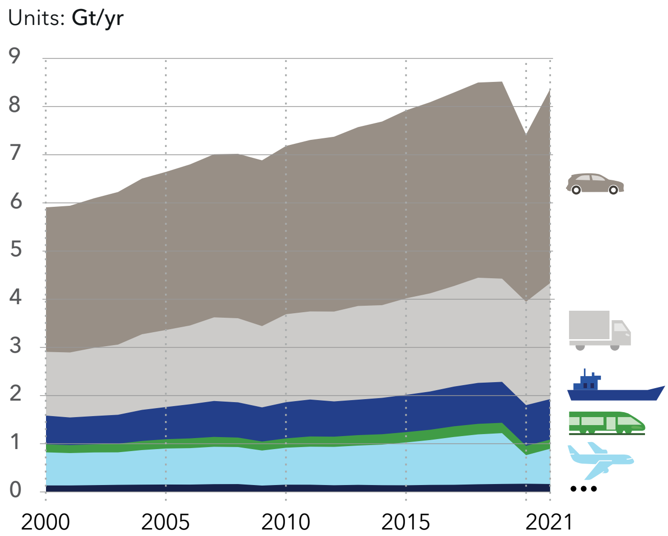
Hitherto, gains in energy efficiency have largely been neutralized by an expanding vehicle fleet, a steady growth in passenger flights, and an increase in the transport of freight on keel. Consequently, transport sector emissions have risen inexorably for many decades, with the singular exception of the years when COVID-19 held the world in its grip. During the pandemic, transport emissions fell by 14%, and aviation emissions more than halved. Emissions have now rebounded to pre-pandemic levels, except in aviation, which is still lagging somewhat (Figure 5).

With exception of the passenger vehicle segment, the transport sector is moving hard to electrify. Despite significant uptake of EVs in China, Europe, and North America, synthetic e- and biofuel blending mandates for road transport and aviation, and International Maritime Organization (IMO) ambitions for low- and zero-carbon fuels in shipping, the transport sector will decarbonize far too slowly – only reducing CO_2 emissions by 39% by mid-century.

Today, transport of passengers and goods accounts for about a fourth of global energy-related CO_2 emissions, and 37% of global CO_2 emissions from all end-use sectors. It is the sector with the highest dependence on fossil fuels, with more than 90% of its energy stemming from crude oil.

FIGURE 5

Global transport sector CO_2 emissions in the last two decades



Harmful emissions in vulnerable places
Beyond its large GHG footprint, the transport of passengers and freight is also responsible for a considerable share of microplastics and fine particulate matter ($PM_{2.5+10}$) emissions, a leading and escalating cause of respiratory and cardiovascular illness and deaths globally (SLOCAT, 2021). A recent study estimates the transport sector`s share of global $PM_{2.5}$ emissions to be around 11%, stemming from tailpipe emissions, evaporative emissions, resuspension of road dust, and particles from brakes and tires (ICCT, 2019). $PM_{2.5}$ emissions are typically located in densely populated areas, amplifying their hazardous impact. In Indian cities, for example, dramatic air quality improvements were recorded during COVID-19 lockdowns (Yadav et al., 2022).

> While transport services will grow significantly in the next 30 years, overall energy demand will only grow marginally. Transport emissions will fall but will be far off course for net-zero by 2050.

Aircraft burning fossil fuel at high altitudes produce nitrogen oxides emissions, vapour trails, and cloud formations which have twice as much global warming contribution as their direct CO_2 emissions (EASA, 2020). Direct CO_2 emissions, sulfur oxides, $PM_{2.5}$, and nitrogen oxides from maritime shipping contribute to ocean acidification and eutrophication in sensitive ocean environments. Owing to its heavy reliance on fossil fuel, transport remains a highly problematic contributor to air pollution where it matters most, despite past and ongoing regulatory curbs.

Distributed and hard-to-decarbonize emission sources
Transportation is distinctive in having distributed GHG emissions. A single point source such as a steel plant can be equipped with carbon capture and storage (CCS) to reduce the emissions at the point of origin. Decarbonizing the transport sector is more challenging, if not impossible, in this regard. Although there are onboard CCS pilots for ships, it is not expected to be feasible to extend this to the entire maritime fleet. That said, it could be an important supplement to achieving GHG emissions reduction if there is a lack of other carbon-neutral fuels. CCS certainly does not apply to aircraft let alone the more than one billion vehicles on the road. A single solution for the decarbonization of transport can only be realized with liquid sustainable carbon fuels from biomass, renewable electricity, and sustainable CO_2 and water. However, feedstock availability and low value chain efficiencies significantly constrain their use. Thus, a variety of solutions are needed to tackle this huge challenge, such as battery electric vehicles, fuel cell electric vehicles, and synthetic low – or zero-carbon fuels that are bio- or hydrogen-based.

Frontrunners in the race to decarbonize transport
Regions such as Europe, Greater China, North America, and OECD Pacific are frontrunners in the uptake of zero-carbon vehicles. In parallel, those regions are investing in hydrogen and hydrogen-based fuels as the most promising option for moving heavy goods over long distances. At the other end of the spectrum, regions like Sub-Saharan Africa and North East Eurasia are very far away from producing the quantities of renewable electricity and the infrastructure required to decarbonize road transport. In the long run, however, a comprehensive transition of the transport sector must be interregional. The decarbonization of maritime and aviation requires corridors supplying non-fossil fuels reliably in the form of bio- and hydrogen-based sustainable aviation fuels, or biofuel blends, ammonia, or other e-fuels for maritime. The scale and timing of such corridors emerging, and the global adoption and rollout of optimal grid infrastructure for EV charging, depend largely on the rate at which frontrunner regions develop, pilot, and scale technologies, and hence manage to cut down costs.

The policy and technology limits challenge
Policies and regulations both push and pull in varying degrees for a cost effective, safe, affordable, and accelerated transition. There are four ways for policymakers to transition the transport sectors, three on the supply side and one on the demand-side to ensure uptake:

Supply – infrastructure and fuels or electricity

1) Support electrification by strengthening the existing (grids) and new infrastructure for charging.

2) Enable existing infrastructure with drop-in fuels, with low- or zero-carbon intensity (e.g. e-kerosene).

3) Facilitate new infrastructure for new fuels that cannot use existing infrastructure (e.g. pure hydrogen).

All three of these strategies require a fourth corresponding action to create investment certainty for market deployment of new technologies and fuels:

Supply – transport technologies and fuels

4) Stimulate the uptake of new or adapted drivetrain and propulsion technologies for vehicles, planes, and ships using new fuels, electric and hybrid modes. Accompany with policies stimulating or mandating the phase out of fossil-dependent transport through carbon pricing, tax disincentives, and bans.

When policy meets technology

Policy has to be sensitive to what technology can and cannot achieve. For example, EVs and associated infrastructure are now well established in some markets. However, driving adoption still requires incentives and attention should be paid to making charging infrastructure as future ready as possible – for example incentivizing home chargers that allow for bi-directional charging for eventual integration into vehicle-to-grid (V2G) systems, as well as connectivity to allow utilities to micromanage smart charging. On the other hand, electrification has its limits and can power some heavy, long-distance trucking but not long-haul aviation and deep-sea shipping. There, policymakers need to work with industry to incentivize R&D, pilot projects, and commercial uptake, as well as commit to large public-private partnerships to deliver both zero-carbon fuel and associated infrastructure – for example green shipping corridors reliant on ammonia. One major challenge for hybrids, batteries, and new fuels, is the physical limits of these technologies regarding energy content per unit weight and volume which directly impact range and cargo options. Hence there is an intricate interrelationship between what policy can enable and technology options for short-, medium-, and long-range transport.

Figure 6 illustrates that there must be different policy and technology solutions for different types of transport. It needs acknowledging that certain combinations of infrastructure, fuels, and means of transport can only decarbonize parts of the short-, medium-, or long-range sub-segments within road, shipping, and aviation. As policymakers work in parallel to advance existing and emerging best available technologies, some long-term solutions may have to be prioritized for long-range and heavy-duty transport, since there are no other options in the short term to reach climate targets.

Action is needed now

The present pace of transition in the transport sector falls severely short of the goals of the Paris Agreement. Consequently all opportunities to accelerate change need to be seized as soon as possible. Electrification, the lowest-hanging fruit for the road transport sector, as a 'ready now' and least-cost option, is heading in the right direction, but with a regulatory framework that is far from ambitious enough. In parallel, intensive collaboration between all stakeholders is needed now in the hard-to-electrify transport subsectors to ensure that alternative low- and zero-carbon fuels needed in aviation and maritime will indeed be 'ready later'.

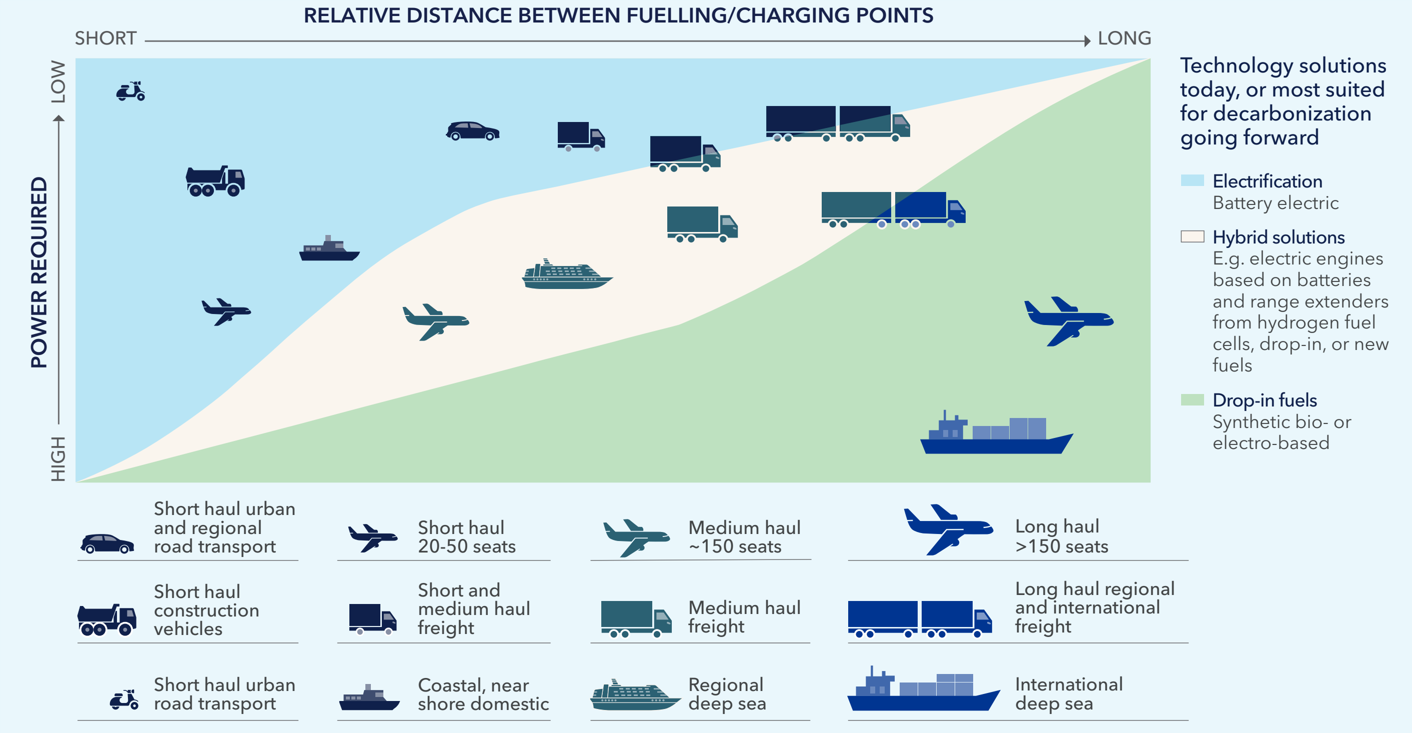
Any net-zero pathway demands that we should electrify everything that we feasibly can, and as quickly as possible. Where electrification is not a reasonable option – or a very poor one – hydrogen-based fuels or biofuels are the best alternatives, and all attention should be devoted to accelerating the critical path to widespread availability.

About this report

This report draws on DNV's detailed, system-dynamics model of the global energy transition to 2050. It presents a deeper view than we have hitherto offered on the transport sector's transition to 2050, with a strong focus on the next decade regarding technological and infrastructure challenges and solutions. The policy landscape shaping the transition in road transport, maritime and aviation is laid out in detail and connected to ongoing and near-term developments. We have adopted a 'fuel-based' perspective, highlighting the synergies and interactions between the energy sources powering transport, rather than simply comparing and contrasting the transitions unfolding in the different transport sectors.

FIGURE 6

Electric, hybrid and alternative fuel solutions towards 2050

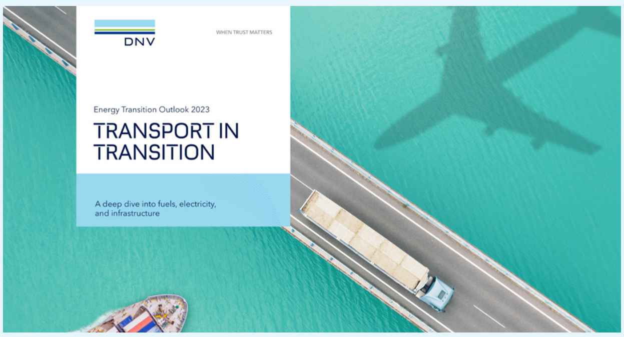


The easiest vehicles to electrify are those with shorter ranges and predictable routes, like buses, delivery vans, and small trucks. Predictable routes make it easier to plan and install charging infrastructure along their routes. Moreover, they can easily meet their energy demands with the current state of battery technology, while reducing their operating costs and carbon footprint.

Similarly, motorcycles and passenger vehicles fall in the easy-to-electrify category. While their shorter ranges and predictable routes make them viable candidates for electrification, the higher upfront cost of electric cars is a significant barrier to widespread adoption. However, as battery technology improves and charging infrastructure expands, these vehicles will become increasingly viable options for electrification.

Heavy-duty trucks, ships, and planes require large amounts of energy to cover long distances, making electrification difficult with current battery technology. The higher upfront cost and low energy density of batteries are the main barriers to electrification in these transport segments. Ongoing research is exploring alternative technologies, such as new battery chemistries and fuel cells, to meet their energy needs.

While electrification of transportation is a crucial step towards a more sustainable future, it is essential to recognize that not all vehicles and sectors are equally easy to electrify. Therefore, a multifaceted approach that combines research, policy, and innovation should advance the technology and commercial readiness of feasible transition alternatives tailored to each transport segment.



Access our full *Transport in Transition* report at www.dnv.com/eto/transport

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Combining technical, digital and operational expertise, risk methodology and in-depth industry knowledge, we empower our customers' decisions and actions with trust and confidence. We continuously invest in research and collaborative innovation to provide customers and society with operational and technological foresight. With origins stretching back to 1864 and operations in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.

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