TRANSPORT

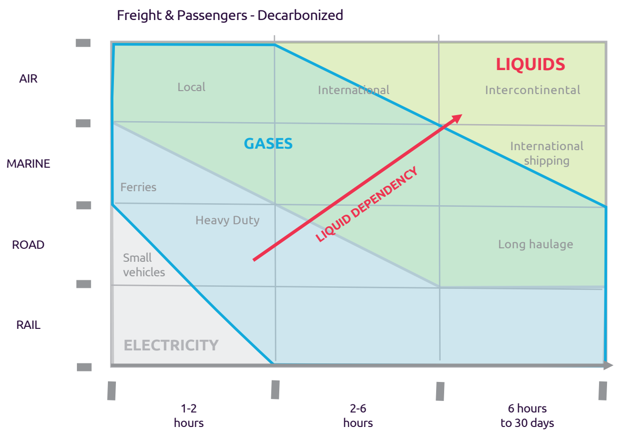
A FUNDAMENTAL SHIFT AWAY FROM FOSSIL FUEL DERIVED ENERGY SOURCES, REPLACED BY CLEAN ALTERNATIVES, AND SUPPORTED BY CHARGING AND GIGA-SCALE BATTERY INFRASTRUCTURE

Current situation and challenges

Transportation in its many forms currently produces over 1,200 $MtCO_2$ per year, 30% of total emissions in the EU. Liquid fossil fuels drive most air, marine, road and rail movements, from most captive usage to less captive (see figure below). Fossil liquids are dense in energy, convenient for logistics and not easy to replace. In Europe, they currently account for 72% of primary energy use.

The daunting challenge ahead is to free transportation from liquid fossil fuel usage[1] and to develop the new clean technologies and associated infrastructure that will enable sustainable and convenient private and public transportation.

Figure 15 - Dependency on liquid fossil fuel usage per transportation type



> **"We need political quotas for the use of synthetic fuels in aviation to accelerate mass production."**
>
> **Markus Pieper**, Member of the European Parliament

Solutions, projects and scale-up

Three types of transportation energy sources – synthetic liquid fuels, hydrogen and electricity – combined with new mobility modes, are directly contributing to decarbonization in all forms of transportation. Demand for transportation energy will fall from 360 Mtoe today to around 200 Mtoe by 2050, made up of:

- Synthetic liquids: 40 Mtoe[2].
- Biomass liquids: 30 Mtoe.
- Hydrogen and gases: 50 Mtoe.
- Electricity: around 50 Mtoe.
- A small share of fossil fuels: 25 Mtoe, down from 340 Mtoe today.

An array of technologies is needed, from higher to lower liquid dependency:

1. Synthetic liquid fuels - mostly for air and maritime use

Giga-scale synthetic fuels production facilities are needed before 2030, close to transport hubs, ports and airports. They will synthetize at scale:

- Carbon-based synthetic fuels such as kerosene, methanol or ethanol in plants consuming green hydrogen and carbon captured from industry (circular economy in industrial hubs).
- Ammonia liquid fuels, especially for marine transportation, with its dedicated logistics. The production of green ammonia from green hydrogen can also serve the chemical industry.

Carbon-based synthetic fuels can be used by nearly all standard airplanes and vessels. To be able to run on ammonia, vessels need to be retrofitted with dedicated fuel cells and ammonia management systems.

2. Pure hydrogen – for intermediary marine, road and rail use

Pure hydrogen in its different forms, combined with fuel cells, is a solution when liquids are not required for smaller range journeys (more space available onboard) but where electricity is not a solution (battery limits and charging times). Beyond ferries and trains, Europe must focus on trucks, buses and other road heavy duty vehicles: develop its own models of vehicles, implement infrastructures including charging points along corridors and for captive fleet.

3. Ease the adoption and use of e-mobility

The European electric vehicle market is expected to reach six to seven million per year by 2030[3], with most net-zero scenarios requiring 80% of passenger car stock to be electric by 2050. The key to this is a huge expansion in private and public charging infrastructure and access to vast quantities of Li-ion batteries.

4. Cheaper, cleaner and more efficient batteries made in Europe

Industrial scale battery production in Europe will be achieved by the development of ten li-ion gigafactories in 2030, supported by large scale battery recycling facilities to ensure reuse of vital components and limit environmental impacts.

5. New forms of urban mobility

The ongoing proliferation of high-emission private motor vehicles carrying individuals is not compatible with the achievement of Europe's net-zero targets. Yet public transport alternatives are not always accessible, with disjointed infrastructure, scattered data and multiple payment points.

Public, shared and free-floating transport systems must be developed, providing door-to-door flexibility, reliability and convenience and offering a viable alternative to cars. Streamlined mobility systems offering multiple modes of shared transportation across Europe will be essential, accessed and paid for securely using standardized, user-friendly IT platforms. Private and public operators must work jointly to solve the data, business models and technology challenges.

Impacts

- **€111 billion total market (turnover + investments) per year in 2030.**
- **1.1 million permanent jobs in 2030.**
- **128 $MtCO_2$ avoided per year in 2030.**

List of projects - TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

#33 - SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR AVIATION
Establish giga-scale production facilities in industrial clusters and transportation hubs

#34 - SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR LONG-DISTANCE SHIPPING
Establish giga-scale production facilities in industrial clusters and transportation hubs

#35 - SCALE UP GREEN N-LIQUID AMMONIA PRODUCTION AND LOGISTICS INFRATSRUCTURE FOR LONG-DISTANCE SHIPPING
Green ammonia and energy production facility at large ports

#36 - DEPLOY AMMONIA-FUELED VESSELS FOR LONG-DISTANCE SHIPPING
Retrofit existing vessels to shift from fossil fuel combustion engines to ammonia fuel-cell propulsion engines

Pure hydrogen for medium-distance marine, road and rail use

#37 - SHIFT SHORT- AND MEDIUM-DISTANCE FERRIES TO HYDROGEN FUEL-CELL PROPULSION
Retrofit existing ferries to shift from fossil fuel combustion engines to H_2 fuel-cell propulsion engines

#38 - DEVELOP HYDROGEN USAGE FOR HEAVY-DUTY ROAD FREIGHT
Deploy hydrogen refueling stations along the key pan-European road corridors

#39 - SHIFT EUROPEAN TRUCK INDUSTRY TO HYDROGEN
Develop EU-based production of fuel-cell heavy-duty trucks, buses and waste vehicles

#40 - TRANSITION FOSSIL-POWERED INTERCITY TRAINS TO HYDROGEN
Develop and deploy urban/suburban hydrogen-powered trains

Ease the adoption and use of e-mobility

#41 - ELECTRIFY SHORT-DISTANCE TRUCK TRANSPORT, WASTE COLLECTION AND URBAN BUS FLEETS
Low-GHG, silent and clean air city transportation: last-mile logistics, public transport and services

#42 - FOSTER PRIVATE EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY
Massively deploy charging points at private homes and offices

#43 - FOSTER PUBLIC EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY
Slow to fast charging for urban areas and ultra-fast charging deployment projects along major transit routes

#44 - DEVELOP FASTER, CHEAPER, MORE CONVENIENT TECHNOLOGIES FOR EV CHARGING
Lever European R&D to invent disruptive charging solutions that will be highly competitive on global market

Cheaper, cleaner and more efficient batteries made in Europe

#45 - SUPPLY THE EUROPEAN AUTOMOTIVE INDUSTRIES WITH "MADE IN EUROPE" LI-ION BATTERIES
Li-Ion battery gigafactories to serve the increasing e-mobility market and develop jobs and know-how in Europe

#46 - CREATE A 100% CIRCULAR BATTERY ECONOMY IN EUROPE
Establish an extensive network of battery collection and recycling facilities to lower the GHG footprint of batteries and re-use precious resources

#47 - STIMULATE THE DEVELOPMENT OF NEXT GENERATION BATTERY TECHNOLOGY FOR MOBILITY USE
Lever European R&D to invent disruptive alternative battery technologies to Li-ion and invest in gigafactories to manufacture these new solutions

New forms of urban mobility

#48 - BUILD NEW URBAN MULTIMODAL TRANSPORT SYSTEMS FOR EASY DOOR-TO-DOOR JOURNEY PLANNING, EXPERIENCE AND PAYMENT
Public-private platforms leveraging AI, data and end-to-end payment business models, and reinforcement of physical mobility equipment and infrastructure

#49 - LEVER SHARED AUTONOMOUS VEHICLES TO REDUCE THE NUMBER OF CARS IN AN INCREASING NUMBER OF EUROPEAN CITIES BY 30%
Large scale deployment of automated vehicles in shared fleets and public transport

[1] *https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf, Scenario 1.5TECH, Gross Inland Consumption, Non-Energy uses*
[2] *https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf*
[3] *https://about.bnef.com/electric-vehicle-outlook/*

#33

SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR AVIATION

Establish giga-scale production facilities in industrial clusters and transportation hubs

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Biofuels for aviation are neither price-competitive nor technologically mature, due to a lack of development projects
- **Solution:** Production of e-fuels for aviation (e-kerosene) within five facilities in strategic hubs (if relevant they can also provide e-fuels for maritime transport)
- **Key impacts:** 10 $MtCO_2e$, €1.9 billion total market, 28,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to create five facilities in major European airports, with a total electrolyzer capacity of 6 GW. The project will result in 3 million tons of green liquid e-fuel for airplanes produced per year, 500,000 t of hydrogen produced per year, and 9.3 $MtCO_2$ captured per year.

- Identify five European cargo airports, ideally coupled with a maritime port (such as Hamburg, Amsterdam, Valencia or Piraeus/Athens).
- In each location, build one facility by 2030 to enable additional yearly production of 600,000 t of synthetic hydrocarbon fuels for aviation (e-kerosene), leading to a total additional output of three million tons in Europe.
- A total electrolyzer capacity of 6 GW is needed, either produced on-site or complemented with hydrogen supplied by pipes.
- To ensure a genuinely sustainable production of alternative fuel, the facilities must have access to a large supply of green electricity, ideally sourced from nearby offshore wind or solar power plants.
- Incentivizing policies and technological progress (such as aircraft energy efficiency and e-kerosene production processes) are also required to further develop the e-kerosene market and encourage the retrofitting of existing planes.
- The same facility, combining carbon and green hydrogen, can produce hydrocarbon fuels for several modes of freight: e-kerosene for aviation with project #33, and methanol for maritime vessels with project #34.
- Key stakeholders to involve include public authorities, energy providers, airports, flag carriers (such as for example KLM Royal Dutch Airlines in Amsterdam, or Lufthansa in Frankfurt), and freight forwarders.

Projects that inspired this analysis: Copenhagen airport's partnership with transport operators (Orsted, Maersk, SAS, DSV Panalpina) for an e-fuel factory by 2030, Joint Venture in Oslo between Sunfire GmbH, Climeworks AG, Paul Wurth SA and Valinor for an e-kerosene factory by 2026.

Why this technology and project are needed to reach net-zero

Aviation is a major source of CO_2 emissions in the EU, accounting for about 3% of total emissions[1] and being the second highest emitting sector in transport, after road vehicles[2]. It remains difficult to reduce the emissions of the sector: existing planes are amortized over long periods of time, and bio-based fuel is much more expensive (€950-1,015/ton) than fossil-based kerosene (€600/ton)[3]. Nonetheless, developing green propulsion and fuel production technologies remains necessary to reach a net-zero carbon economy: bio-based jet fuels, generating no emissions during combustion are one such solution. Though rarely used nowadays, biofuel output potential (between 0.355 and 2.3 million tons can be produced per year) will increase in the years to come, reaching between 0.55 and 3.5 million tons in 2025 according to the European Aviation Environmental Report[4] .

Adding 1 million tons through the project proposed here already represents twice the output capacity by 2025 under the moderate scenario (550 t) and approximately the same as the total increase predicted (3.5 Mt - 2.3 Mt = 1.2 Mt) under the maximum output scenario in 2025. The challenge is to produce liquid carbon neutral fuels sustainably, profitably and at an industrial scale. To make e-fuels competitive in aviation, production technology and costs must be improved, with public authorities incentivizing private investments and prioritizing renewable fuels. Additionally, new infrastructure must be built at strategic locations, such as production facilities within transportation hubs.

Few projects have been launched in Europe to demonstrate this technology, due to its high costs. However, in May 2020, the Copenhagen municipality formed a partnership with several transport operators such as Orsted and Maersk to create an industrial-scale production factory supplying sustainable fuel for the city's airports, but also for maritime and road transports, with a maximum capacity of 250,000 tons per year by 2030. This justifies the idea of a production hub, designed to the supply of both e-fuel for aviation (project #33), and for maritime shipping (project #34).

Impacts

	2030	2050
CLIMATE IMPACT	**10 $MtCO_2e$ avoided**	**100 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€1.9 billion total market** €1.5 billion cumulated investment by 2030, €0.1 billion yearly average (2020-2030) €1.7 billion turnover in 2030	**€15.9 billion total market** €12.2 billion cumulated investment by 2050, €0.4 billion yearly average (2020-2050) €15.5 billion turnover in 2030
JOBS	**28,000 total jobs** 2,000 construction jobs for investment 26,000 production jobs for turnover	**239,000 total jobs** 6,000 construction jobs for investment 233,000 production jobs for turnover

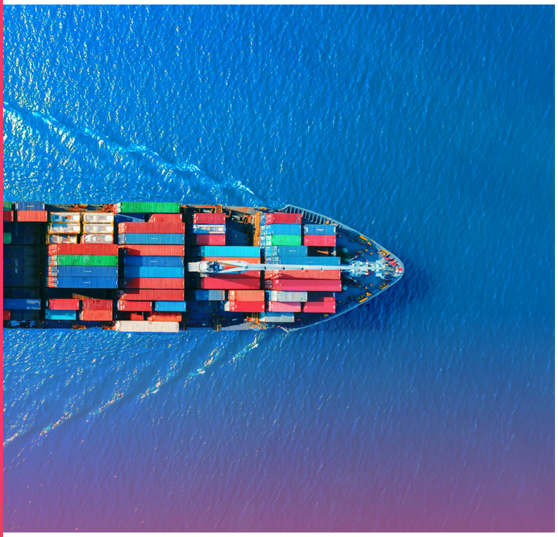
#33 [1]https://ec.europa.eu/clima/policies/transport/aviation_en#:~:text=to%20climate%20change%3F-,Direct%20emissions%20from%20aviation%20account%20for%20about%203%25%20of%20the,and%20a%20non%2DEU%20country.
[2]https://www.easa.europa.eu/eaer/topics/overview-aviation-sector/emissions
[3]https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf
[4]Ibid

SCALE UP GREEN C-LIQUID E-FUEL PRODUCTION FOR LONG-DISTANCE SHIPPING

Establish giga-scale production facilities in industrial clusters and transportation hubs

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use



IN A NUTSHELL...

- **Issue:** LNG, the cleanest fuel currently available at an industrial scale, still emits CO_2; Liquid biofuels represent a promising alternative but are not cost-competitive
- **Solution:** Scale production to drive down the cost of e-fuels for shipping (methanol)
- **Key impacts:** 7.7 $MtCO_2e$, €3.6 billion total market, 55,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to create five port facilities across the EU, each dedicated to the production of 1 million tons of e-fuel (methanol) each year for European and international cargo shipping, with a total electrolyzer capacity of 10.5 GW. The project will result in 5 million tons of green liquid e-fuel for ships produced per year as of 2030, consuming 850,000 tons of hydrogen and 6.875 $MtCO_2$ per year.

- Identify five European cargo ports ideally coupled with airports (such as Hamburg, Amsterdam, Valencia or Piraeus/Athens).
- In each location, build one facility by 2030 which enables an additional yearly production of 1 million tons of synthetic hydrocarbon fuels for cargo shipping (methanol).
- A total electrolyzer capacity of 10.5 GW is needed, either built on-site or streamlined with hydrogen provided by pipes.
- To ensure a genuinely sustainable production of alternative fuel, the facilities must have access to a large supply of green electricity, ideally sourced from nearby offshore wind or solar power plants.
- In addition to the new facilities, incentivizing policies and technological progress (engine energy efficiency, e-fuel production processes) is required for developing of the methanol fuel market and to encourage the retrofitting of existing ships which will run on methanol.
- Within this project dedicated to e-fuels for the marine sector, additional synergies can be achieved through the simultaneous provision of e-kerosene to airports, as described in project #33.
- Key players to involve include public authorities, energy providers, port operators, shipping lines operators, and freight forwarders.

Projects that inspired this analysis: Copenhagen municipality partnership with transport operators (Orsted, Maersk, SAS, DSV Panalpina) for an e-fuel factory by 2030.

Why this technology and project are needed to reach net-zero

While international shipping represents 2 to 3% of all greenhouse gas emissions in the world, maritime transport accounts for 3.7% of CO_2 emissions in the EU, 30% of which are produced by container ships[5]. The European Commission published its first report on the matter in 2019[6], studying 11,600 ships over 5,000 gross tonnage of various sizes (container ships, roll-on and roll-out passenger ships, bulk carriers, tankers), representing almost 40% of the global merchant fleet.

The European Commission already implemented compulsory emission and fuel monitoring for high tonnage cargo or passenger ships in 2013.

Several technological and operational improvements have been proposed to reduce this environmental impact, such as reducing speed or implementing energy efficient systems.

But LNG, the cleanest fuel currently available at an industrial-scale, still emits CO_2: therefore, it remains necessary to find a zero-emission fuel for shipping, as encouraged by the European Parliament in the context of the Green Deal[7].

E-fuels (methanol, hydrogen or ammonia) are produced from electricity, which can come from renewable sources to minimize further carbon emissions. The hydrogen produced from electrolysis can be used directly or synthesized with carbon monoxide or nitrogen to produce methanol or ammonia respectively.

Alternative fuels need to become competitive with classic fuels in terms of cost. Additionally, infrastructure and typical operations, like storage and security protocols, will also need to be adapted.

Impacts

	2030	2050
CLIMATE IMPACT	**7.7 $MtCO_2e$ avoided**	**61.8 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.6 billion total market** €2.6 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2030) €3.4 billion turnover in 2030	**€28.3 billion total market** €37.9 billion cumulated investment by 2050, €1.3 billion yearly average (2020-2050) €28.3 billion turnover in 2050
JOBS	**55,000 total jobs** 4,000 construction jobs for investment 51,000 production jobs for turnover	**424,000 total jobs** 19,000 construction jobs for investment 405,000 production jobs for turnover

#34 [5]*https://ec.europa.eu/clima/news/commission-publishes-first-annual-eu-report-CO₂-emissions-maritime-transport_en*
[6]*https://ec.europa.eu/clima/news/commission-publishes-first-annual-eu-report-CO₂-emissions-maritime-transport_en*
[7]*https://www.europarl.europa.eu/doceo/document/TA-9-2020-0005_EN.html*

#35

SCALE UP GREEN N-LIQUID AMMONIA PRODUCTION AND LOGISTICS INFRASTRUCTURE FOR LONG-DISTANCE SHIPPING

Green ammonia and energy production facility at large ports

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Ammonia is a promising zero-emissions fuel for shipping, but is still produced mainly from grey hydrogen and remains much more expensive than traditional fuel
- **Solution:** Test and deploy at scale production facilities of green ammonia for use as e-fuel for maritime shipping
- **Key impacts:** €4.3 billion total market, 65,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

In line with Project #36 (1,160 ships converted to ammonia fuel-cell propulsion engine), the goal of the project is to reach a yearly production capacity of 5 Mt of green ammonia fuel for European and international cargo shipping, consuming 840,000 tons of hydrogen per year as of 2030. The scaling up of the project will follow the technological advancements in ammonia-powered ships, as the first engines developed by the ShipFC Project will be finalized in 2023.

The project will optimize the process of sustainable ammonia production using green hydrogen, to drive progress in maritime ammonia-powered propulsion and deploy at a large-scale ammonia storage and refuelling.

- Identify large cargo ports in the EU, with easy access to renewable energy (ideally sourced from nearby offshore wind or solar power plants) to ensure a genuinely sustainable production of alternative fuel: preferably Southern Europe such as Spain or Portugal.
- Build facilities in these locations to enable a yearly production of 5 Mt of green ammonia fuel for cargo shipping by 2025.
- For 2030, the project aims at a total production of five million tons of green ammonia (enough to power 1,160 cargo ships per year[8]).
- Key players to involve include public authorities, energy providers, port operators, shipping lines operators, and freight forwarders.

Projects that inspired this analysis: ShipFC consortium project, NoGAPS Project.

Why this technology and project are needed to reach net-zero

Ammonia (NH_3) is traditionally used in the agricultural sector to produce fertilizers (10.2 million tons of such nitrogen fertilizer are used in the EU[9]). Recently its application in shipping fuel has been extensively discussed, since its use does not emit CO_2 due to the lack of a carbon atom in the NH3 molecule. This makes it an ideal technology for a zero-emissions economy. It can be stored in high temperatures in a liquid form, though adapted safety measures must be implemented. Ammonia can also be produced anywhere, allowing Europe to close the gap with leading nations in this technology (such as China, contributing 40% of the global supply of ammonia).

However, ammonia production needs to be carbon-neutral, using green hydrogen obtained from electrolysis. Nowadays, ammonia production heavily relies on fossil fuels and is far from carbon-neutral, emitting 1.8% of all global CO_2 emissions[10]. Furthermore, ammonia is still much more expensive and less available than heavy fuel oil traditionally used by vessel operators. Thirdly, ammonia-powered ships have yet to be designed, as no suitable ship engine exists for now.

Several European projects are dedicated to proving the feasibility of ammonia ships before 2025. Launched in January 2020, the ShipFC project gathers 14 European firms and organizations to create the first commercial ship powered by green ammonia by late 2023. The initiative is already looking into retrofitting different kinds of ships with ammonia fuel cells and has received €10 million of funding from the EU. MAN Energy Solutions is also working on a two-stroke ammonia ship engine, to be showcased by 2024. Finally, the NoGAPS Project, launched in May 2020 studies the challenges for ammonia supply chains that must be addressed to allow large-scale deployment of NH_3-powered ships in Europe.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in ships converted to green ammonia.*	*Counted in ships converted to green ammonia.*
ECONOMIC IMPACT	**€4.3 billion total market** €2.6 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2030) €4.1 billion turnover in 2030	**€28.3 billion total market** €8.3 billion cumulated investment by 2030, €0.3 billion yearly average (2020-2050) €16.3 billion turnover in 2050
JOBS	**65,000 total jobs** 4,000 construction jobs for investment 61,000 production jobs for turnover	**249,000 total jobs** 4,000 construction jobs for investment 245,000 production jobs for turnover

#35 [8]See calculation in the Excel spreadsheet
[9]https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_mineral_fertiliser_consumption
[10]https://www.ft.com/content/2014e53c-531f-11ea-a1ef-da1721a0541e

DEPLOY AMMONIA-FUELED VESSELS FOR LONG-DISTANCE SHIPPING

Retrofit existing vessels to shift from fossil fuel combustion engines to ammonia fuel-cell propulsion engines

TRANSPORT

Synthetic liquid fuels for long-distance air and maritime use

IN A NUTSHELL...

- **Issue:** Carbon-free alternatives to fuel oil have yet to be adopted at a large scale by cargo transportation
- **Solution:** Launch demonstration projects of long-range zero-emissions maritime ammonia fuel
- **Key impacts:** 13.6 $MtCO_2e$, €5.8 billion cumulated investment, 9,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The goal of the project is to launch, as soon as an ammonia-powered ship engine has been validated in Europe, the retrofitting of 10% of long-distance merchant ships across the EU by 2030 (1,160 ships)[11]. This will demonstrate the operational feasibility and the commercial viability of ammonia-powered long-distance merchant ships.

- Identify strategic cargo ports in the EU, with easy access to future facilities of green ammonia production (see Project #35) and renewable energy.
- Launch the retrofit of 1,160 ships to ammonia-powered engines by 2030.
- Main stakeholders include public authorities, energy providers, green hydrogen specialists, port operators, shipping lines operators, freight companies, commercial ship manufacturers, fuel cell technology specialists, and institutes of technology.
- N.B.: the project can be adapted to smaller port-based ships.

Projects that inspired this analysis: ShipFC consortium project, NoGAPS Project.

Why this technology and project are needed to reach net-zero

Ammonia (NH_3) is traditionally used in the agricultural sector to produce fertilizers (11.8 Mt of such nitrogen fertilizer are used in the EU yearly[12]). But recently, ammonia's application in shipping fuel has been extensively discussed, since its combustion does not emit CO_2 due to the lack of a carbon atom in the NH_3 molecule; this makes it an ideal technology for a zero-emissions economy. It can be stored in high temperatures in a liquid form, however adequate safety measures must be implemented. Ammonia can also be produced anywhere, allowing Europe to close the gap with the leading nations in this technology (such as China, providing 40% of all supplies of ammonia in the world), and make Europe less dependent on imports.

However, ammonia production needs to be carbon-neutral, using green hydrogen obtained from electrolysis. Nowadays, ammonia production mainly relies on fossil fuels and is far from carbon-neutral, emitting 1.8% of all global CO_2 emissions[13]. Furthermore, ammonia is still much more expensive and less available than the heavy fuel oil traditionally used by vessel operators. Thirdly, ammonia-powered ships have yet to be designed, as no ship engine exists at the moment.

Several European projects are dedicated to proving the feasibility of ammonia ships before 2025. Launched in January 2020, the ShipFC project gathers 14 European firms and organizations to create the first commercial ship powered by green ammonia by late 2023. The initiative is already looking into retrofitting different kinds of ships with ammonia fuel cell and has received €10 million of funding from the EU. MAN Energy Solutions is also working on a two-stroke ammonia ship engine, to be showcased by 2024. Finally, the NoGAPS project, launched in May 2020, studies the challenges for ammonia supply chains that must be addressed to allow large-scale deployment of NH_3-powered ships in Europe.

Impacts

	2030	2050
CLIMATE IMPACT	**13.6 MtCO₂e avoided**	**54.3 MtCO₂e avoided**
ECONOMIC IMPACT	**€5.8 billion cumulated investment** €0.6 billion yearly average (2020-2030)	**€23.2 billion cumulated investment** €0.8 billion yearly average (2020-2050)
JOBS	**9,000 total jobs**	**12,000 total jobs**

#36 [11]https://ec.europa.eu/clima/sites/clima/files/transport/shipping/docs/swd_2020_82_en.pdf
[12]https://www.fertilizerseurope.com/fertilizers-in-europe/facts-figures/
[13]https://www.ft.com/content/2014e53c-531f-11ea-a1ef-da1721a0541e

SHIFT SHORT- AND MEDIUM-DISTANCE FERRIES TO HYDROGEN FUEL-CELL PROPULSION

Retrofit existing ferries to shift from fossil fuel combustion engines to H_2 fuel-cell propulsion engines

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** Hydrogen-powered engines for ferry shipping, although tested at pilot level, have yet to be deployed at a large scale
- **Solution:** Launch large-scale retrofit of hydrogen propulsion systems for ferries, and prove market readiness for hydrogen as a fuel and large-scale production
- **Key impacts:** 0.8 $MtCO_2e$, €0.3 billion total market, 4,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The first goal of the project is to launch the retrofit of 50% of European ferries into hydrogen-powered ships, each with a fuel cell power of 2 MW (in line with existing hydrogen-powered ferries[14]) by 2030. This will demonstrate the operational feasibility and commercial viability of the large-scale deployment of a zero-emissions propulsion system.

In line with this first objective, the project simultaneously aims at a yearly production capacity of 60,000 tons of green hydrogen fuel for short-distance ships, as the technology for GW-scale electrolyzers is developed in European projects. A deployment of green hydrogen production of this size will allow technical development, optimization of production processes and cost reduction, thus solving the main challenges currently faced by the technology.

- Identify five major ferry ports in the EU (such as Norway, the Netherlands, Spain, Greece or Portugal) with easy access to future facilities of green hydrogen production (emerging hydrogen clusters) and renewable energy supply (ideally from nearby offshore wind parks or PV solar plants).
- In each location, build a green hydrogen production facility, to drive forward electrolysis technology (accelerate the development of selected technologies with the strongest commercial potential and proven results for large-scale deployment).
- For 2030, launch the retrofit of 50% of the European ferry fleet (350 ships[15]) to 2 MW hydrogen fuel cell engines and produce 60,000 tons of green hydrogen dedicated to short-distance shipping fuel.
- Main stakeholders include public authorities, energy providers, port operators, ferry operators, maritime equipment manufacturers, fuel cell technology specialists and institutes of technology.

Projects that inspired this analysis: H_2SHIPS project, ZeFF project, Seashuttle project, Flagships project, ShipFC (ammonia-powered engine retrofit), 2x40 GW Green Hydrogen Initiative, HYPOS, HySynGas, Elekrolysefabriek.

Why this technology and project are needed to reach net-zero

Short-sea shipping, defined as the transportation of cargo and passengers with maritime transports on short distances (along the coast, from port to port, inland in small seas or rivers, without crossing an ocean), is a critical part of the freight chain in Europe as it is responsible for 37% of intra-EU trade[16]. This activity is complementary to road transportation (accounting for 45% of intra-EU trade), creating intermodal freight networks.

Retrofitting short-sea ships with LNG, as it has been attempted in Europe, is insufficient to decarbonize the sector, while hydrogen fuel cells are a viable solution (for short distance maritime transportation as well as for freight trucking).

Many European projects have already been launched to start the decarbonization of ferry transportation. Contrary to other zero-emitting fuels such as ammonia (for which no ship engine has been designed yet), hydrogen-fueled commercial ships exist since 2010, the offshore platform supply vessel *Viking Lady* being the first to use this technology. The H_2SHIPS project aims to pilot a hydrogen port-based ship in Amsterdam, a hydrogen station for open sea ships in Amsterdam and hydrogen ships on the Seine by 2022. Project ZeFF (Zero-emission Fast Ferry) received €1 million of public support in December 2018 to create hydrogen ferries in Norway. The Seashuttle project was also backed by the Norwegian government and targets 20% of zero-emissions coastal routes. Finally, the 2019 Flagships project received €5 million of funding from the EU to create two hydrogen fuel cell ferries in France and Norway.

95% of the world's hydrogen production is currently 'grey', using fossil fuels (natural gas or coal) in a cost-effective and technologically mature process[17], but with 10 tons of CO_2 emitted per ton of hydrogen produced[18]. 'Blue' hydrogen can also be produced in a process limiting the CO_2 emissions through carbon capture and storage. However, to reach a net-zero-emission economy, the production of hydrogen needs to be fully decarbonized, with electrolysis. This requires designing high capacity electrolyzers through technological development, and drastically reducing the price per kW installed capacity through large-scale deployment of facilities.

Impacts

	2030	2050
CLIMATE IMPACT	**0.8 $MtCO_2e$ avoided**	**1.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€0.3 billion total market** €1.2 billion cumulated investment by 2030, €0.1 billion yearly average (2020-2030) €0.1 billion turnover in 2030	**€0.3 billion total market** €2 billion cumulated investment by 2050, €0.1 billion yearly average (2030-2050) €0.2 billion turnover in 2030
JOBS	**4,000 total jobs** 2,000 construction jobs for investment 2,000 production jobs for turnover	**4,000 total jobs** 1,000 construction jobs for investment 3,000 production jobs for turnover

#37 [14]The 2 MW power target is coherent with existing hydrogen-powered ferries (https://www.uib.no/sites/w3.uib.no/files/attachments/fuel_cells_and_hydrogen_in_maritime_applications.pdf and https://www.oceanhywaycluster.no/member-area-hydrogen-vessels/hydrogen-vessel-1-68b62-g2dc4-2d4hx-8hgrc-544ls-99839-r8dbz and https://energy.sandia.gov/hydrogen-fuel-cell-funding-awarded-for-feasibility-study/)
[15]http://www.shortsea.fr/sites/default/files/fichiers/public/research_for_tran_committee-_the_eu_maritime_transport_system_focus_on_ferries.pdf
[16]https://www.ecsa.eu/sites/default/files/publications/ECSA_SSS_Download%201_0.pdf
[17]https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf
[18]https://www.hydrogen4climateaction.eu/2x40gw-initiative#:~:text=Improving%20the%20EU%20Climate,to%20the%20EU%20climate%20objectives

DEVELOP HYDROGEN USAGE FOR HEAVY-DUTY ROAD FREIGHT

Deploy hydrogen refueling stations along the key pan-European road corridors

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** Widespread implementation of H_2 in road transport is limited by poor infrastructure penetration and reliability
- **Solution:** Building a 'spine' based on high-utilization freight lays the foundation for expansion into passenger transport
- **Key impacts:** €4.8 billion cumulated investment, 7,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to pilot the deployment of freight hydrogen corridors in Europe. They will consist of large stations ensuring hydrogen refueling as well as production on site with small electrolyzers and photovoltaic panels. The stations will be located strategically along each corridor.

The aim is both to create the necessary infrastructure for an increased number of heavy-duty hydrogen trucks (as anticipated in Project #39), and to locally produce part of the fuel needs with renewable energy.

- Identify heavy-duty truck freight network corridors in Europe of 1,000 km, along the nine larger transport axes identified in the TEN-T (Trans-European Transport Network) program[19]. These nine core corridors had been previously identified by the European Commission in order to focus EU-backed infrastructure projects.
- Develop large hydrogen refueling stations along these corridors for heavy-duty trucks.
- Implement local hydrogen production in each Hydrogen Refueling Station with photovoltaic panels on roofs and electrolyzers, aiming at 1,000 kg of hydrogen production per day[20].
- Main stakeholders include developers and manufacturers of hydrogen generation and fuel cells products, companies specialized in trucking, shipping and rail freight, and renewable energy providers.

Projects that inspired this analysis: GIFT (intercontinental corridor selection), FCH ReFuel (hydrogen infrastructure), H_2ME 1 and H_2ME 2 (expansion of the European hydrogen vehicles fleet, fueling stations and hydrogen production techniques), H2020 call for proposals: "Scale-up and demonstration of innovative hydrogen compressor technology for full-scale hydrogen refueling station".

Why this technology and project are needed to reach net-zero

Heavy-duty vehicles, such as trucks, buses and coaches, constitute a significant share of CO_2 emissions in the EU (~25% of CO_2 of road transport emissions, and 6% of total emissions within the Union)[21]. Between 65% and 70% of these emissions are produced by heavy-duty trucks[22], although new regulations (such as Euro I to VI) have been released to impose stricter emission standards.

Fully decarbonizing this mode of freight transport will have significant environmental benefits on a local and European level. However, widespread implementation of greener, hydrogen-powered heavy-duty trucks in Europe will require significant improvements to the infrastructure along the main commercial routes.

Although only 120 hydrogen refueling stations currently exist, the Hydrogen Roadmap for Europe expects this number to rise to 3,700 in 2030 (all sizes), for a cumulated investment of €8.2 billion, to accommodate an increasing volume of H_2 vehicles[23].

European projects are moving in this direction: the H_2Piyr project is one example of an EU-backed Hydrogen Corridor initiative, building six refueling stations along a 900 km long Spanish, French and Andorran corridor by 2021.

To accelerate the decarbonization of freight movement within Europe, an efficient green fueling infrastructure adapted for trucking needs to be put in place along these strategic corridors. The price of hydrogen must be kept at a low level to ensure competitiveness for long-haul transport (around €2.7/kg for trucks according to a 2019 study by the Hydrogen Council[24]). One solution is to implement local production at truck stations, with photovoltaic panels installed on roofs coupled with small electrolyzers, to guarantee renewable and cheap hydrogen sourcing.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in hydrogen trucks in circulation.*	*Counted in hydrogen trucks in circulation.*
ECONOMIC IMPACT	**€4.8 billion total market** €0.5 billion yearly average (2020-2030)	**€40 billion total market** €1.3 billion yearly average (2020-2050)
JOBS	**7,000 total jobs**	**20,000 total jobs**

#38 [19]The TEN-T network has a total length of ~48,000 km (https://books.google.fr/books?id=_WRnDAAAQBAJ&pg=PA149&lpg=PA149&dq=ten-t+europe+length&source=bl&ots=YL7xu9X4X3&sig=ACfU3U2QeGhaNS1nHi82pOFDdxtU64n55w&hl=fr&sa=X&redir_esc=y#v=onepage&q=ten-t%20europe%20length&f=false)
[20]Based on Hydrogenics HySTAT fueling stations with electrolysis-based production (https://www.hydrogeni cs.com/hydrogen-products-solutions/energy-storage-fueling-solutions/hydrogen-fueling-stations/)
[21]https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en
[22]https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/628268/EPRS_BRI(2018)628268_EN.pdf
[23]https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf
[24]https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

SHIFT EUROPEAN TRUCK INDUSTRY TO HYDROGEN

Develop EU-based production of fuel-cell heavy-duty trucks, buses and waste vehicles

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** There is currently no large scale zero-emissions solution for the commercial transportation of goods by heavy vehicles
- **Solution:** Develop fleets of heavy-duty hydrogen-powered trucks across Europe
- **Key impacts:** 3 $MtCO_2e$, €7.2 billion cumulated investment, 11,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to launch an initiative in five countries to accelerate the development and testing of hydrogen heavy vehicles, leading to the production of 45,000 hydrogen-powered freight trucks by 2030. This is in line with the ambitious target of the Hydrogen Roadmap for Europe, anticipating 45,000 hydrogen-fueled heavy trucks and buses by 2030[25].

- Identify five countries (in Central (e.g. Germany), Eastern and Northern Europe).
- Create an initiative to stimulate the hydrogen and fuel cells industry. This can be done by funding the development of hydrogen-powered freight trucks, through partnerships between public authorities, institutes of technology and manufacturers.
- The project will lead to the production of 45,000 hydrogen freight trucks coming in to replace existing diesel vehicles.
- Main stakeholders include: national ministries of transport, local Institutes of technology, heavy-duty truck manufacturers (such as Daimler Trucks), freight transportation operators (such as DHL), logistic specialists (such as Schenker AG).

Projects that inspired this analysis: FuelCellsWorks Initiative, REVIVE (Refuse Vehicle Innovation and Validation in Europe), Fuel Cells and Hydrogen Joint Undertaking (FCH JU), Joint Venture between Daimler Trucks and Volvo Group JV.

Why this technology and project are needed to reach net-zero

Heavy-duty vehicles, such as trucks, buses and coaches, constitute a significant share of CO_2 emissions in the EU (about 25% of road transport CO_2 emissions, and 6% of total emissions within the Union)[26]. Between 65% and 70% of these emissions are produced by heavy-duty trucks[27], though new regulations (such as Euro I to VI, which do not cover CO_2 primarily) have been released to impose stricter emission standards.

Fully decarbonizing this mode of freight transport will have significant environmental benefits on a local and European level. Today, only hydrogen-fueled trucks can achieve this goal, as current battery technology is not economically viable for long-haul truck application in terms of size and weight[28].

Though individual fuel cell cars have recently been introduced to the market, a comparable zero-emissions solution for road freight is yet to be deployed at the European level. However, hydrogen applications for heavy duty trucks are steadily moving from first-generation proof-of-concept to pre-commercial and real-life prototypes, as several projects accelerate the development of this technology in Europe.

In October 2019, the German Federal Ministry for Transport and Digital Infrastructure announced €23.5 million of funding going to hydrogen mobility projects, including €8.1 million dedicated to the development of heavy trucks (a project jointly developed by Shell, MAN, Anleg GmbH and TU Braunschweig). In April 2020, Daimler Trucks and Volvo announced they would create a joint venture to design hydrogen-powered heavy-duty commercial vehicles. Anticipating a quick adoption of this technology, the Hydrogen Roadmap for Europe sets a target of 45,000 fuel cell trucks and buses for 2030 and expects hydrogen-powered vehicles to represent 40% of all heavy-duty truck sales in 2050[29].

Impacts

	2030	2050
CLIMATE IMPACT	**3 $MtCO_2e$ avoided**	**166.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€7.2 billion cumulated investment** €0.7 billion yearly average (2020-2030)	**€352.8 billion cumulated investment** €11.8 billion yearly average (2020-2050)
JOBS	**11,000 total jobs**	**176,000 total jobs**

#39 [25]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*
[26]*https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en*
[27]*https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/628268/EPRS_BRI(2018)628268_EN.pdf*
[28]*http://pan.ckcest.cn/rcservice/doc?doc_id=31115*
[29]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

#40

TRANSITION FOSSIL-POWERED INTERCITY TRAINS TO HYDROGEN

Develop and deploy urban/suburban hydrogen-powered trains

TRANSPORT

Pure hydrogen for medium-distance marine, road and rail use

IN A NUTSHELL...

- **Issue:** European fleets of diesel-powered intercity trains need to be replaced by zero-emission transport solutions
- **Solution:** Decarbonize intercity rail connections by deploying hydrogen-powered trains
- **Key impacts:** 0.2 $MtCO_2e$, €3.4 billion cumulated investment, 5,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The project's goal is to pilot hydrogen intercity and commuter train projects in selected European regions to replace the diesel-powered locomotives they currently use, with minimal adaptation of existing railways. This project is in line with the ambitions of the European Hydrogen Roadmap, anticipating 570 hydrogen trains by 2030 and a share of 9% of all railway transports powered by hydrogen in Europe by 2050 under a 2-degree target scenario[30].

- Identify ten European regions currently using diesel-powered intercity trains.
- Assist the ten regions and/or the local railway operators in launching calls for intercity hydrogen train tenders by 2025.
- Ensure each call for tenders is comprised of 15 intercity hydrogen trains and one hydrogen refueling station, aiming at a total replacement of 150 diesel intercity trains.
- Key stakeholders include railway manufacturers with experience in hydrogen-powered trains (such as Alstom), European regions involved, railway operators (such as SNCF or RMV).

Projects that inspired this analysis: deal between Alstom and SNCF in France (15 hydrogen regional trains for 2021-2022)[31], deal between Alstom and LNGV in Germany (14 hydrogen trains for 2021)[32], deal between Alstom and RMV (27 hydrogen trains for 2022)[33].

Why this technology and project are needed to reach net-zero

Commuter trains are still commonly powered by diesel engines in Europe, but their replacement by hydrogen locomotives, advocated by the Hydrogen Roadmap for Europe by the Fuel Cells and Hydrogen Joint Undertaking[34], has started in 2019.

This solution was successfully launched in 2018 in Germany and additional hydrogen trains are already planned in several European countries such as France, which involves railway manufacturer Alstom and its Corafia iLint model.

In comparison to diesel, hydrogen reduces not only CO_2 emissions but also local pollutants and noise levels of trains, which matter in dense areas. The hydrogen alternative requires the implementation of additional infrastructure for hydrogen trains, which are more cost-effective and faster to install than to electrify lines and electric locomotives. This includes a limited number of hydrogen stations built along existing railways to ensure adequate refueling.

Impacts

	2030	2050
CLIMATE IMPACT	**0.2 $MtCO_2e$ avoided**	**1.3 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€3.4 billion cumulated investment** €0.3 billion yearly average (2020-2030)	**€24.3 billion cumulated investment** €1.2 billion yearly average (2020-2050)
JOBS	**5,000 total jobs**	**18,000 total jobs**

#40 [30]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*
[31]*https://www.lemondedelenergie.com/sncf-commande-15-trains-hydrogene-alstom/2019/09/06/*
[32]*https://www.alstom.com/fr/press-releases-news/2019/10/alstom-va-tester-son-train-pile-hydrogene-aux-pays-bas*
[33]*https://www.alstom.com/fr/press-releases-news/2019/5/fahma-une-filiale-de-rmv-passe-commande-alstom-de-la-plus-grande-flotte*
[34]*https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

ELECTRIFY SHORT-DISTANCE TRUCK TRANSPORT, WASTE COLLECTION AND URBAN BUS FLEETS

Low-GHG, silent and clean air city transportation: last-mile logistics, public transport and services

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** Over 70% of goods used daily are transported within and between cities via heavy duty trucks that are large CO_2 emitters
- **Solution:** Develop heavy-duty electric trucks, buses, waste collectors and demonstrate the feasibility of reliable deployment to gain scale and reduce costs
- **Key impacts:** 13.4 $MtCO_2e$, €99.5 billion cumulated investment, 149,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Electrify short and medium distance truck transport in Europe

- Pioneer electric truck transport along short and medium distances in Europe by incentivizing truck manufacturers to invest in electric technologies.
- Inspirational technology: Volvo FL truck with 16 tons capacity and 300 km range.
- The project aims at a share of 10% of electric vehicles in the EU truck fleet by 2030.
- The aim of the project is to scale up electric truck transport capabilities in Europe through public-private investment initiatives to unlock capital, i.e. take advantage of the European Investment Bank's transport lending criteria.
- It will reduce greenhouse gases and noise pollution created by trucks on short distance routes in Europe, while not jeopardizing the importance of truck transport in delivering goods.

Projects that inspired this analysis: Volvo LIGHTS initiative in the US: $90 million public-private investment partnership between California Climate Investments and Volvo to make electric truck transport a viable capability.

Project type 2: Deploy electric vehicles for public transport, waste collection, and postal deliveries in urban locations

- Bring together public and private stakeholders to electrify public transport, waste collection and postal services.
- The aim of the project is to mobilize national and European funds to act as financial support to cities and municipalities in replacing current vehicle fleets by electric fleets.
- Start with ten major EU cities by 2025 and identify implementation obstacles before scaling up in other European cities on a 2030 horizon.
- City entities including public transport, postal or waste services must initiate tenders to replace ageing fleets and incentivize vehicle manufacturers to increase supply.
- Main stakeholders: cities management to set up tenders, vehicle manufacturers to prepare and compete for large electric vehicle orders, European investment banks to provide financial support to city transport budgets via financial mechanisms like green bonds.

Projects that inspired this analysis: 1) Paris RATP plan bus 2025 with 4,500 new buses of which 80% will be electric; 2) La poste (French postal service) massive deployment of electric light vehicles for last mile delivery.

Why this technology and project are needed to reach net-zero

- Heavy vehicles, which include trucks and buses, account for 6% of EU total yearly CO_2 emissions i.e. over 300 million tons of CO_2.
- Deploying trucks will reduce heavy vehicle-related CO_2 emissions in the EU and boost job creation as a result of the need for innovative electric technologies and charging infrastructures.
- Urban centers suffer from noise pollution and fine particulate matter created by public transport and city vehicle-based services. Replacing fleets with EVs will allow cities to eliminate such noise and atmospheric problems.
- The replacement of city vehicle fleets can also revitalize European engine producers by creating activity for European manufacturers with tenders, motivating them to increase their cost-competitiveness and supply capacities.

Impacts

	2030	2050
CLIMATE IMPACT	**Project type 1 (trucking): 8 $MtCO_2e$ avoided** **Project type 2 (bus): 4 $MtCO_2e$ avoided** **Project type 2 (waste): 1.3 $MtCO_2e$ avoided** **Project type 2 (postal): 0.1 $MtCO_2e$ avoided**	**Project type 1 (trucking): 16 $MtCO_2e$ avoided** **Project type 2 (bus): 6.1 $MtCO_2e$ avoided** **Project type 2 (waste): 1.7 $MtCO_2e$ avoided** **Project type 2 (postal): 0.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**Project type 1 (trucking): €56.7 billion cumulated investment** €5.7 billion yearly average (2020-2030) **Project type 2 (bus): €37.1 billion cumulated investment** €3.7 billion yearly average (2020-2030) **Project type 2 (waste): €5.1 billion cumulated investment** €0.5 billion yearly average (2020-2030) **Project type 2 (postal): €0.5 billion cumulated investment** €0.05 billion yearly average (2020-2030)	**Project type 1 (trucking): €160.7 billion cumulated investment** €8 billion yearly average (2030-2050) **Project type 2 (bus): €123.8 billion cumulated investment** €6.2 billion yearly average (2030-2050) **Project type 2 (waste): €10.5 billion cumulated investment** €0.5 billion yearly average (2030-2050) **Project type 2 (postal): €0.9 billion cumulated investment** €0.04 billion yearly average (2030-2050)
JOBS	**Project type 1 (trucking): 85,000 total jobs** **Project type 2 (bus): 56,000 total jobs** **Project type 2 (waste): 8,000 total jobs** **Project type 2 (postal): 1,000 total jobs**	**Project type 1 (trucking): 120,000 total jobs** **Project type 2 (bus): 93,000 total jobs** **Project type 2 (waste): 8,000 total jobs** **Project type 2 (postal): 1,000 total jobs**

FOSTER PRIVATE EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY

Massively deploy charging points at private homes and offices

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** With the declining prices of EVs, increasing variety of EV models and growing driving ranges, access to charging infrastructure will soon be the only remaining barrier for EV uptake
- **Solution:** Deployment of additional charging infrastructure at home and in offices is essential for accelerating EV market penetration
- **Key impacts:** 57.9 $MtCO_2e$, €80.2 billion cumulated investment, 120,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

The program will focus on putting in place favorable financial conditions for individuals and private entities to facilitate investment towards installing their own charging infrastructure. The project will target one private charger per EV, with 40 million EV cars by 2030 and 80% of cars being EV by 2050[35].

- Rework current incentive programs across EU countries and propose a 'boosting plan' in the very short term (2020-2021), coordinated at EU and national levels, with new subsidies and tax reduction schemes to encourage the roll-out of private charging stations (at home or at work).
- Additionally, work on developing new business models with private companies to secure a rapid return on investment from the private charging point deployment. For example, installation of private charging in parking zones increases rent prices of nearby real estate.
- Rely on five countries to lead the implementation. These include Germany, France and the Netherlands, which together account for 20% of the European EV market[36]. From there, the goal is to get other EU countries on-board.
- Adapt financing schemes and implementation across countries and localities according to:
    - ◊ The urbanization heterogeneities of countries. For instance, in Germany, almost two-thirds of households have a garage or a parking space.
    - ◊ The status of the local EV ownership, charging infrastructure, consumer preferences and ability to finance (e.g. a single suburban house in a developing area vs. an apartment building in a major capital - how to drive adoption in both?).
- This can take the form of 'cash-back' on installation by certified electricians/installers or even providing capital for no-money-down installations.

Main stakeholders: Academics, knowledge and innovation centers (Delft University of Technology (NL), smartlab innovations GmbH (DE); Parking Energy, Finland); EU institutions for the funding, private companies to propose bundled offers (EV sale plus the charging infrastructure), or end-to-end energy solutions by energy companies or mobility providers.

Clusters: Netherlands, Germany, France, Italy

Why this technology and project are needed to reach net-zero

Despite persistent heterogeneity, standardization and technological progress have boosted the deployment of chargers, and EV uptake is closely mirrored by the spread of charging infrastructure. Indeed, charging accessibility is fundamental to improving the general acceptance of EVs. E-mobility therefore relies on a massive deployment of charging infrastructure, along with further technological standardization.

In 2017, the number of private chargers at residences and workplaces was estimated at almost three million worldwide, and the most widely used charging installations for electric cars were owned by households and fleets. Currently, private charging points account for more than 90% of installations in Europe[37].

Ubiquitous charging is locally labor-intensive, meaning it will have a strong impact on the overall economic recovery, and it is ready to be rolled out on short notice. In addition, the European Commission is also seeking to increase the level of home charging by requiring that charging stations be built into new residential buildings with over 20 parking spaces as of 2025[38].

Impacts

	2030	2050
CLIMATE IMPACT	**57.9 $MtCO_2e$ avoided**	**297.1 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€80.2 billion cumulated investment** €8 billion yearly average (2020-2030)	**€656.9 billion cumulated investment** €32.8 billion yearly average (2030-2050)
JOBS	**120,000 total jobs**	**493,000 total jobs**

#42 [35]For 2050, in a study on the impact of EV on Europe's future emissions, the EEA envisioned two scenarios for the share of EV as part of the entire EU car fleet in 2050: 50%, or 80% (https://www.eea.europa.eu/publications/electric-vehicles-and-the-energy/download)
[36]https://www.statista.com/statistics/625795/eu-electric-vehicle-market-share-by-country/
[37]https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points
[38]https://bellona.org/news/transport/electric-vehicles/2018-01-newly-agreed-eu-buildings-law-to-require-buildings-readiness-for-electric-vehicles

FOSTER PUBLIC EV CHARGING INFRASTRUCTURE TO EASE ADOPTION OF SHORT-DISTANCE E-MOBILITY

Slow to fast charging for urban areas and ultra-fast charging deployment projects along major transit routes

TRANSPORT

Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** Public chargers complement the role of private ones, are an important component of the EV supply infrastructure, but represent only 5% of total chargers
- **Solution:** Deployment of additional fast-charging public infrastructure along highways and transit routes
- **Key impacts:** €16 billion cumulated investment, 24,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

- In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), deploy 8 million public charging points (one per 5 EVs[39], with both slow and fast charging capabilities) across Europe by 2030. It is that there currently are 175,000 public chargers in Europe[40], including the Netherlands, Germany, France and Norway, with more than 10,000 public charging points each.
- Make deployment of public charging points a core part of the motorway maintenance and expansion plans going forward, with spaces earmarked for future charging infrastructure.
- Deployment needs to be further accelerated via subsidy and regulatory initiatives as well as increased piloting of new charging technologies throughout Europe. Work to create a regulatory environment to support new technologies like vehicle-to-grid solutions (new regulatory frameworks to ease resell of energy to the grid, or innovative energy compensation models for customers who are part of V2G activities).
- Ensuring a low cost of renewable energy facilities is another key point. With technological evolutions, the price for purchasing and installing a bi-directional charger went from 10,000 down to 4,000-5,000 euros in three years (from 2017 to 2020). The project needs to establish strong links with existing smart charging initiatives, to ensure grid stability. New technologies will also decrease the maintenance cost of charging infrastructures.
- Inspiring company product: Tesla Supercharger network.
- Main stakeholders: TU Delft, The urban institute Hungary Zrt, Hungary; ElaadNL, Netherlands; Smartlab innovations GmbH, Germany; Delft University of Technology, Netherlands; Local Utilities (like Germany-based utility EnBW).
- Clusters: Netherlands, Germany, France, Spain and Italy.

Projects that inspired this analysis:

- *OSCD (Orchestrating Smart Charging in mass Deployment) lead by the TU Delft.*
- *UK initiative to install wireless public charging pads across residential streets, car parks and taxi ranks.*
- *E.ON x Clever and NEXT-E. E.ON has collaborated with Denmark's eMSP Clever to establish a network of 180 ultra-fast charging stations in seven countries connecting Norway to Italy.*
- *Mega-E is being implemented by Allego in partnership with Finland's Fortum, to develop a charging network of 322 ultra-fast chargers and 27 smart charging hubs across 20 central European and Scandinavian countries. It focuses on bringing multimodal charging hubs to metropolitan areas.*

Why this technology and project are needed to reach net-zero

Limited existence of charging infrastructure and long charging time compared to refueling at petrol stations are the main barriers for EV adoption in long distance travel. The EU had 175,000 public charging points in 2019[41].

- Slow public chargers are commonly found in urban areas where they can be used with other options including private off-street parking. The number of slow public chargers varies across cities depending on availability of off-street parking and the number of cars among other factors. The Netherlands has the highest number of slow chargers at 36,000[42]. Fast chargers only represent a small proportion of total EVSE in Europe, although the continent is emerging as one of the most popular destinations for DC fast charging stations deployment.
- Mass deployment of public EV infrastructure is needed, especially in vehicle-dense urban locations. Increasing the affordability of EV travel between major cities across Europe is also necessary. Most publicly accessible chargers are slow charging outlets, always complemented by publicly accessible fast chargers. Fast chargers are especially important in urban environments due to land availability constraints in densely populated European cities. In addition, fast chargers are essential to increase the appeal of EVs by enabling long distance travel.
- EVs are also assets for storage and renewable energy integration. Smart charging is an emerging business model to fasten EV adoption and allowing EV drivers to benefit from renewable energy sources. However, to enable this, either charging stations or the vehicle must communicate with smart grids. Currently, installed EV chargers are mostly unidirectional, preventing a roll-out of different technologies like Vehicle to Everything (V2X).

Ubiquitous charging is key in incentivizing rapid EV adoption. It is locally labor-intensive and ready to be rolled out on short notice. The Trans-European Transport Network (TEN-T) regulation – particularly the Innovation and New Technologies section – facilitates the deployment of low carbon transport infrastructure, while the Connecting Europe Facility (CEF) provides funding. As an example of EU funding programs, the Green Vehicles program supports road transport innovation including research on the interface between vehicle and charging infrastructure[43].

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€16 billion cumulated investment** €1.6 billion yearly average (2020-2030)	**€131.4 billion cumulated investment** €6.6 billion yearly average (2030-2050)
JOBS	**24,000 total jobs**	**99,000 total jobs**

#43 [39]*https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points*
[40]*https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf*
[41]*https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf*
[42]*https://nederlandelektrisch.nl/charging-infrastructure*
[43]*https://ec.europa.eu/inea/sites/inea/files/green_vehicles_brochure_2018.pdf*

DEVELOP FASTER, CHEAPER, MORE CONVENIENT TECHNOLOGIES FOR EV CHARGING

Lever European R&D to invent disruptive charging solutions that will be highly competitive on global market

TRANSPORT | Ease the adoption and use of e-mobility

IN A NUTSHELL...

- **Issue:** The EV charging experience complicates customers' e-mobility journey and slows down EV uptake
- **Solution:** Accelerate R&D on wireless charging and electrified road technologies to enable a faster, cheaper, and more convenient charging experience
- **Key impact :** €18.2 billion cumulated investment, 27,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Develop and scale static wireless charging technology

The goal of the project is to develop a new generation of wireless EV charging technologies with the aim of decreasing technology costs (go-mainstream) and supporting the development of common EU wireless charging standards.

- Identify stakeholders (OEMs, academies, cities, and others) currently working on wireless charging technologies. As an example, international German OEMs are already investing in this technology.
- Fund their R&D activities via public-private investment partnerships with consortia of private companies.
- Identify pilot cities for wireless charging deployment and support/subsidize their initial construction phase.
- After the initial development phase, work on scaling-up this solution across EU countries through public-private partnership models.
- Main deployment stakeholders: Europe based international OEMs (such as BMW, Renault), European regions (start with France and Germany), academies and research institutes, European e-mobility associations (such as Avere).

Projects that inspired this analysis:

- *As part of the INCIT-EV project, together with 32 partners across Europe, Renault will launch an initiative: dynamic induction-charging system (wireless chargers) integrated into road networks will be installed in Paris to allow EVs to charge while on the move, giving vehicles freedom and a greater range.*
- *Pilot project of new EV taxis wireless charging in Nottingham in 2020, financed by the UK transport department with a €4 million investment.*

Project type 2: Research and Development in the area of electrified roads technology

The goal of the project is to accelerate R&D activities on electrified technologies and identify the best business model to deploy and scale-up this technology.

- Identify stakeholders (see 'Main stakeholders' below) currently working on electrified road technology.
- Accelerate R&D investments via public-private funding partnerships and find the adequate business model for deployment (i.e. financing model).
- Identify one to two target countries and roll out further pilot projects like the Swedish '2 km pilot road' started in 2018: 50 km of electrified roads in Europe by 2025, scaled up to 100 lines of 20 km each by 2030.
- Main stakeholders: transport research labs, private companies (such as Europe-based OEMs, construction companies), energy companies and grid operators (DSOs, TSOs).

Projects that inspired this analysis: First European project launched in Sweden in 2018 with a cost of €1.1 million per km of electrified roads. Sweden aims to electrify 20,000 km out of its 500,000 km of roads.

Why this technology and project are needed to reach net-zero

Limited coverage of charging infrastructure and long charging times are the main barriers to EV adoption. The charging experience is another key issue as the lack of standardization, unclear pricing schemes and insufficient interoperability between charger providers further complicate customer journeys[44]. Further differences exist as chargers can be equipped with different sockets, which complicates charging and constrains automakers to equip their EVs with several types of plugs.

Wireless EV charging via magnetic resonance technology enables charging without connection[45]. This type of charging delivers the same power, efficiency level and charge speed as conventional plug-in charging methods[46]. Wireless EV charging technologies can operate with similar efficiency range – at 90% to 93% efficiency, with Plug-in EV Chargers, 88% to 95% efficiency range end-to-end, from grid to battery[47].

Rolling out electrified roads can be the fastest way towards full EV adoption: the batteries of electric cars and trucks are recharged by two tracks of rail in the road, transferring energy, recharging the batteries of electric cars and trucks[48]. EVs profiting from this technology, referred to as 'dynamic charging', will have relatively smaller chargers, eventually decreasing total cost of ownership[49].

Furthermore, dynamic charging will improve the flexibility of EVs especially over long distances, facilitating and encouraging long-haul vehicles such as heavy-duty trucks or regional buses to switch to electric batteries[50]. As heavy-duty vehicles, which are large motorway users, represent 6% of all EU CO_2 emissions each year[51], implementing electrified roads will thus contribute to reduce overall carbon emissions.

Charger deployment is locally labor-intensive, ready to be rolled out at short notice, so the benefits can be reaped when they are most needed. The Trans-European Transport Network regulation - in particular, the innovation and new technologies section - facilitates the deployment of low-carbon transport infrastructure, while the Connecting Europe Facility provides funding. As an example of an EU funding program, the Green Vehicles program has a total budget of €56 million and supports road transport innovation including research on interfaces between the vehicle and the charging infrastructure.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**Project type 1 (wireless): €16 billion cumulated investment** €1.6 billion yearly average (2020-2030) **Project type 2 (roads): €2.2 billion cumulated investment** €0.2 billion yearly average (2020-2030)	**Project type 1 (wireless): €131.4 billion cumulated investment** €6.6 billion yearly average (2030-2050) **Project type 2 (roads): €6.7 billion cumulated investment** €0.3 billion yearly average (2020-2050)
JOBS	**Project type 1 (wireless): 24,000 total jobs** **Project type 2 (roads): 3,000 total jobs**	**Project type 1 (wireless): 99,000 total jobs** **Project type 2 (roads): 5,000 total jobs**

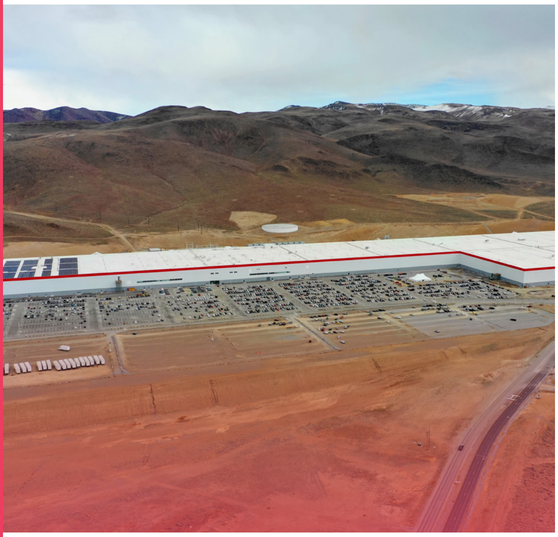
#44 [44]*Key Factors Defining the E-mobility of Tomorrow, Capgemini Invent, 2018*
[45]*Could Wireless charging play a role advancing EV adoption? https://electricautonomy.ca/2020/02/26/wireless-ev-charging-advancing-ev-adoption/*
[46]*Ibid.*
[47]*Ibid.*
[48]*World's first electrified road for charging vehicles opens in Sweden https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden*
[49]*Ibid.*
[50]*https://www.iea.org/reports/global-ev-outlook-2020*
[51]*https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en*

SUPPLY THE EUROPEAN AUTOMOTIVE INDUSTRY WITH 'MADE IN EUROPE' LI-ION BATTERIES

Li-ion battery gigafactories to serve the increasing e-mobility market and develop jobs and know-how in Europe

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe



IN A NUTSHELL...

- **Issue:** Scaling EVs requires massive quantities of lithium-ion batteries, currently mostly manufactured in Asia
- **Solution:** Multiple li-ion battery production gigafactories in locations where batteries can be most sustainably produced
- **Key impacts:** €33.2 billion total market, 223,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

New Li-ion battery gigafactories of 30 GWh capacity each in Europe by 2030

- in line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), the project aims to cover two-thirds of EU's EV market demand through European supply by 2030 (including production capacities already planned on the EU territory by Asian players such as SK Innovation, CATL, …) with the lowest environmental impact possible. The remaining one-third of the EV fleet will be powered with next-generation battery tech (see Project #47).
- 305 GWh additional li-ion battery production capacity will be needed by 2030 (to which must be added the demand for the stationary market, not considered in this analysis), i.e. 10 additional gigafactories of 30 GWh capacity each.
- To ensure low CO_2 impact of production, the four gigafactories must be set up in countries with the lowest power sector carbon intensity (max ~200 gCO_2eq/kWh[52]) and close to passenger car assembly lines[53]: This includes Northern France, Eastern Austria, Northern Slovakia, Northern Spain.
- *Projects that inspired this analysis: Northvolt's Gigafactory in Sweden is an excellent example of what the EU battery value chain ambition will look like:*

◊ *Large scale production plant (32 GWh) with auxiliary firms and JV in several countries.*

◊ *100% supplied by renewable power which is relevant considering amounts of energy needed.*

◊ *Fully automatized.*

◊ *Integrated with a recycling facility to support a circular approach.*

◊ *Located near centers of raw material supplies.*

◊ *Able to manufacture not only cells but the whole integrated system including the BMS, to target various markets, including the stationary one.*

Why this technology and project are needed to reach net-zero

Transport is responsible for nearly 30% of Europe's carbon emissions, or about 1.1 $GtCO_2e$ in 2018. Individual road transportation accounts for half of this. Meanwhile, the EU's emissions target for 2030 is about 100 $MtCO_2e$ below that, and emissions from this sector must drop to 340 $MtCO_2e$/year by 2050[54].

The stakes for developing technologies able to massively cut emissions from this sector are high. Among the range of technical possibilities, Li-ion batteries are gradually taking the lion's share of the new "clean" vehicles market, and demand is expected to soar.

In the EU Commission's scenarios to net-zero by 2050, about 80% of the passenger car fleet is electric. Batteries will thus be a key enabler for clean mobility and an important tool to increase renewable energy integration. While the battery accounts for 40% of the cost of an EV, only 3% of manufacturing capacity is currently based in Europe[55], while more than 75% of it is located in Asia.

The challenge is both environmental and industrial: Not only do batteries produced in Asia have a significant CO_2 footprint due to the high carbon content of the power sector, but if Europe fails in riding this new wave of industrialization, its automotive sector will strongly suffer from the shift to electric mobility.

The urgency is to create a competitive manufacturing value chain in Europe, centered around sustainable battery cells production. About 12 Li-ion battery gigafactories have been announced for construction in Europe by 2030, among which half are planned by foreign players, for a total production capacity of ~283 GWh.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€33.2 billion total market** €26.8 billion cumulated investment by 2030, €2.7 billion yearly average (2020-2030) €30.5 billion turnover in 2030	**€106.6 billion total market** €114.2 billion cumulated investment by 2050, €5.7 billion yearly average (2030-2050) €106.6 billion turnover in 2050
JOBS	**223,000 total jobs** 40,000 construction jobs for investment 183,000 production jobs for turnover	**691,000 total jobs** 86,000 construction jobs for investment 605,000 production jobs for turnover

#45 [52]https://www.eea.europa.eu/data-and-maps/daviz/CO₂-emission-intensity-5#tab-googlechartid_chart_11 and https://www.electricitymap.org/map
[53]https://www.acea.be/statistics/tag/category/european-production-plants-map
[54]https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12
[55]https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0176&from=EN#footnote8

CREATE A 100% CIRCULAR BATTERY ECONOMY IN EUROPE

Establish an extensive network of battery collection and recycling facilities to lower the GHG footprint of batteries and re-use precious resources

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe

IN A NUTSHELL...

- **Issue:** Recycling EV batteries will reduce the environmental impact of the production of new batteries
- **Solution:** Create large scale battery recycling facilities across Europe to ensure reuse of these components and limit environmental impacts
- **Key impacts:** 11.3 $MtCO_2e$, €13.9 billion total market, 87,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in the EU passenger car fleet in 2050), the project aims to create an additional annual recycling capacity of 3.6 million tons of car batteries in major European regions by 2030 (compared to a current capacity of ~46,000 tons[56]). The project aims to do so by building 360 recycling factories with a 10,000-ton capacity each. The topic can later be extended towards a 2050 horizon, with the aim of 18.5 million tons of EV batteries recycling capability.

- Identify strategic locations across Europe, in countries with the lowest power sector carbon intensity and close to passenger car assembly lines (Northern France, Eastern Austria, Northern Slovakia, Northern Spain, Northern Europe).
- Deploy EV battery recycling factories per location of 10,000 tons annual recycling capacity.
- Key stakeholders include battery collection and recycling specialists such as G&P Batteries, battery manufacturers (such as Northvolt or Wamtechnik), aluminum companies (such as Norsk Hydro) and international organizations promoting battery recycling (such as ICM AG).

Projects that inspired this analysis: Frederikstad recycling factory project in Norway by Northvolt and Norsk Hydro and SungEel MCC Americas battery recycling facility project in New York.

Why this technology and project are needed to reach net-zero

Lacking large supplies of rare-earth metals and lithium supply sourcing, and having limited local production of batteries, Europe can mitigate these strategic weaknesses by becoming a leader in recycling and repurposing technology. Recycling EV batteries decreases the need for extraction of valuable raw materials (lithium, cobalt, manganese, nickel), reducing the cost and the environmental impact of their extraction for the manufacturing of future batteries and avoiding the pollution of landfill.

Currently, Europe only has a 46,000 tons EV battery recycling capacity. This is distributed between France with (21,000 tons), Finland, Norway, Denmark, and Belgium with a cumulated capacity of 25,000 tons.

Existing projects help drive the commercial supply: for instance, battery maker Northvolt, and Norwegian aluminum and renewable energy company Norsk Hydro, are planning to create a new recycling facility in Norway by 2021, to process and recycle 8,000 tons of batteries yearly.

Nevertheless, additional demand-side policies and technology measures are also required to sustain the market development. These can include requirements or additional taxes levied on high carbon emitting vehicles. Furthermore, imposing standardized battery design to enable simpler and/or automated disassembly can improve the cost competitiveness of batteries.

Impacts

	2030	2050
CLIMATE IMPACT	**11.3 $MtCO_2e$ avoided**	**57.7 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€13.9 billion total market** €4.2 billion cumulated investment by 2030, €0.4 billion yearly average (2020-2030) €13.5 billion turnover in 2030	**€49.2 billion total market** €17.9 billion cumulated investment by 2050, €0.6 billion yearly average (2020-2050) €48.6 billion turnover in 2050
JOBS	**87,000 total jobs** 6,000 construction jobs for investment 81,000 production jobs for turnover	**300,000 total jobs** 9,000 construction jobs for investment 291,000 production jobs for turnover

#46 [56]https://www.transportenvironment.org/sites/te/files/publications/2019_06_Element_Energy_Batteries_on_wheels_Public_report.pdf

#47

STIMULATE THE DEVELOPMENT OF NEXT-GENERATION BATTERY TECHNOLOGY FOR MOBILITY USE

Lever European R&D to invent disruptive alternative battery technologies to Li-ion and invest in gigafactories to manufacture these new solutions

TRANSPORT

Cheaper, cleaner and more efficient batteries made in Europe

IN A NUTSHELL...

- **Issue:** Battery research is fragmented. As many different potential technologies are studied simultaneously, there is no clear commercially viable alternative to Li-ion
- **Solution:** Establish a cross-EU research and implementation initiative, incentivizing both breakthrough battery research and manufacturing at scale
- **Key impacts:** €16.4 billion total market, 110,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Project type 1: Research and development on next generation battery technology

The project's goal is to create three centers to stimulate R&D activities on next-generation EV batteries across the EU by 2025, while at the same time building the standards, regulations, and commercial instruments to accelerate the deployment of successful technologies with a clear path to commercial viability.

The project takes inspiration from the EU-wide research and innovation project in all segments of the battery value chain (including the development of environmentally sustainable alternative technologies), backed by a €3.2 million public investment approved in December 2019 by the European Commission[57].

- Accelerate R&D on next-generation battery technologies and find the most adequate business model for large-scale deployment, by creating research centers in three European countries.
- Each center can be dedicated to a different battery technology. Technologies that enable upstream value chains entirely within the EU (e.g. reducing Cobalt/Lithium consumption), as well as technologies with specific advantages for non-automotive use cases (such as large-scale low-cost seasonal electricity storage) must be prioritized.
- Main stakeholders include public authorities, battery research laboratories, institutes of technology, electric vehicle companies, Europe-based OEMs.

Projects that inspired this analysis: IPCEI on batteries in Europe, ARPA-E's projects on battery in the US.

Project type 2: Develop and scale next-generation battery production

Once the research centers created under Project type 1 have demonstrated the feasibility of next-gen battery technologies and have identified a clear path towards large-scale implementation, project type 2 will aim at accelerating the development of production facilities.

In line with the projections made for Project #42 (40 million EV in 2030, 80% of EV in passenger car fleet in 2050), the project aims to cover one-third of EU's EV battery demand through European supply by 2030 (including production capacities already planned on the EU territory by Asian players such as SK Innovation, CATL, and others) with the lowest environmental impact possible. The remaining two-thirds of the EV fleet will be powered with lithium-ion batteries (see Project #45).

About 150 GWh next-generation battery production capacity will be needed by 2030, i.e. 38 gigafactories of 4 GWh capacity each.

- Identify strategic locations in Europe (ideally the locations of the Project type 1) and build a total of 38 4-GWh production capacity factories.
- To ensure low CO_2 impact from production, the three factories will be set up in countries with the lowest power sector carbon intensity (max ~200gCO_2eq/kWh[58]) and close to passenger car assembly lines[59]: this includes Northern France, Eastern Austria, Northern Slovakia, Northern Spain.
- Main stakeholders include public authorities, battery research laboratories, institutes of technology, electric vehicle companies, Europe-based OEMs.

Projects that inspired this analysis: Northvolt's gigafactory in Sweden.

Why this technology and project are needed to reach net-zero

Lithium-ion, the only commercially viable EV battery solution today, is not without drawbacks. Lithium resources are unevenly distributed across the world and extracted through a polluting process. The technology also requires cobalt, which again is a precious resource, mainly mined from the Democratic Republic of Congo, creating significant CO_2 emissions. Additionally, lithium is limited in terms of performance, as some applications (other than for EV batteries) are too expensive. For large-scale, long-term energy storage, such as seasonal grid storage, alternative solutions are needed.

Numerous next-generation technologies are studied simultaneously across the world to develop alternatives to lithium-ion batteries. Some technologies aim primarily at outperforming Li-ion tech (longer life cycles, higher energy density, etc.): solid state batteries for instance introduce a solid compound instead of a liquid electrolyte to improve safety. Other technologies aim at reducing the environmental impact of battery production. Lithium-sulfur batteries (Li-S) rely on sulfur, a much more accessible resource with smaller environmental impact than lithium; however the cycle life of this battery remains inferior to li-ion as of now. Likewise, sodium batteries (Na-ion) would use sodium (an extremely abundant material, extractable from seawater) instead of lithium, while also withstanding more charge cycles than Li-ion batteries.

Impacts

	2030	2050
CLIMATE IMPACT	*Counted in vehicles in circulation.*	*Counted in vehicles in circulation.*
ECONOMIC IMPACT	**€16.4 billion total market** €13.2 billion cumulated investment by 2030, €1.3 billion yearly average (2020-2030) €15 billion turnover in 2030	**€53.4 billion total market** €63.2 billion cumulated investment by 2050, €3.2 billion yearly average (2030-2050) €50.2 billion turnover in 2050
JOBS	**110,000 total jobs** 20,000 construction jobs for investment 90,000 production jobs for turnover	**349,000 total jobs** 47,000 construction jobs for investment 301,000 production jobs for turnover

#47 *[57]https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705*
[58]https://www.eea.europa.eu/data-and-maps/daviz/CO2-emission-intensity-5#tab-googlechartid_chart_11 and https://www.electricitymap.org/map
[59]https://www.acea.be/statistics/tag/category/european-production-plants-map

BUILD NEW URBAN MULTIMODAL TRANSPORT SYSTEMS FOR EASY DOOR-TO-DOOR JOURNEY PLANNING, EXPERIENCE AND PAYMENT

Public-private platforms leveraging AI, data and end-to-end payment business models, and reinforcement of physical mobility equipment and infrastructure

TRANSPORT

New forms of urban mobility

IN A NUTSHELL...

- **Issue:** Cars in urban areas represent 40% of road transport CO_2 emissions, and contribute to air and noise pollution. Public, shared and free-floating transport needs to be competitive against private car ownership in terms of door-to-door flexibility, reliability and convenience
- **Solution:** Establish streamlined mobility platforms offering multiple modes of shared transportation in European groups of cities
- **Key impacts:** 9.7 $MtCO_2e$, €12.4 billion total market, 187,000 jobs in 2030

Innovation bet

Acceleration and scale-up

Drive to market scale

Project opportunity and ambition

Contribute to define and illustrate the model of a city where all inhabitants can travel easily, efficiently, and conveniently from door to door, whether they live downtown or in the suburbs.

Public authorities and private operators must build the business model for open data (required data, who pays and how, and the payment flows). Payments need to be a part of the scope. To give up car usage, trips with any conventional and new free-floating decarbonized vehicles must be easy to use, plan and pay.

The project takes the form of a publicly-led public-private partnership. The urban areas covered by the project will share experiences to learn at each stage of their roll-out.

- Select groups of one-million-inhabitant urban areas (city including surrounding urban periphery) in Western, Eastern, and Southern Europe and Nordic countries.
- Gather public and private players specialized in shared transportation, AI, navigation and public transportation.
- Achieve a 50% reduction in use of individual cars, with special attention to peri-urban areas.
- Scale up green shared vehicles (electric cars, electric mopeds, electric kick-scooters, electric bicycles, other shared mobility), including peri-urban, to facilitate public transport access.
- Scale up the existing public transport networks to accommodate an increased number of users, following the 50% shift from private vehicles.
- Build the data, economic and payment frame enabling an inter-related ecosystem of public and private mobility services platforms: smoothen the flow of data and payments, establish clear data business model for operators and citizens.
- Regulatory sandbox: free innovation during the pilot phase in selected cities. In 2025, based on learnings, adapt European and national laws to enable seamless door-to-door mobility.
- Key stakeholders include public authorities (adapting the regulations to accommodate multimodal mobility platforms), urban mobility authorities, public transport operators (metro, buses, tramway, train), digital platform operators, navigation service providers (such as Vulog, Moovel, Google Maps or Free2Move), new mobility services (such as new European operators, Uber, Lyft, Google, Lime, Bird, etc.), future operators of autonomous vehicles and operators of charging infrastructures.

Projects that inspired this analysis: Vulog-powered multiple-city and multimodal shared mobility platforms Aimo in Stockholm and Poppy in Brussels and Antwerp.

Why this technology and project are needed to reach net-zero

Cities account for over 70% of CO_2 emissions in the world[60] and urban traffic contributes to 40% of all CO_2 emissions linked to road transportation in Europe[61]. Implementing more sustainable and fluent mobility solutions in European urban areas is crucial to reach a net-zero economy.

To reduce CO_2 emissions of passenger cars used for multi-city travel, public transportation needs to offer price competitiveness, flexibility and reliability, not only in densely populated cities but also in the nearby urban periphery. Aggregating on-demand and green mobility services on a single, streamlined application is one solution to reduce the dependence on passenger cars.

This end-to-end solution can guide users across the different urban transport options, identifying in real-time most optimal modes by comparing prices and timeframes. The project requires coordination of public and private operators to manage customer data collection and analysis. The application must be a one-stop payment platform, receiving and managing payments for all types of daily transportation.

In addition to public transport (including metro, buses, tramway, and trains), introducing on-demand light green vehicles, such as electric mopeds or kick-scooters, can also improve flexibility of shared transportation. Users would be able to use several transport options, each adapted to different lengths of journey (from a last-mile ride to a daily commute) over a single day.

Such multiple-city, multimodal and zero-emission mobility platforms have been successfully deployed in Northern Europe over the past years, through projects such as Whim (offering public transport as well as bikes, cars or e-scooters) and Aimo in Stockholm, or Poppy in Antwerp and Brussels.

Impacts

	2030	2050
CLIMATE IMPACT	**9.7 $MtCO_2e$ avoided**	**19.5 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€124.3 billion cumulated investment by 2030** €12.4 billion yearly average (2020-2030)	**€336.4 billion cumulated investment by 2050** €16.8 billion yearly average (2030-2050)
JOBS	**187,000 total jobs**	**252,000 total jobs**

[60]https://www.c40.org/why_cities#:~:text=Cities%20consume%20over%20two%2Dthirds,levels%20and%20powerful%20coastal%20storms.
[61]https://ec.europa.eu/transport/themes/urban/urban_mobility_en

LEVER SHARED AUTONOMOUS VEHICLES TO REDUCE THE NUMBER OF CARS IN AN INCREASING NUMBER OF EUROPEAN CITIES BY 30%

Large scale deployment of automated vehicles in shared fleets and public transport

TRANSPORT | New forms of urban mobility

IN A NUTSHELL...

- **Issue:** Promote the use of shared autonomous mobility in medium and large cities
- **Solution:** Launch pilot projects of shared autonomous vehicles (taxis or minibuses) across ten one-million-inhabitant European cities
- **Key impacts:** 0.6 $MtCO_2e$, €18.7 billion cumulated investment, 28,000 jobs in 2030

Innovation bet | Acceleration and scale-up | Drive to market scale

Project opportunity and ambition

The goal of the project is to launch several fleets of shared autonomous vehicles (either taxis or minibuses) in 10 large-size European cities by 2030. In addition to enriching the existing public transport systems and optimizing traffic, these fleets will contribute to a reduction of individual car use in urban environments, limiting CO_2 emissions.

- Select ten voluntary European cities with one million inhabitants, total ~10 million inhabitants.
- Deploy pilot projects of shared autonomous vehicles in real-life traffic conditions, aiming at a reduction of individual car use by 30% in 2030 (fleets of 18,900 vehicles, either taxi-sized or minibuses).
- Ensure the redesign of the urban scene necessary to reach the adequate safety standards for autonomous vehicles (local regulation, high-fidelity 3D mapping, optimized infrastructures and traffic rules).
- Key stakeholders include public transportation authorities, national ministries of transport, original equipment manufacturers (such as MAN, Daimler, Volvo).

Projects that inspired this analysis: FABULOS (Future Automated Bus Urban Level Operation Systems) conducting pilot projects in five European cities, Ruter AS project in Oslo, AVENUE autonomous bus testing in four European cities.

Why this technology and project are needed to reach net-zero

Cities are responsible for over 70% of CO_2 emissions in the world[62] and urban traffic stands for 40% of all CO_2 emissions linked to road transportation in Europe[63]. Implementing more sustainable and fluent mobility solutions in European urban areas is therefore crucial to reaching a net-zero emissions economy.

Shifting urban mobility towards public transport and decarbonizing available public transport are key levers to reduce urban emissions. Accelerating the adoption of zero-emission autonomously driving public vehicles is one such solution: they can replace CO_2 emitting passenger cars and increase the attractiveness of an enriched public transport system. This can decrease urban passenger car ownership, thus improving air quality.

The European Union has already communicated its interest in zero-emissions shared autonomous vehicles. In 2019, then EU Commissioner for Transport Violeta Bulc announced expectations of fully autonomous vehicle capability (level 5) by 2030. Additionally, three international consortia were selected by the EU funded project FABULOS in February 2020, to manage the implementation of autonomous buses in five European cities (Gjesdal, Helmond, Helsinki, Lamia and Tallinn)[64]. These pilot projects, already in place in Helsinki, will demonstrate the feasibility (ability to be monitored from a control center, adaptability to difficult terrain and obstacles) and the value of this technology.

Impacts

	2030	2050
CLIMATE IMPACT	**0.6 $MtCO_2e$ avoided**	**4.0 $MtCO_2e$ avoided**
ECONOMIC IMPACT	**€18.7 billion cumulated investment by 2030** €1.9 billion yearly average (2020-2030)	**€217.3 billion cumulated investment by 2050** €10.9 billion yearly average (2030-2050)
JOBS	**28,000 total jobs**	**163,000 total jobs**

#49 *[62]https://www.c40.org/why_cities#:~:text=Cities%20consume%20over%20two%2Dthirds,levels%20and%20powerful%20coastal%20 storms.*
[63]https://ec.europa.eu/transport/themes/urban/urban_mobility_en
[64]https://fabulos.eu/three-consortia-will-pilot-self-driving-shuttles-as-part-of-regular-traffic-in-five-european-cities/