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THE PATHWAYS STUDY:

Achieving fossil-free commercial transport by 2050

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Executive Summary

Achieving a fossil-free commercial transport system in the timeframe of the Paris Agreement target is not only possible, but also financially attractive from a societal perspective. This is the key conclusion of The Pathways Study initiated by Scania.

CO_2 emissions can be reduced by over 20 percent simply by optimising transport systems, for example through improved routing and better load management. Moreover, there are several fuel- and powertrain pathways to a fossil-free future. Biofuels offer the highest CO_2 emissions reduction pathway and electrification is the most cost-effective. Other technologies, such as hydrogen fuel cells and e-highways, have important use cases to consider and may be critical for select geographies and applications.

To reach this goal, the industry must begin to change rapidly and immediately. New technologies can take a long time to achieve wide adoption, as the existing stock of vehicles turns over slowly. This means that for 2050 to be fossil-free, changes at scale are required already by 2025, including not just new technologies but also new infrastructure, behaviours, and partnerships.

Introduction to Pathways

To limit warming to two degrees Celsius, in line with the United Nations Sustainable Development Goals and the Paris Agreement, the world will need to become fully fossil-free by 2050. This is a significant challenge, one which will require dramatic changes across all sectors in the form of new technologies, new infrastructure, and completely new business models. This study aspires to start a discussion on the decisions and actions that need to be taken today.

After the energy industry, transport is the largest source of global CO2 emissions and currently contributes nearly a quarter of global emissions. Commercial road transport represents nearly a quarter of that. The research shows that we can reach a fossil-free commercial transport system by 2050 – and that doing so reduces rather than adds societal costs on a cumulative basis.

The research goal was not to forecast how the industry will develop, but rather to start from the end goal of reaching zero CO2 emissions by 2050. From there, the research team determined what technology development, infrastructure development, and market adoption actions will be necessary to reach the goal. The impact that can be expected from these actions has been quantified, and the speed and intensity required to meet the Paris Agreement target outlined.

Several pathways to reach a fossil-free transport future, ranging from full electrification to a portfolio of powertrain types, have been identified. The transport sector and adjacent industries must begin to change rapidly and immediately to reach these goals. New technologies can take a long time to achieve wide adoption, as the existing stock of vehicles turns over slowly. This means that for 2050 to be fossil-free, changes at scale are required by 2025, including not just new technologies but also new infrastructure, behaviours, and partnerships.

Since the pace and degree of change required is unprecedented, the heavy vehicle manufacturing industry cannot achieve this transformation alone. Resources to enable this transition must be allocated and cooperation across the industry and adjacent sectors, including the public sector, will be required.

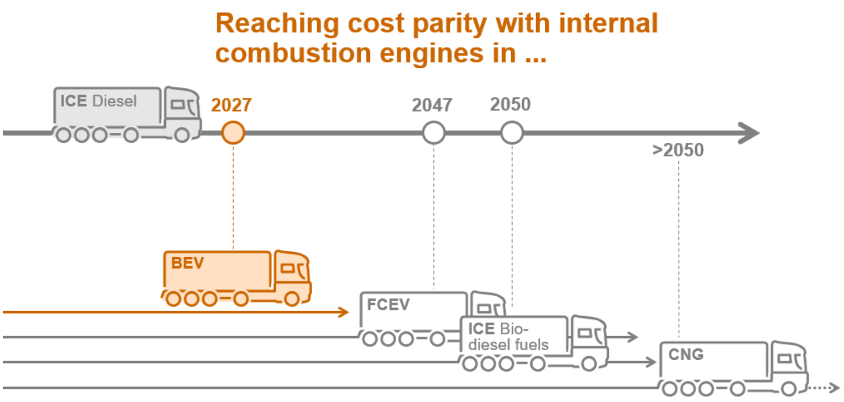
Pathways research – approach and method

In a “back-cast” modelling approach beginning with a range of 2050 scenarios, researchers calculated what it would take to achieve a fossil-free commercial transport ecosystem.

Initially, a detailed model integrating the elements of logistics system and powertrain efficiency, technology cost and technology penetration, transportation and shipping demand, and “well-to-wheel” carbon emissions was built.

Technology cost was incorporated using a proprietary total cost of ownership (TCO) model that considers powertrain, fuel, and infrastructure costs to create a metric in euros per kilometre that is consistent across technologies. As shown in the exhibit, long-haulage battery electric trucks could reach cost parity with diesel engines as early as 2027, while fuel cell vehicles could reach parity in 2047[1].

Low electricity prices in Sweden give BEV a cost advantage among long-haul drivetrains and fuels



SOURCES: Energy Insights, ICCT and team assumptions

The well-to-wheel carbon emissions were calculated based on the emission factors of each fuel and technology. This enables an understanding of the abatement potential of each scenario relative to a “business-as-usual” scenario where current operations continue without change.

The emission calculations were comprehensive, spanning production to end-use of fuel and electricity. Given this was a back-casting exercise, the assumption was that adjacent industries will also reach the Paris target, meaning that by 2050, the energy sector will also reach a point of fossil-free power for commercial transport’s global energy needs. It was therefore assumed that the cost of renewable integration would be reflected in slightly higher electricity prices. A sensitivity analysis for the European market showed that if the grid only decarbonises along the trajectory dictated by current economics and regulation, a 90-percent reduction of cumulative emissions on average could still be obtained.

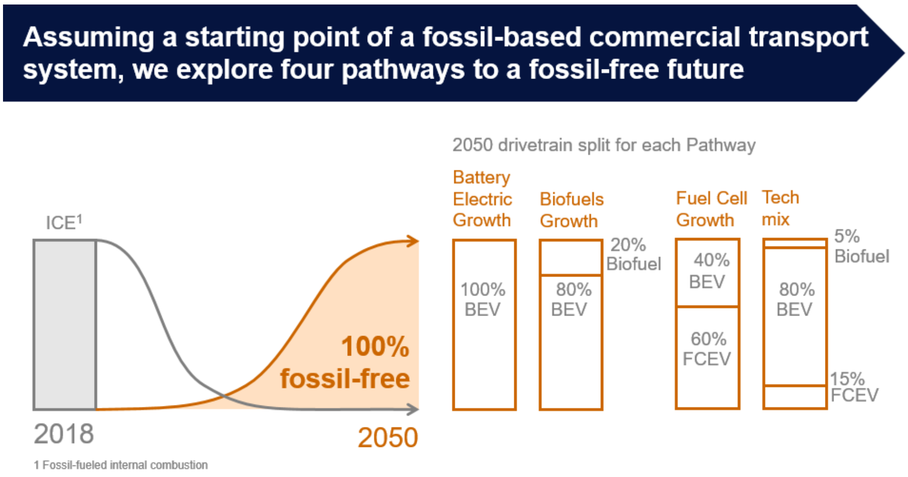
Each of these inputs were adjusted based on the transport segment, region and time frame being modelled. In the initial phase of the study, the focus was on the three commercial transport segments responsible for 90 percent of commercial vehicle carbon emissions – distribution vehicles, long-haulage transport, and city bus transport – in four diverse geographies: Sweden, the US, Germany and China.

Scenarios explored: Four pathways to a fossil free future

Four scenarios or “pathways” were defined, based on the penetration of competing powertrain technologies by 2050. These technologies were selected based on their potential to deliver a fossil-free transport system. Typically, growth in each technology was

[1] These results assume continued but conservative cost reduction in battery packs and fuel cell systems from today to 2050, at -4% and -8% cumulative average growth rate (CAGR) respectively, which are lower than the over -10% CAGR cost declines the technologies have exhibited over the past 5 years

modelled to start at the point of cost parity with internal combustion engine vehicles. These scenarios were designed to serve as cornerstone cases to show whether it is possible to reach fossil-free transport on each path, and what is required to do so.



We We chose to explore four scenarios:

1. **Battery electric vehicle (BEV) growth**: In this scenario, commercial transportation is fully electrified by 2050.
2. **Biofuels growth**: Biofuels used in internal combustion engines are the near-term choice to begin abating CO_2 emissions, but in the long run, battery electric vehicles constitute the majority, with biofuel-based internal combustion engines powering 20 percent of vehicles in 2050 based on maximum possible use of globally available biofuel supply.
3. **Fuel cell electric vehicles (FCEV) growth**: Fuel cell vehicles grow very rapidly to power most vehicles by 2050, with adoption starting later than battery electric due to larger cost disadvantage. The remainder of the volume in the end-state is battery electric.
4. **Technology mix**: Multiple powertrain technologies and infrastructures will coexist, with a mix of battery electric, fuel cell, and biofuel-powered internal combustion engine vehicles.

For each pathway, the total greenhouse gas abatement potential was calculated in terms of carbon dioxide equivalent (CO_2e) and the total cost to the system, including all public and private sector investments required in technology and infrastructure. Each of the four pathways requires different shifts in fuels and technology, as shown in the exhibit [at right].

Strong climate and financial returns

The research points the way to a cleaner, more efficient future:

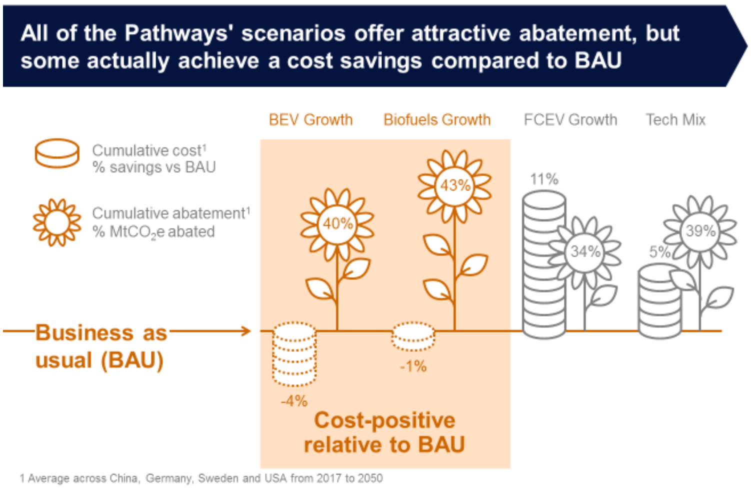
- A fossil-free commercial transport system is attainable by 2050 and delivers cost savings relative to business-as-usual operations through a combination of increased logistics and vehicle efficiency and through fossil-free fuels and powertrains.

- Emissions can be abated by over 20 percent simply by optimising transport systems and making non-powertrain vehicle improvements.
- Several fuel and powertrain pathways to a fossil-free future can be pursued:
  - Biofuels is the highest carbon abatement pathway
  - Electrification is the most efficient and cost-effective pathway
  - Other technologies have important use cases to consider and may be critical for select geographies and applications.
- Each pathway requires an unprecedented pace of change.

These findings are consistent across geographies and indicate that we can build a cleaner and more cost-effective global commercial transport system. However, building a fossil-free commercial transport system in just one generation will not be easy. Players across the transport sector and adjacent industries will need to work together, and with the public sector, in new ways. Innovation will need to accelerate, along with new technology adoption, at unprecedented pace. As a result, investments will need to begin now.

Reaching a fossil-free system by 2050 is not only possible but also delivers cost savings

The research shows that several paths can lead to fossil-free commercial transport if investments begin immediately. In addition to reducing greenhouse gas emissions, these investments could yield significant savings, lowering the overall cost to society of building, maintaining, and operating commercial transport by 20 percent or more compared to business-as-usual..

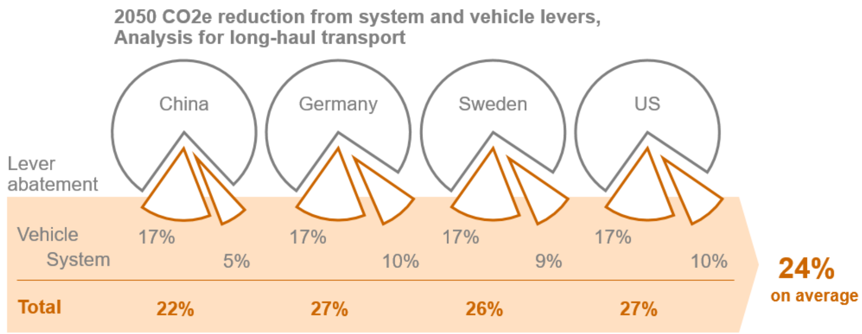


The degree and timing of cost savings potential differ by pathway. The lowest-cost scenario, the battery electric vehicle pathway, already yields savings relative to maintaining business-as-usual infrastructure within the next decade and delivers total system savings of about 20 percent by 2050. In Sweden, for example, a lowest-cost abatement pathway is 25 percent cheaper than business-as-usual in 2050 with the greater savings due primarily to Sweden's comparatively low electricity prices.

Emissions can be abated by over 20 percent through logistics system and vehicle efficiency

More than 20 percent in emissions abatement can be achieved by optimising system and non-powertrain vehicle improvements, such as improving routing and load management, as shown in the exhibit below. The remainder of emissions can be abated with alternative powertrains and fuels.

Improving system and vehicle efficiency could close about 24% of the 2050 emissions gap for commercial transport



Most logistics and vehicle system transport improvements pay for themselves relatively quickly, making widespread adoption likely. Some regions have especially large addressable opportunities for efficiency improvements in logistics management and vehicle performance. However, in China, for example, achieving widespread efficiency gains may be more challenging due to obstacles which include the widespread practice of overloading in goods transport and insufficient IT resources to address, identify, and share data to enable load consolidation. Policy changes and infrastructure investments in China could potentially yield efficiency gains of more than 40 percent by removing or reducing such obstacles.

Several paths to a fossil-free future

Biofuels is the highest abatement pathway

The study indicates that a scenario with a high deployment of biofuels in the end-state can deliver full abatement by 2050 while delivering maximal abatement over the course of the transition, relative to other pathways. This increased abatement does come at higher cost, however.

While capex and infrastructure costs of this pathway are very low because biofuels can be used to replace diesel in internal combustion engines and infrastructure, opex is almost two times higher in 2050 due to the high cost and energy intensity of biofuel production relative to renewable electricity.

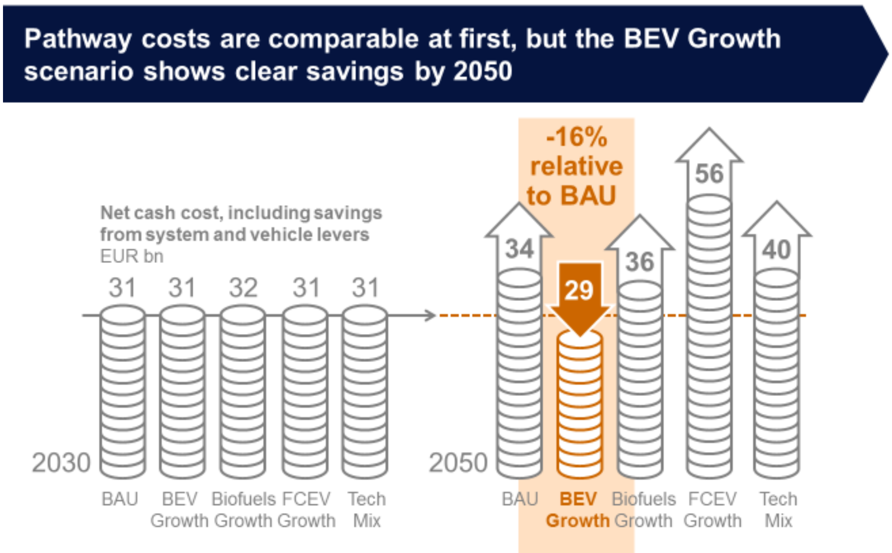
If diesel fuel was produced synthetically by renewable electrolysis (power-to-fuel), the cost and energy intensity would be even greater, and carbon capture technology would be required to render the fuel truly carbon-emissions free due to the persistence of point source combustion emissions. For biofuels, the study assumes that the planting of the feedstock for biofuel production would naturally abate the point source combustion emissions without need for carbon capture technology.

Electrification is the most efficient and cost-effective pathway

Taking into account infrastructure and battery size requirements, the research shows that electrification can deliver up to 6 percent in cumulative savings through 2050, with about 21 percent lower system cost in 2050 compared with diesel.

The total cost of ownership for battery electric vehicles reaches parity with diesel for all vehicle segments, even long-haulage, by 2031. In fact, it is currently at cost-parity for bus and distribution applications in Sweden and for buses in Germany.

Delivering the battery electric vehicle scenario by 2050 will require four to five times more infrastructure investment relative to the present situation, but it will decrease operating expenses by 40 percent, making for a cost profile that is very different from the diesel model. The battery electric vehicle growth pathway offers the most cost-effective route and delivers almost 20 percent total system cost savings by 2050 compared to business-as-usual.



The sensitivity on a wider scope for emissions was also examined, considering the emissions from the production of all motors, batteries, and fuels. The potential of each pathway – except biofuels growth – to abate emissions is slightly reduced by this expanded scope. In fact, even when the carbon emissions impact of all battery electric vehicles is included – raw material mining, synthesis and formulation – the battery electric vehicles growth pathway still abates the second most carbon. While the battery electric vehicles pathway still reaches zero emissions by 2050 at the lowest cost relative to other pathways, players along the battery value chain will need to reduce the energy and carbon intensity of their operations to maximise the abatement potential of the electric powertrain.

Alternative pathways have important advantages and use cases to consider

If maximising carbon abatement over the coming decades is the chief objective, biofuels will be critical, given they lend the unique advantage of being able to play a near-term role in reducing emissions while the dominant engine on the road is still internal combustion. That said, their deployment may be challenged by high cost relative to other fuels and powertrains and by bioavailability. If exclusively used for commercial transport, biofuels could supply a maximum of 20 percent of 2050 global commercial transport demand. However, since there will be competing demand from applications that are more challenging to electrify, such as marine and air transport, this maximum is unlikely.

Fuel cell vehicles, though more expensive to deploy, may become attractive alternatives to battery electric powertrains in markets where regulatory support for hydrogen technology is high, and supply of hydrogen is plentiful and available at low cost. Additionally, they are better suited to long-haulage transport due to higher range relative to battery electric vehicles, a key consideration for long distance transport.

Assuming high utilisation, electric highways used for long-haulage transport could be a cost-positive enabler of electrification, particularly in the coming decade when battery pack costs remain high and further energy density improvements have yet to be commercialised. Electric highways could deliver 17 percent increased abatement by reducing the size and quantity of batteries required by the commercial transport system.

Pathways where multiple powertrain technologies coexist in the end state will need to overcome the cost of building and maintaining multiple forms of infrastructure, but could be critical for use cases and geographies where electrification is difficult to deploy.

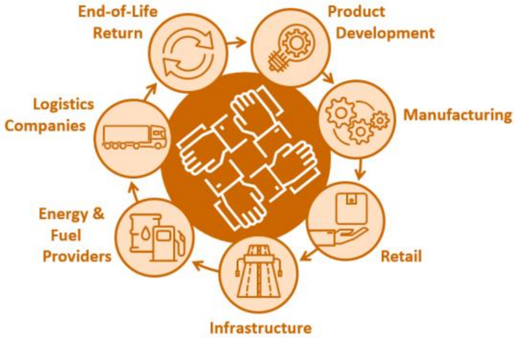
Each pathway requires an unprecedented pace of new technology adoption in mobility industries and adjacent sectors

Success of each of these abatement pathways requires not only an unprecedented rate of technological change but also requires adjacent industries to innovate, for example high renewables in electricity generation and continued falling battery prices.

Given the scope of our 2050 goals, it is critical to begin allocating resources differently starting now to develop and commercialise new technologies. To meet the Paris Agreement target cost-effectively, we need to achieve an adoption rate growth of new fossil-free powertrain technologies of at least 5 to 10 percentage points per year on average across regions and achieve full sales penetration by 2040. Change at high speed and at scale take time; historical examples of other disruptive infrastructure and technology changes, such as the adoption of solar photovoltaic technology or 3G broadband, moved at a fraction of this pace. Thus, this rate and scope of change represent a new horizon and a great challenge.

Cooperation will be key to achieve a fossil-free future

Transforming the transport and logistics ecosystem will require powerful new partnerships



No single player can overcome this challenge alone – no regulator, lawmaker, or company. Public and private sector stakeholders across countries and regions around the world will need to cooperate in new ways, sharing ideas, financial resources, and risk. System and equipment providers will need to adopt new powertrain technology; transport providers must adopt emerging technology; retailers and transport buyers need to drive CO2 reductions in their supply chains; energy providers must continue to drive renewables penetration and ensure grid stability. And policymakers must work with industry to accelerate decarbonising technology to market.

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