Implications of the energy transition for the European storage, fuel supply and distribution infrastructure

Report

Trinomics

Contract details

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CONTENTS

List of acronyms

AFID	Alternative Fuels Infrastructure Directive
BoP	Balance of Plant
CEPS	Central European Pipeline System
CFPP	Cold Filter Plugging Point
CNG	Compressed Natural Gas
DME	Dimethyl Ether
DMFC	Direct Methanol Fuel Cell
EE	Energy Efficiency
ETBE	Ethyl Tertiary Butyl Ether
FAME	Fatty Acid Methyl Ester
GHG	Green House Gases
HEFA	Hydroprocessed Esters and Fatty Acids
HFO	Heavy Fuel Oil
HVO	Hydrotreated Vegetable Oils
ICE	Internal Combustion Engine
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
LTS	Long Term Strategy
MTBE	Methyl Tert-Butyl Ether
P2X	Power-to-X
PtG	Power-to-Gas
PtL	Power-to-Liquid
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non Biological Origin
SAF	Sustainable Aviation Fuels

Executive Summary

Context & purpose of the study

In December 2019, the Commission presented the **European Green Deal**, a commitment to tackling climate and environmental-related challenges. Achieving climate neutrality by 2050 is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement.

The Commission set its vision for a climate-neutral EU in November 2018, looking at all the key sectors and exploring pathways for transition, with its European **strategic long-term** vision for a prosperous, modern, competitive and climate neutral economy.[1] This vision indicates the reduction in the share of fossil liquids (excluding non-energy use) in the total final energy consumption, from a 30% share in 2015 to 25% in 2030 to12% Energy Efficiency (EE) and 8% Power-to-X (P2X) in 2050. This vision is currently being strengthened as the Commission develops the package 'Fit-for-55', which is due in summer 2021 and which will accelerate the transition.

The purpose of the study is to explore the implications of replacing conventional fossil fuels with low carbon alternatives on the bulk fuel storage sector and the entire supply chain infrastructure, which aim to secure security of supply of conventional and alternatives fuels. The scope of conventional fossil fuels includes:

- Liquid fuels: diesel, gasoline, kerosene, marine fuels, gas oil;
- Gaseous fuels: Liquid Petroleum Gas (LPG), natural gas (covering only for the use as transport fuel).

Many of these fuels have various end-uses and also alternative-fuel substitutes. However, for the purpose of exploring fuel infrastructure adaptations, the short list of renewable alternatives was defined to include the widest possible range of applications, and covers: biodiesel (Fatty Acid Methyl Ester (FAME) & Hydrotreated Vegetable Oils (HVO)); bioethanol; compressed/liquid hydrogen; e-fuels like methanol; e-kerosene; e-gasoline; e-diesel; bio-LPG.

From this list of alternative fuels, some represent essentially the same chemical substance as the incumbent fossil fuels, while others have completely different characteristics, with potential implications on several elements of the supply chain.

Implications of energy transition on supply chain components

Identification of the main trends

Decarbonising the transport sector is a challenging task. The biggest decrease in Green House Gas (GHG) emissions is expected in passenger cars due to significant electrification of the fleet. The emission from heavy goods vehicles and especially aviation is expected to decrease to a lower extent. Consequently, the emissions from these transport modes will gain in importance, as their relative share on the total emissions will increase substantially.

[1] A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy: https://ec.europa.eu/clima/policies/strategies/2050_en

To reach the decarbonisation goals of the sector by 2050, important changes in mobility patterns are necessary to achieve the planned emission levels, and will rely on:

- **Lowering the overall energy demand** in transport, assuming energy efficiency is an imperative that should be applied in all sectors;
- **Changes in mobility patterns and modal shifts**, as long-term trends in lifestyle choices have a high impact on mobility and therefore also on transport modes used;
- In addition to decreasing energy demand, **deployment of alternative fuels** with low carbon footprint is the second part of the decarbonisation efforts in the transport sector. It is apparent that the most important trajectory is direct electrification of vehicles, especially passenger cars. The Long Term Strategy (LTS) scenarios see 20% share of all alternative fuels (e-liquid, liquid biofuel, natural gas, biogas, e-gas, hydrogen and electricity) in transport (road, maritime, inland shipping, aviation, and rail) in 2030, and this share is projected to increase to over 80% in most scenarios.

Several transport fuel products are already being substituted and this trend will continue with the increased deployment of alternative fuels. Whatever the volume for each of these products, the diversity of fuels is likely to drastically increase, making the different supply chains and related security of supplies more complex.

In the building sector, the reduction of energy consumption through increased insulation and more efficient equipment is already under way in Europe. Renewable energy for heat generation is also deploying progressively, while low carbon energy vectors for heating & cooling (electricity, but also new vectors like hydrogen, e-gases and liquids, or other renewable liquids) are more recent options. Today, the most common technologies using renewable sources to deliver heating and cooling services in buildings are solar thermal, geothermal, biomass boilers and ambient energy.

To further decarbonise the industry, energy efficiency and electrification of industrial heat and steam production are seemingly the most technologically mature options. Electrification of industrial heat (that relies on decarbonised electricity) is a promising solution. There is significant potential to electrify low temperature industrial heat with heat pumps (up to approximately 100°C). Other fuel switching options do exist, but at various levels of technological readiness; these would mainly be switching from fossil fuels to mostly biomass, but also to hydrogen and e-fuels.

Main implications for conventional fuels supply chains in Europe in the context of the energy transition

Regardless of how the energy-mix in a clean-energy future will look like, it will have to ensure energy security, providing an uninterrupted supply of energy to consumers. Both clean energy transition & security of energy supply should go hand in hand, requiring the fuel supply chains to be resilient, and to deliver conventional and alternative fuels to all final consumers.

The focus of this study is on the specific implications that the energy transition poses for these alternative (low-carbon) and the conventional fuel supply chains in the European geographic area as well as the specific supply chain vulnerabilities that might increase in significance in the context of the transition process.

Based on the description of the major future trends in the previous sections, the **main global implications** for the European fossil fuel supply chains are:

1. Lower demand for conventional liquid and gaseous fuels, leading to major changes in the supply chain logistic;
2. Decentralisation or re-localisation of alternative fuel production, resulting in the need to reconfigure the existing supply chains to connect them with the new production facilities;
3. Limited supply of sustainable biomass, leading to competition between different end-uses (energy or material) and meaning that no alternative fuel solution can cover all the demand;
4. It is not possible to predict the deployment of alternative fuels with high level of certainty.

These lead to the following **supply chain weaknesses**:

1. Some parts of conventional fossil fuel infrastructure are not suitable for handling alternative fuel substitutes, and it will be necessary to invest in adaptation of existing infrastructure or in building new infrastructure;
2. Since the overall demand for liquid fuels will decline, and the remaining demand will be dispersed among several different energy carriers requiring separate supply infrastructure (over the same geographic area), the unit cost of investment and maintenance will probably be impacted, resulting in more costly investment in infrastructure adaptation;
3. While demand for gases might remain at current levels, the dispersion of demand between natural gas and hydrogen will lead to a similar effect;
4. At the same time, this will also be a weakness of the conventional fuels infrastructure, since it will have to keep the same geographical coverage with a higher amount of liquids given the increasing amount of emerging low carbon fuels, while the utilisation rate will decline, and therefore additional infrastructure (storage and transport) may be required;
5. Fuel infrastructure has a long economic lifetime in comparison to the time horizon in which it is possible to make robust estimates of future technology and demand development; investments are therefore at risk of becoming stranded assets.

Part of the existing **storage infrastructure** (such as tanks and caverns) can be reused, converted or adapted to integrate some of the new liquid fuels, such as biofuels, e-liquids and synthetic fuels. Blending some of these fuels with fossil fuels will not require large investments. For other fuels, new additional investments for storage and distribution will be required, such as for the use of Sustainable Aviation Fuels (SAF), Liquid Natural Gas (LNG) (from fossil gas or from biomethane) and liquid hydrogen-based carriers. Compressed hydrogen (e.g. 350 bar for buses and trucks, and 700 bar for cars) could be handled in the frame of renewable gas infrastructure and repurposed natural gas infrastructure. In addition, increased safety concerns will also have an impact on the cost of the new or repurposed infrastructure.

For energy carriers such as hydrogen or LNG the type of infrastructure currently in use for storage would require investment in new facilities, due to temperature and pressure differences, resulting in high investments in new infrastructure and appropriate safety mechanisms.

From the **security of supply** point of view, the biggest challenge is to prepare the emergency stocks infrastructure for the predicted trends of fuel diversification and declining oil use. The existing oil storage facilities will therefore have to evolve or be replaced by alternative facilities.

As a consequence, a decrease in consumption and diversification of fuels can contribute to the concentration of stock facilities into larger facilities due to decreased profitability. Concentration could possibly increase the distance from end-use locations, compromising the “spread” on the territory and delivery capability, which is a public concern.

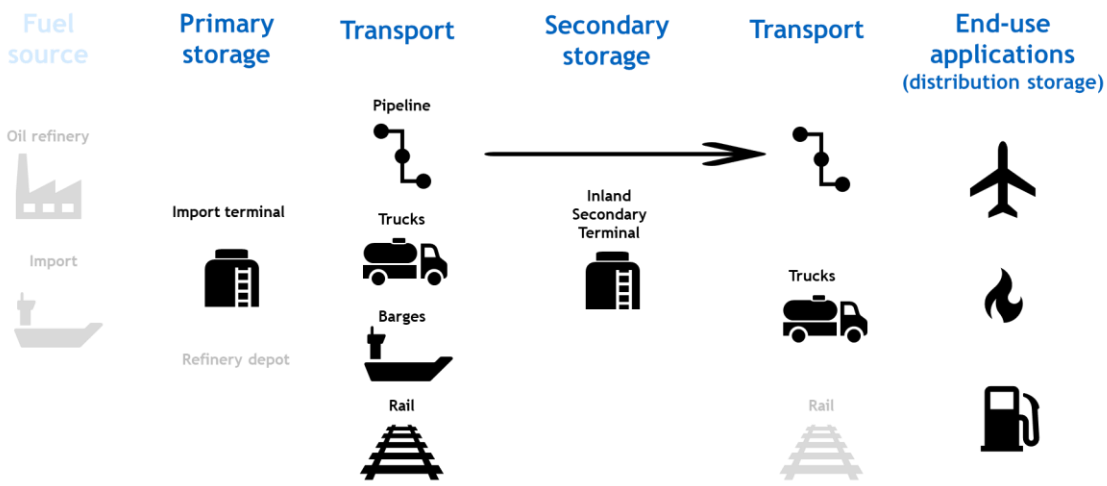
Therefore, a number of existing storage locations could disappear as owners will not be prepared to invest in new infrastructure. As a result, only hubs at strategically important locations may remain which may have a negative impact on the overall network and jeopardise product availability and accessibility, which could also impact the security of supply.

Assessment of fuel supply chains

The implications of the energy transition and the changes from fossil-based to alternative fuels consumption on the infrastructure must be assessed. The study analyses different case studies of infrastructure adaptation to alternative fuels supplies. Each case study focused on one specific alternative fuel conversion and on the components along all stages of the downstream supply chain. In order to examine the possible pathways in a practical way, model case studies that focused on a narrow supply chain pathway were selected. The selection of cases was done with attention to their complementarity, so that all the most important supply chain elements (e.g. different transport modes) are represented at least for some fuels.

The study covers fuel infrastructure to re-purpose as well as new infrastructure. The relevant stages of the supply chains are depicted in figure 0-1.

Figure 0-1 Representation of supply chain elements



Each case pre-defines the fuel which is being produced in a specific industry, addresses all stages up to the final consumer, as transport and distribution mode will depend mainly on the end-use sector (industry, small enterprises, building, transport – passenger or goods), and analyses the following components:

- Adaptation, extension, retrofit or dismantling of tanks, depots and terminals (incl. handling material);

- Changes or replacement of road material (trucks), of shipping equipment (barges & vessels), rail equipment (wagons);
- Changes or replacement of retail stations;
- Changes in daily operation (with a focus on safety procedures and handling techniques) of the storage facilities, the transportation hubs, the distribution equipment (retail stations).

These case studies are generic and are not country specific, meaning that national particularities could lead to nuance some conclusions, due to the influence of a particular geographical distribution of a supply chain, to the use of equipment differing from country to country, or to the weather conditions (e.g. influence of cold or warm weather on liquid viscosity). It is therefore recommended to consider the national aspects, to translate particular conclusions from the study.

Summary of the supply chain adaptations

Globally, three types of changes will be required to ensure continuity of supply of low-carbon and renewable fuels, based on 2 main parameters which are the characteristics and the location of supply production (when it occurs on European territory):

- Limited changes, and even no changes at all for some products which would be produced and distributed along the same logistic chain (e.g. HVO replacing diesel; liquefied biomethane; e-gasoline; e-diesel; bioLPG);
- Important changes due to modification of product characteristics, which would be produced and distributed along the same logistics chain (e.g. FAME replacing biodiesel; bioethanol replacing gasoline, hydrogen; methanol; SAF);
- Complete change of the existing supply chain assets, given the production does not happen at the same place and the existing equipment is not suitable for handling the substitute alternative fuel. However, no such case was identified.

Table 0-1 Supply chains summary

		Geographic/spatial reconfiguration of supply chain	Primary storage	Fuel transport	Secondary storage	Fuel transport	Fuel distribution
1	FAME biodiesel 100%	No	Import terminal	Rail	Inland terminal	Tank trucks	Fuel station - heavy duty trucks
2	FAME biodiesel 100%	Yes	Import terminal	Tank trucks	Inland terminal	Tank trucks	Fuel station - passenger cars; heavy duty trucks
2.a	FAME biodiesel (<100%)	(*)					
3	HVO biodiesel	No	Import terminal	Barge (inland)	bunkered stock / distributor depot	Tank trucks	Domestic heating fuel (domestic tanks)
4	Bioethanol	Yes	(from bioethanol plant)	Tank trucks	Inland terminal	Tank trucks	Fuel station - passenger cars
5	Hydrogen	No	Import terminal	Pipeline	NA	NA	Fuel station - trucks
6	Methanol		Import terminal (from large H2 prod)	Pipeline	Port fuel depot	NA	Bunkering tankers - ships
7	SAF	Partial	Import terminal	Pipeline	Airport storage	NA	Filling planes - aviation turbines
8	liquefied biomethane	No	Import terminal			Tank trucks	Fuel station - heavy duty trucks
9	e-gasoline	No	(small standalone prod facility)	Pipeline	Depot	Tank trucks	Fuel station - passenger cars
10	e-diesel	No	(small standalone prod facility)	Tank trucks	Depot	Tank trucks	Fuel station - trucks
11	bioLPG	Yes	(from refinery)	Tank trucks	LPG cylinder filling plant	Tank trucks	household heating (cylinder tanks)

(*) FAME biodiesel blends are largely used and require limited changes to the existing infrastructure, and were therefore not addressed in the frame of this study.

Legend

(orange)	Important changes required
(yellow)	Limited changes required
(green)	No changes required
(white)	Not included

Conclusions & takeaways

Main conclusions

- The oil infrastructure is globally more widely spread and distributed than other infrastructure, therefore offering a high level of flexibility and adaptability to supply alternative and conventional fuels. Flexible and adaptable infrastructure can contribute to the clean energy transition by allowing to deliver an increasing number of alternative low carbon fuels while ensuring their security of supply;
- Depending on the product, most parts of the existing fossil fuel infrastructure can also be used for alternative fuel supplies, without any changes or with minimal modifications, notably for e-fuels, which have the same characteristics as the fossil-derived fuels they would replace;
- Even when the components that directly handle the fuels are not suitable for the alternative use, the surrounding facilities can be used to minimise the necessary investment (e.g. using the existing fuel stations, import terminals), depending on the fuels to be replaced and its alternative low carbon fuel and applications;
- Since there is currently only limited supply of sustainable biofuels, it is necessary to find specialised applications, where biofuels offer the most viable decarbonisation option;
- The indigenous production of alternative fuels may become decentralised and more geographically dispersed, moving for example closer to biological feedstock places of origin or to remote large renewable electricity plants coupled with hydrogen production. The spatial distribution of existing fuel supply chains will have to be adjusted and new local infrastructure added;
- In some cases, the alternative fuels are not a direct substitute that can be used by the same end-users without any adaptations – for example bioethanol substituting gasoline (in high-percentage blends) or hydrogen substituting natural gas.

Main challenges & opportunities

Opportunities

- Large parts of the conventional fossil fuel infrastructure can already be used for alternative fuel transport, storage and distribution;
- The existence of the oil infrastructure is more widely spread and less dense, therefore it should provide important and actual opportunities for the transition given its flexibility to adapt to fast and important changes in the supply of alternative fuels, from decentralised production, to smaller storage, or an increasing number of products to be delivered.

Challenges

- Due to substantial electrification, especially of the transport sector, the increase of energy efficiency (in all sectors), and the shift to emerging low-carbon and renewable fuels, the demand for fossil-based fuels will decrease in the future and the associated fuel infrastructure will have to be re-purposed accordingly and may be oversized as the demand decreases, leading to some stranded assets;
- The production of alternative fuels will be decentralised and more geographically dispersed. The spatial distribution of existing fuel supply chains will have to be adjusted;
- Disruptions along the supply chains may occur, given the above-mentioned threats, with consequences in supplying to end-consumers;
- It is necessary to ensure that vulnerable consumers that do not have the resources for fuel switch are not left behind by supply chain changes;

- Most of the emerging fuels, except biofuels (bioethanol & biodiesel) which have been blended for several years, are still at an early stage of development and there is limited experience with their handling and use. Therefore, further research may be required regarding their characteristics and impacts on equipment;
- The diversification of fuels will have implications all along the supply chain, including at fuel stations which will become multi-fuel due to a wider range of products used by drivers. Adaptations will be required.

Main takeaways

To address the above-mentioned challenges, policymakers (national and European) should address the following main areas:

- Building a clear pathway and trajectory for renewable and low carbon fuels up to 2050, and assessing the needed infrastructure to supply these fuels and the conventional fuels in a transitory period;
- Involve the oil infrastructure and supply chain sector in the design of the pathway to carbon neutrality, for the adequate consideration of the adaptation of their assets;
- Increasing awareness of the challenges faced by existing infrastructure (storage, transport, distribution) and new infrastructure to deploy, but also the potential opportunities of the emergence of these alternative fuels;
- Raising awareness of the fact that some existing infrastructures belong to regulated markets (all gas infrastructure, e.g. large storage in salt caverns), while others belong to non-regulated markets (which is the case for liquids), which could lead to discrepancies in fast moving markets. Large investments may be required for the transition. The lack of a level playing field with existing fossil-based carriers could jeopardise or postpone investments;
- Assessing the risks of disruption and stranded assets due to major changes;
- Taking the appropriate measures to secure supply and provide a stable framework;
- In the framework of the Oil Stocks Directive and the IEA stockholding regime, anticipating the evolution of fossil-based liquids consumption & emergency storage needs and adapt national and European regulatory frameworks accordingly to a lower/decarbonised energy system;
- Ensuring a level playing field for all types of energies and energy carriers, providing they comply with decarbonisation goals and pathways;
- Supporting industrial operators and investors to adapt existing assets;
- Removing existing alternative fuel deployment barriers such as blending walls in the Fuel Quality Directive;
- Mandating Standardisation bodies to develop missing standards;
- Supporting RD&I efforts to further explore the technical impacts of emerging fuels.

Although some of these policies can be better addressed at the national level, it is also important to set up a unified regulatory approach at the European level.

Unlike natural gas and electricity, there is no comprehensive **European framework** that would cover the entire oil supply chain (as defined in the project). The following regulatory frameworks partially address the supply of oil:

- The Directive on the deployment of Alternative Fuels Infrastructure (AFID[2]) covers CNG and LNG, hydrogen and electricity; moreover, it mostly concerns the fuelling/charging infrastructure and, indirectly, storage infrastructure and fuel transport and distribution;
- The Council Directive imposing an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products[3], regulating emergency storage of liquids;
- The Fuel Quality Directive (FQD[4]), with regards to alternative fuels: reduce GHG intensity of fuels by 6% by 2020; sets a maximum share of 7% of FAME in biodiesel blend;
- The Renewable Energy Directive II (RED II[5]), mandating Member States to oblige fuel suppliers to ensure a share of at least 14% of renewables[6] (with a maximum of 7% for the feed & food crops-based fuels[7]) within the final consumption of energy in the transport sector by 2030.

Other policy frameworks and planning should or could also address the supply of oil:

- All instruments (EU & national) supporting the shift from fossil-based to low carbon and sustainable fuels, such as support schemes, taxation and fiscal incentives, carbon pricing (Emission Trading System or ETS[8], Energy Taxation Directive or ETD[9] and national schemes), quota and mandates, or even ban;
- National Energy & Climate Plans comprise a section on energy security (chapter 3). Storage and transport of oil are only addressed in the frame of securing energy supply in the current framework, without considering the evolution of fuel demand, nor the emergence of new low carbon fuels;
- The Trans-European Transport Network (TEN-T) policy addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports and railroad terminals. The ultimate objective is to close gaps, remove bottlenecks and technical barriers, as well as to strengthen social, economic and territorial cohesion in the EU[10];

Globally, the oil supply chains are more or less included in all planning and measures expected to address security of supply. However, in practice, some elements along the chain are not fully considered.

Europe should build a clear view or pathway for renewable and low carbon fuels by 2050. Europe should include an assessment of the existing oil infrastructure of the transition scenarios which are used to design decarbonisation policies (such as in the Clean Target Plan).

For the next National Energy & Climate Plans (NECP) revision (draft mid-2023, final mid-2024), MSs could:

- More precisely indicate which alternative liquid fuels will be considered for 2030 & 2050;
- Include all infrastructure elements within their impact assessment.

[2] Dir 2014/94/EU available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN

[3] 2009/119 directive, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0119&from=FR

[4] Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (Text with EEA relevance), available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0030&from=EN

[5] Dir 2018/2001, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=fr

[6] Article 25 RED II

[7] Article 26 RED II

[8] https://ec.europa.eu/clima/policies/ets_en

[9] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12227-EU-Green-Deal-Revision-of-the-Energy-Taxation-Directive_en

[10] The current TEN-T policy is based on Regulation (EU) No 1315/2013

In the framework of the Oil Stocks Directive, MSs could anticipate the evolution of their fossil-based liquids consumption & emergency storage needs and adapt their legal framework accordingly. In this framework, close coordination would be required between MSs.
In the frame of the Fuel Quality Directive, the impact of going beyond the current threshold should be assessed. Several studies show that most EU infrastructure (and fleet[11]) could already accommodate the use of B10 and E10.
Some MSs may have to provide support to investments in new storage and transport assets and equipment to investors, infrastructure operators, and other concerned market actors. The Guidelines on State Aid for Environmental Protection and Energy (2014-2020) should be revised accordingly.
Europe could play a role in supporting the research of the technicalities of infrastructure adaptation. RD&I efforts could be dedicated to further explore the impacts of emerging fuels on different equipment, due to different operating conditions and chemical characteristics.

Since the right to determine its own energy mix lies with the Member State (based on TFEU), the EU is not in a position to define what alternative fuels and in which sectors they will be used. It is therefore mainly in the hands of **national governments** to indicate to industry what role the alternative fuels are expected to play for a cost effective transition to a low carbon economy (e.g. which fuels and in which sector). However, the EU/EC can coordinate actions to ensure compatibility with the Internal Market. This will give infrastructure operators a more precise picture of what level of demand can be expected. Based on this, more qualified investment decisions can be made on whether it makes sense to convert existing infrastructure and which assets should be phased out.
The EU regulation includes at least two basic instruments: the NECPs and the national policy frameworks mandated by the AFID. The NECPs should include targets for the use of alternative fuels and the National Policy Framework (NPF under the AFID) should also include a wider assessment of future development of alternative fuel markets (in the transport sector) including other alternative fuels.
In the frame of these instruments, MSs should plan decarbonisation of the liquid fuel applications by consulting the sector, based on impact assessments and considering:

- Geographic coverage of the different fuel uses, and their related infrastructure;
- Loss of value and stranded assets where dismantling is required due to decrease in global consumption;
- New specific threats and risks of disruption;
- Permitting delivery or renewal of existing assets.

Such planning should be transparent and provide visibility to all concerned stakeholders.

Infrastructure owners and operators should also anticipate these global trends, by considering the following measures:

- Prepare business continuity plans based on realistic scenarios of future fuel demand to avoid investing in stranded assets;
- The most cost-effective way is to replace equipment at the end of lifetime; consider using materials and equipment that will be suitable for alternative fuel use;

[11] Cf the List of ACEA member company passenger cars, light commercial vehicles (vans) and heavy-duty vehicles (or heavy-duty engine models) that are compatible with using 'B10' diesel fuel, available at https://www.acea.auto/uploads/publications/ACEA_B10_compatibility.pdf. And the MVaK vehicles lists, available at https://www.mvak.eu/wp-content/uploads/2020/11/mvak_approval_list_b10_v07.pdf
Cf also the "Engine tests with new types of biofuels and development of biofuel standards" funded by Horizon 2020, and carried out by the European Standardization Committee (2019), available at https://www.cen.eu/work/Sectors/Energy/Pages/Biofuels.aspx

- Consider the spatial differences of alternative fuel supply chains to existing fossil fuel chains;
- Support research for equipment to assess compatibility with new fuels (valves, pumps, pipes, hoses, ….);
- Support the development of standards for the use of (neat) alternative fuels or hi-percentage blends;
- Take all required measures to work with national regulators in developing guidance, standards and plans to meet emerging safety requirements for future energy sources;
- Assess the needed skills and knowledge in handling alternative fuels and infrastructure adaptation, in order to adopt the required training strategies;
- Consider creating partnerships along the whole supply chain, from production to end-use, to construct resilient energy supply chains in close collaboration with all concerned parties.

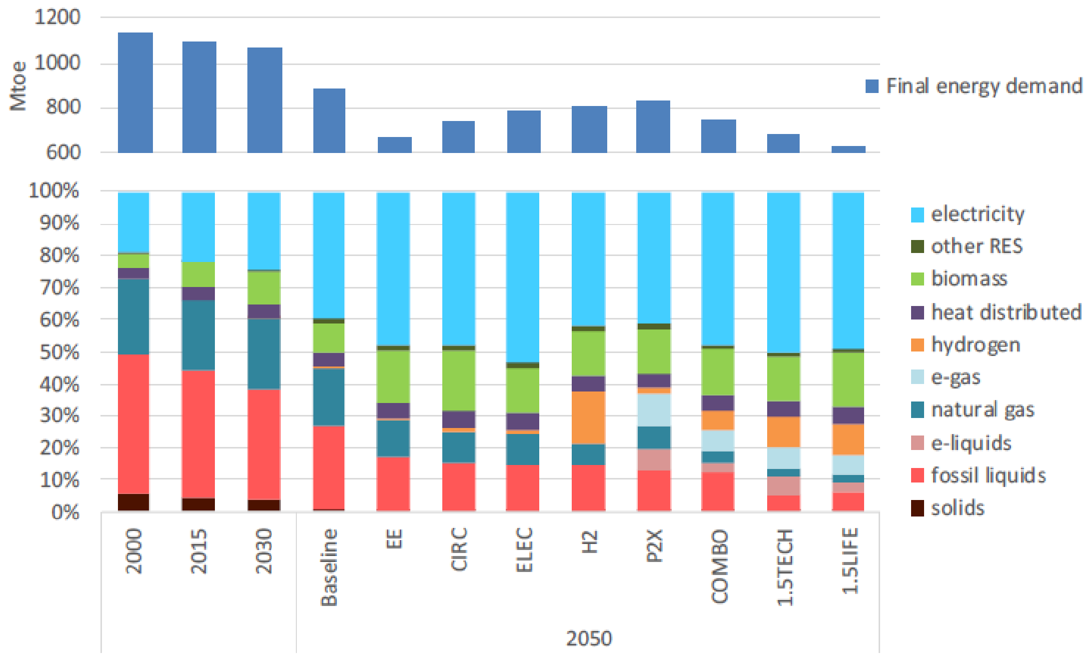
1 Introduction

1.1 Context of the study

In December 2019, the Commission presented the **European Green Deal**, a commitment to tackling climate and environmental-related challenges. The European Green Deal is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. Achieving climate neutrality by 2050 is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement.

The Commission set its vision for a climate-neutral EU in November 2018, looking at all the key sectors and exploring pathways for the transition, with its European **strategic long-term** vision for a prosperous, modern, competitive and climate neutral economy.[12] This model-based quantitative analysis explores eight economy wide scenarios achieving different levels of emissions reduction, illustrated through the share of energy carriers in final energy consumption in Figure 1-1.

Figure 1-1 Share of energy carriers in final energy consumption, EU Long Term Strategy[13]



Source: EC's LTS, figure 20

The Long Term Strategy (LTS) explores three categories of scenarios. The first category addresses the *well below 2°C ambition*, aiming for GHG emissions reduction levels in 2050 of around 80% compared to 1990. Five different scenarios are assessed in this category, considering different portfolios of decarbonisation options. All scenarios integrate strong improvement in energy efficiency and developments of renewable energy as well as improvements in transport system efficiency, which goes well beyond the assumptions of the Baseline scenario. On top of this, three of these scenarios are

[12] A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy: https://ec.europa.eu/clima/policies/strategies/2050_en
[13]https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

driven by decarbonised energy carriers and examine the impacts of switching from the direct use of fossil fuels to zero/carbon-neutral carbon carriers, namely electricity (ELEC), hydrogen (H2) assuming the deployment of the necessary hydrogen infrastructure and distribution also via the gas grid and e-fuels (P2X), in order to meet the prescribed level of ambition. The other two scenarios examine how stronger energy efficiency measures (EE) or the transition to a more circular economy (CIRC) can deliver the desired emissions reduction, assuming standardisation of recyclable material and improved systems for waste collection.

The second category comprises one scenario, which serves as a bridge between the first and third categories. It combines the actions and technologies of the five first scenarios into a sixth scenario (COMBO), though, without reaching the level of deployment of each technology as in the first category. All pathways are assumed to be available and it results in net GHG emissions reduction (including LULUCF) in 2050 of close to 90% compared to 1990.

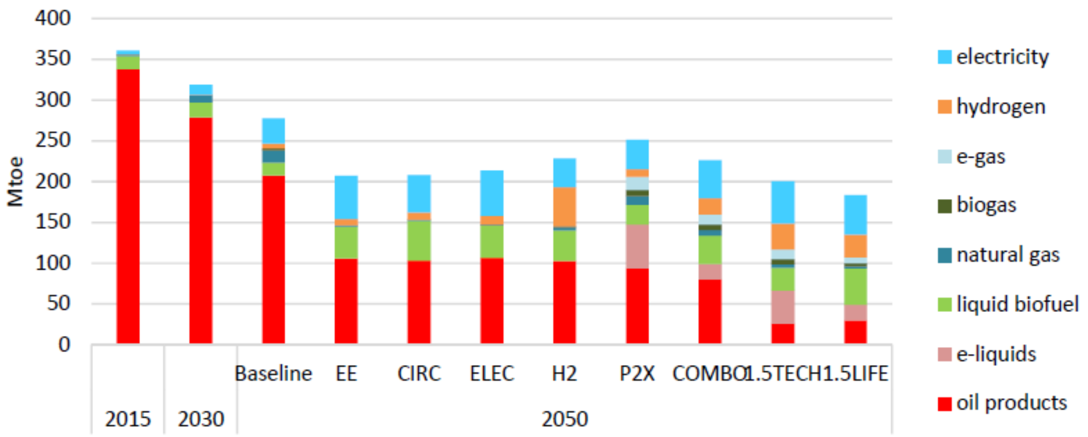
The third category of scenarios achieves net zero GHG emissions by 2050, *pursuing efforts to achieve a 1.5°C temperature change*. One scenario (1.5TECH) aims to further increase the contribution of all the technology options, and relies more heavily on the deployment of biomass associated with significant amounts of carbon capture and storage (BECCS) in order to reach net zero emissions in 2050. The second scenario (1.5LIFE) relies less on the technology options of 1.5TECH, but assumes a drive by EU business and consumption patterns towards a more circular economy. Similarly, the increase in climate awareness of EU citizens translates in lifestyle changes and consumer choices more beneficial for the climate. These include a continuation of the trend by EU consumers towards less carbon intensive diets, the sharing economy in transport, limiting growth in air transport demand and more rational use of energy demand for heating and cooling.

The share of fossil liquids (excluding non-energy use) in the total final energy consumption, even with the 6 first scenarios achieving “only” 80% GHG reduction, declines very strongly : from 30% in 2015 to 25% in 2030 to between 12% (EE) and 8% (P2X) in 2050. The sharpest decreases happen in the 1.5°C scenarios due to a combination of use of several zero-carbon or carbon-neutral fuels/energy carriers, notably in transport. This is because the scenarios include the most ambitious CO_2 efficiency for light duty vehicles and, in the case of 1.5LIFE, the additional effect of lifestyle changes shifting mobility to low energy options. Around half of the remaining fossil-derived liquid(or most – depending on the decarbonisation scenario) is actually used as a raw material in industry. In several scenarios (P2X, COMBO, 1.5TECH and 1.5LIFE), fossil-derived liquid used as energy is partially substituted by e-liquids, accounting for 2-4% of gross inland consumption.

In the transport sector, there is no single solution for the future of low-emission mobility - all main alternative options are required, but to a different extent in each transport category (heavy/light road, aviation, rail, shipping). Electricity and hydrogen will be used in dedicated powertrains. Furthermore, for those transport modes where the deployment of zero-emission vehicles is unfeasible due to energy density requirements or technology costs, carbon-neutral fuels such as advanced biofuels and e-fuels can be used in Internal Combustion Engines.

In the 1.5TECH scenario, the share of oil products in the transport sector is expected to decrease from 94% in 2015, to less than 13% by 2050, as illustrated by Figure 1-2. In the same scenario, the share of e-liquids will be around 20% by 2050, and the share of biofuels around 14% (starting with a 4.5% share in 2015) in the total fuel consumption of the transport sector.

Figure 1-2 Fuels consumed in the transport sector in 2050, EU Long Term Strategy[14]



Source: EC's LTS, figure 57

Systems Integration Strategy

The EU Systems Integration Strategy regards electrification as a key tool in the decarbonisation of our economy, especially in the road transport sector. However, it is also recognised that direct electrification is not the most efficient decarbonisation pathway for all end-use sectors. Therefore, it is necessary to support the use of renewable and low-carbon fuels, including hydrogen, and biofuels. The most suitable transport modes for use of sustainable biofuels and synthetic fuels are (according to the strategy) maritime and aviation. The proposed actions in the strategy should lead to the development of a comprehensive terminology and tracking system for ensuring the sustainability characteristic of these fuels, which should eventually lead to increased deployment and use.

1.2 Purpose of the study and fuel scope

The purpose of the study is to explore the implications of replacing conventional fossil fuels with low carbon alternatives on the bulk liquid storage sector and the entire supply chain . The scope of conventional fossil fuels includes:

- Liquid fuels: diesel, gasoline, kerosene, marine fuels, gas oil;
- Gaseous fuels: LPG, natural gas (covering only for the use as transport fuel).

Many of these fuels have various end-uses and also alternative-fuel substitutes. However, for the purpose of exploring fuel infrastructure adaptations, the short list of renewable alternatives was defined to include the widest possible range of applications. The fuel substitutions are summarised in

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

Table 1-1, and in general they cover:

- Biodiesel;
- Bio-based ethanol;
- Synthetic fuels (based mostly on hydrogen), including methanol;
- Renewable hydrogen;
- Bio-based LPG (propane and butane).

Table 1-1 List of fossil fuels and renewable substitutes

Conventional fossil fuel	Renewable substitute
diesel	biodiesel (FAME)
gas oil	biodiesel (HVO)
gasoline	Bioethanol
methane / LNG	compressed / liquid hydrogen
ship (marine) fuel	e-fuel (methanol)
kerosene (Jet A1)	e-fuels (H2 derived)
gasoline	e-gasoline
diesel	e-diesel
LPG	bio LPG

Conventional biofuels, also referred to as 'first-generation', are typically derived from crops which can also be used as food or feed[15] (bioethanol is produced from sugarcane, sugar beet, maize, wheat through fermentation and distillation, while biodiesel is produced from vegetable oils such as rape, soybean, palm oil, through transesterification). Advanced biofuels[16], also referred to as second- or third-generation, are typically derived from plant material which does not have an alternative use as food; they can be based on waste biomass, cereal stalks, other dry plant matter, or crops grown especially for fermentation into biofuels (algae, Miscanthus); at present, mainly produced on R&D, pilot or demonstration scales.

From this list of alternative fuels, some represent essentially the same chemical substance as the incumbent fossil fuels, while others have completely different characteristics, with potential implications on several elements of the supply chain. In the frame of this study it is not possible to consider all alternative fuels, such as recycled carbon fuels[17], which number increases continuously. This list of alternative fuels covers all the main types of energy carriers from a technical point of view, and is deemed representative of the range of low carbon and renewable alternatives.
Other products of refineries such as lubricating oils, greases, asphalt or sulphur are not in the scope of the study.

The selected fuels are thereafter covered by the selected fuel substitution study cases.

1.3 Supply chain scope

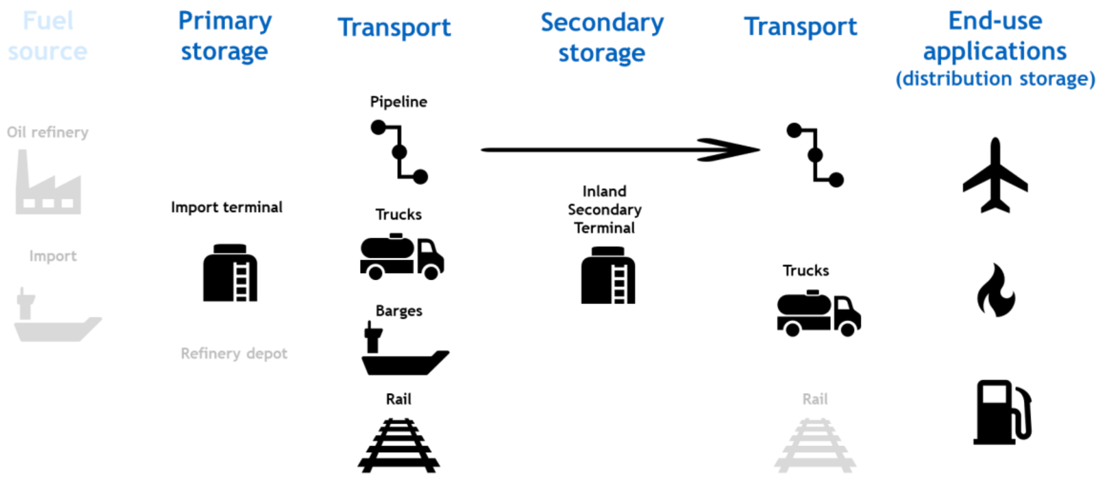
In general, this study will cover 2 broad categories of fuel infrastructure. Firstly, it is the existing fossil fuel infrastructure that will have to be reused, upgraded, transformed for another use or dismantled as a consequence of the energy transition. Secondly, the study will consider new infrastructure and facilities that will have to be built to enable use of new types of fuels. The study will explore only the part of fuel supply chain located in Europe. The fuel production phase – refineries and other fuel production sites – is excluded from the scope. From primary storage, the scope will cover the whole

[15] https://www.europarl.europa.eu/RegData/etudes/BRIE/2015/545726/EPRS_BRI%282015%29545726_REV1_EN.pdf
[16] The Renewable Energy Directive II defines 'advanced biofuels' as biofuels that are produced from the feedstock listed in Part A of Annex IX (of the same directive)
[17] The broad category of recycled carbon fuels can represent for example Fisher-Tropsch-based synthetic fuels or pyrolisys based fuels. See for example Malins (2020). Beyond Biomass? Alternative fuels from renewable electricity and carbon recycling. Available at: https://theicct.org/sites/default/files/publications/Cerulogy_Beyond-Biomass_May2020_0.pdf

downstream part of supply chains, comprising transport and distribution of the finished products to the consumer. The relevant stages of the supply chains are:

- Primary storage: fuel import facilities or terminals (e.g. in ports) and central distribution depots of fuel distributors;
- Fuel transport mode: pipelines, rail, truck or barge transport;
- Secondary storage: inland secondary terminals;
- Fuel transport: usually truck, and pipelines for airports;
- End-use application: distribution sites, such as fuel stations, ports, airports, filling equipment.

Figure 1-3 Representation of supply chain elements



To keep the study focused, model cases of fuel supply chains, consisting of the above described infrastructure elements will be selected to represent a typical fuel supply pathway. For example, the concerned part of a conventional gasoline supply chain might be represented by the infrastructure elements presented in Table 1-2.

Table 1-2 Example of gasoline supply chain elements

Primary storage	Fuel transport mode	Secondary storage	Transport from secondary storage to end-use application	End-use application
Refinery (out of scope) / import terminal	Rail wagons, pipelines, barges, tank trucks	Inland secondary terminals	Tank trucks	Fuel station (tertiary storage) & filling equipment

2 Implications of energy transition on supply chain components

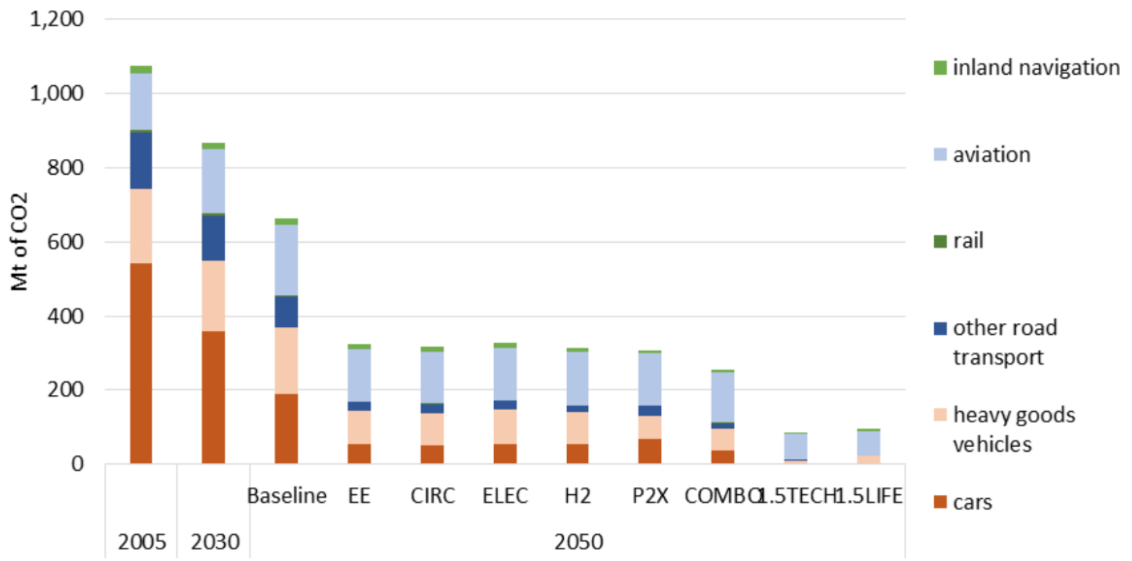
2.1 Identification of the main trends

2.1.1 Long term trends in transport sector

Decarbonising the transport sector is a challenging task. As illustrated below in Figure 2-1, the Long Term Strategy (LTS) expects that the emissions in the transport sector will have to decrease by 19% by 2030 and by at least 80% by 2050, when compared to 2005 levels. The biggest decrease is expected in passenger car emissions, due to significant electrification of the fleet. The emissions from heavy goods vehicles and especially aviation are expected to decrease to a lower extent (in case of aviation by only 5-8%). Because of this, the emissions from these transport modes will gain in importance, as their relative share of the total emissions would increase substantially.

However, the solution cannot lie only in decarbonisation of transport fuels, since the production of renewable energy in required volumes is not currently achievable. Wider changes in mobility patterns are necessary to achieve the planned emission levels.

Figure 2-1 CO_2 emissions from transport in 2050 (in $MtCO_2$)



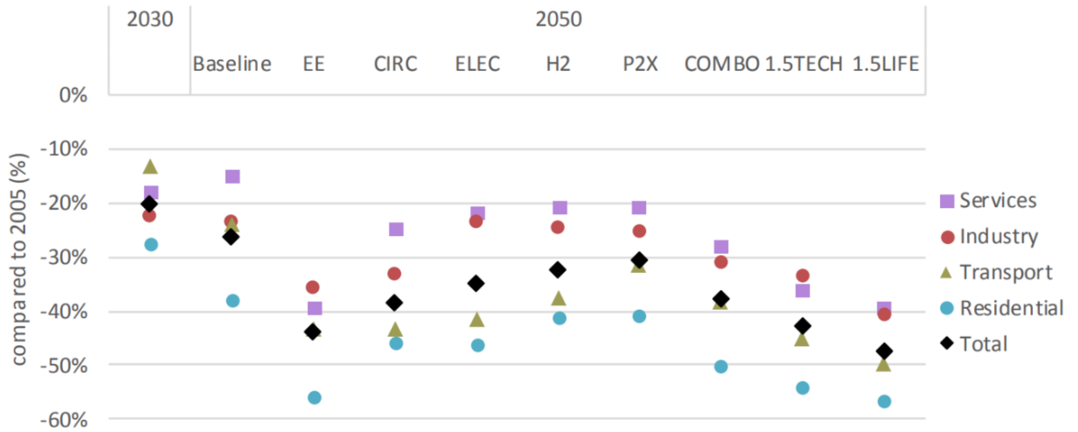
Source: EC's LTS, figure 58

Lowering the overall energy demand in transport

Energy efficiency is an imperative that should be applied to all sectors, including transport. Applying energy efficiency means improved engine design, as well as vehicle design leading, for example to aerodynamic gains. However, these efficiency gains should lead to decrease in energy demand, instead of inducing larger volumes of transit.[18] This means that more substantial changes in the vehicle design, in particular lightening of the vehicles and deploying cars with lower power output, suitable for example in urban mobility, is necessary. Figure 2-2 below illustrates that, according to the LTS, energy consumption in the transport sector needs to decrease by 30% - 50% by 2050 to reach the abovementioned 80% decreases in GHG emissions.

[18]Wei (2007). Impact of energy efficiency Impactofenergyefficiencygains on output and energy use with Cobb-Douglas production function. Available at: https://doi.org/10.1016/j.enpol.2006.08.009

Figure 2-2 Changes in sectoral final energy consumption (% change vs 2005)



Note: "Services" includes here the agriculture sector.

Source: Eurostat (2005), PRIMES.

Changes in mobility patterns and modal shifts

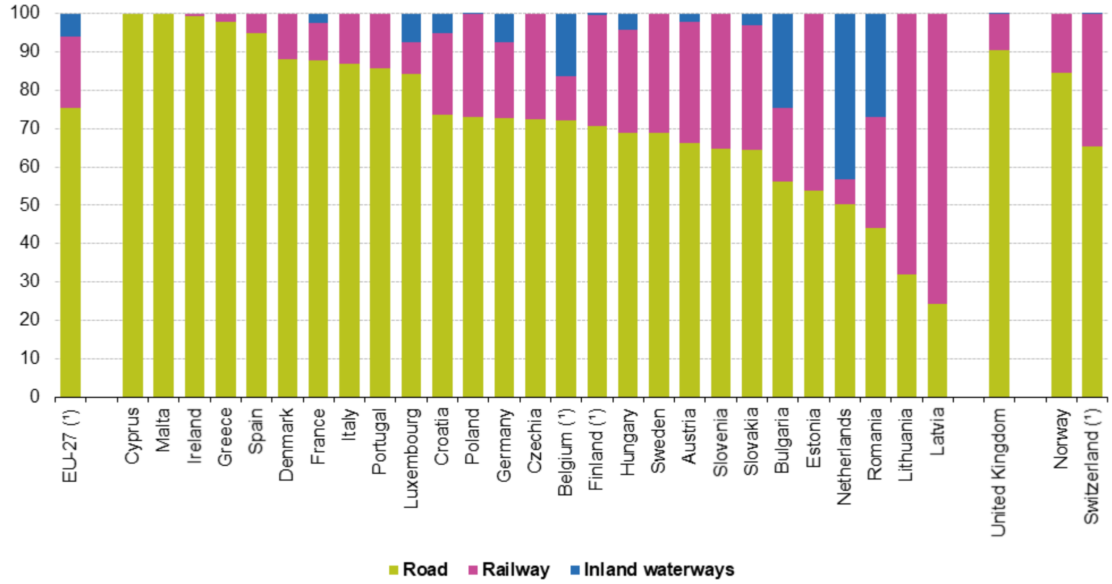
Long term trends in lifestyle choices also have a great impact on mobility and therefore also on transport modes used. While there is only partial evidence that younger generations tend towards lower numbers of car ownership and usage (and that these trends are sustainable into the future)[19], it is clear that especially cities are increasingly focusing on enabling alternative modes of transport, including public transportation, cycling or walking. Progress in digitalisation of transport will eventually enable deployment of self-driving cars and further economisation of car fleets by facilitating uptake of shared mobility. Since full realisation of these trends is possible only in the long term, these trends will initially be realised mainly in urban areas, though rural areas will benefit as well, especially by focusing on the development of public transport options.[20]

Apart from personal mobility, modal shifts in the transportation of goods are also needed. As shown in Figure 2-1, the current emissions from road transport of goods represents around 1/3 of the total emissions of the transport sector.

[19]Focas and Christidis (2017). What drives car use in Europe? Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC105792/kjna28517enn.pdf
[20]Agora Verkehrswende (2017). Transforming Transport to Ensure Tomorrow's Mobility. Available at: https://static.agora-verkehrswende.de/fileadmin/Projekte/2017/12_Thesen/Agora-Verkehrswende-12-Insights_EN_WEB.pdf.

Figure 2-3 shows that about 75% of the goods in the EU are transported by road. At the same time, rail transport requires only 20% of energy per unit of transported goods, which is a substantial potential from energy efficiency gains and GHG emissions reduction. It can therefore be expected that rail transport will play a more significant role in the future.

Figure 2-3 Modal split of inland freight transport, 2018 (% share in tonne-kilometres)



Note: Countries are ranked based on share of road transport.
(¹) Estimated values.
Source: Eurostat (online data code: tran_hv_frmod)

Based on these trends, the LTS predicts a total decrease in energy consumption in transport, which will be driven mainly by a decrease in road transport. On the other hand, rail and aviation transport energy demand is predicted to rise by around 20% in most scenarios (for aviation, the increase is projected due to increased demand for long-distance leisure travel mainly).

Figure 2-4 Change in energy consumption per mode in 2050 compared to 2005

Deploying alternative fuels

In addition to decreasing energy demand, deployment of alternative fuels with low carbon footprint is the second part of the decarbonisation efforts in the transport sector. It is apparent that the most important trajectory is direct electrification of vehicles, especially passenger cars. The LTS scenarios see 20% share of all alternative fuel (e-liquid, liquid biofuel, natural gas, biogas, e-gas, hydrogen and electricity) in transport (road, maritime, inland shipping, aviation, and rail) in 2030, and this share is projected to increase to over 80% in most scenarios. In the scenarios reaching net zero emission by

2050, the share of electric cars (including fuel cells) is expected to reach over 96% of the total passenger car fleet.[21] Fuel cell hydrogen cars would play only a limited role in most scenarios, even up to 2050 (e.g. around 16% in 1.5TECH). For light commercial vehicles, currently dominated by diesel, the share of electric powertrains could increase to 58-80% of vehicle stock by 2050. Similarly to passenger cars, in the 1.5 scenarios (reaching net zero emissions), the share of electric drivetrains would reach 92%.[22] Electrification is also the main option for buses and rail. Concerning rail transport, the scenarios assume that over 90% of passenger rail and over 80% of freight rail transport should be electrified by 2050.

For heavy duty road vehicles, the transition might require continued development of a mix of technologies, including battery electrification, particularly for short haul, but also advanced biofuels, hydrogen fuel cells, e-liquids and e-gas, while electrification does not seem to be the most viable option, at least for long haul (given, e.g. the weight and size of batteries). Predictions for this transport mode are very sensitive on the chosen assumptions and scenarios, and therefore deliver varying results. By 2050, either fuel cell, electric, or LNG drivetrains could be increasingly deployed, but a significant share of the vehicle fleet will still be relying on ICE drivetrains(at least 40% in most LTS scenarios[23], fuelled by e-fuels, biofuels and/or fossil-derived fuels) or electric hybrids.

For inland navigation, the trends up to 2050 show only limited electrification that would reach only a negligible percentage of the stock (up to 3% in the 2 scenarios reaching net zero by 2050). Propulsion with liquid fuels would still represent the major share of vessels, reaching around 81-87% (the rest would be covered by gaseous fuels). However, a significant share of liquid fuels is expected to be covered by liquid biofuels and e-liquids (81-84% in the scenarios reaching net zero by 2050).

Decarbonisation of the aviation sector presents one of the most significant challenges, especially since demand for air travel is expected to increase significantly – air transport activity, including extra-European flights, is expected to increase by 101% between the years 2015 and 2050. According to the International Air Transport Association (IATA)'s annual review 2019[24], the demand for air transport is set to double over the next 20 years. More recently, after the covid-19 first wave, on 27th of July 2020, IATA released an updated global passenger forecast[25] showing that the recovery in traffic has been slower than had been expected. In its base case scenario, global passenger traffic (revenue passenger kilometres or RPKs) will not return to pre-COVID-19 levels until 2024, a year later than previously projected. But the long term projections seem unchanged.

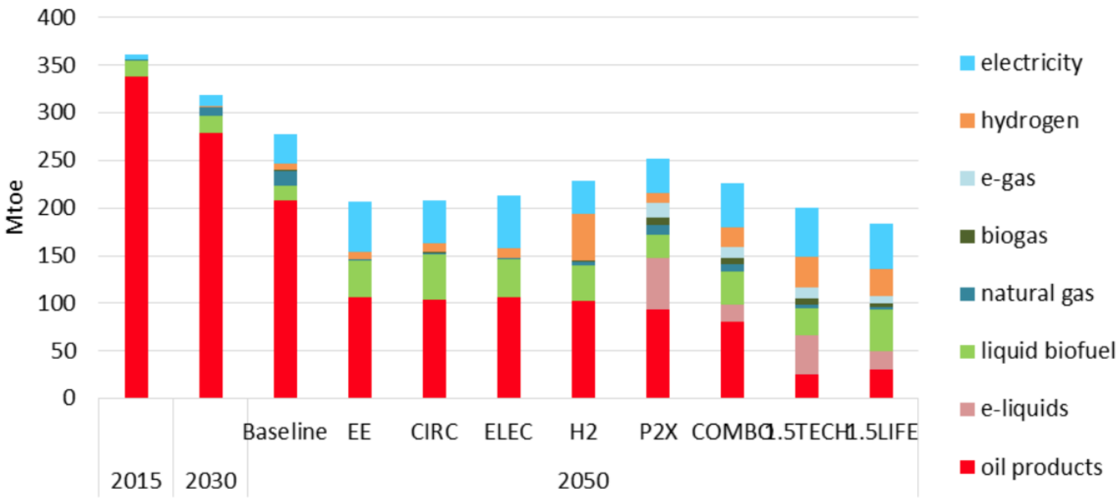
Since electrification is a very limited option for air transport, the biggest role is expected to be played by liquid biofuels, which could cover 20% to 25% of fuel consumption by 2050, or liquid RFNBOs, covering up to 14% of fuel consumption in the P2G scenario. Even so, fossil-based kerosene would still cover around 75% of aviation fuel demand in scenarios reaching 80% emissions reduction and around 30%-40% of demand in scenarios reaching net zero emissions in 2050.

The LTS scenarios of aggregated transport sector demand is presented in Figure 2-5. It is apparent that in 2030, the sector will still be dominated by fossil fuels. The emission reductions after 2030 will be to a large extent achieved by decreasing the overall energy demand. Even though electrification will be a solution for many transport modes, it will still only have a limited share of the total energy

[21] Figure 49 of the LTS
[22] Figure 50 of the LTS
[23] Figure 51 of the LTS
[24] https://annualreview.iata.org/environment/#intro
[25] https://www.iata.org/en/pressroom/pr/2020-07-28-02/

consumption. In many scenarios, liquid biofuels will actually represent a similar share of energy consumption as electricity, and the use of hydrogen and liquid RFNBOs (e-liquids) will only play a more substantial role in scenarios that focus on the promotion of these particular energy carriers. While fossil-based fuels will still cover a large portion of energy demand in transport, the consumption in absolute numbers could fall to less than one third of 2015 levels. A substantial cut in oil product consumption would happen only in case of the scenarios achieving net zero emissions by 2050.

Figure 2-5 Fuels consumed in the transport sector in 2050



Source: PRIMES.

Impacts on fuel use

Several transport fuel products are already being substituted and this trend will continue with the increased deployment of alternative fuels:

- Motor diesel being gradually replaced by gasoline, a trend driven primarily by emission standards, as diesel vehicles have higher NOX and particulate matter emissions;
- Growing diversity of gasoline components and gasoline specifications (E5, E10, etc.);
- Growing volume and diversity of biofuels (such as bioethanol and biodiesel, currently in the frame of the Renewable Transport Fuel Obligation, RTFO), replacing gasoil and gasoline;
- Growing volume and diversity of sustainable aviation fuels (SAF) replacing kerosene;
- Potentially growing volume of LNG (natural gas fuels, such as CNG and LNG, are considered as alternative options, at least for a transitory period);
- Growing volume of (renewable) hydrogen;
- Growing volume of synthetic fuels;
- Growing volume of e-fuels like methanol, ammonia, or DME potentially for the aviation, rail and navigation sectors.

Whatever the volume for each of these products, their diversity will drastically increase, complexifying the different supply chains and related security of supplies.

2.1.2 Impacts in other sectors (heating, industry)

In the building sector, the reduction of energy consumption through increased insulation and more efficient equipment is already under way in Europe. Renewable energy for heat generation is also deploying progressively, while low carbon energy vectors for heating & cooling (electricity, but also new vectors like hydrogen, e-gases and liquids, or other renewable liquids) are more recent options.

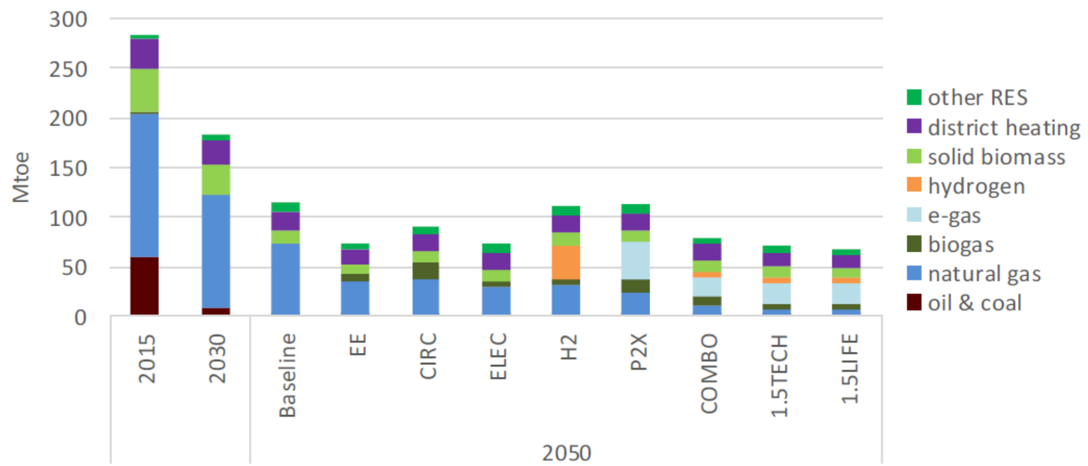
Today, the most common technologies using renewable sources to deliver heating and cooling services in buildings are solar thermal, geothermal, biomass boilers and ambient energy. According to some assessments, around 45% of all heat demand can be provided by geothermal by 2050.[26] Solar thermal is a widely used low-cost technology for domestic hot water in Southern Europe, and solar-heated buildings and solar district heating systems have been successfully demonstrated in Central Europe. High Coefficient of Performance (CoP) heat pumps are key to utilising geothermal and ambient energy (aerothermal and hydrothermal) and have already significant market shares in several countries in Europe.

The deployment rate of renewable heat (also in the industrial sector) currently stands at 19% in the EU but varies among Member States and in terms of technologies deployed. The specific options for the fuel switch from fossil fuels to zero-carbon/carbon-neutral energy vectors must be closely examined as the optimal heating and cooling supply option is determined by specific local circumstances in function of the availability of local renewable resources, the presence or feasibility of energy infrastructures, buildings' technical systems and their links with the broader energy system. Electrification of heating in buildings through heat pumps is an important pillar in decarbonisation of heating, assuming the electricity supply is decarbonised.

District heating and cooling networks also have the potential to help deliver a wide range of renewable energy sources for buildings, particularly in cities. District heating and cooling systems currently supply about 12% of EU's heating and cooling demand but there is a potential to expand them to supply 50% of the heat demand.[27]

As illustrated by Figure 2-6 (LTS), with the higher penetration of electricity, and increased energy savings, the consumption of other fuels used for heating purposes declines. Already, by 2030, the use of oil would sharply decline, even in the baseline scenario.

Figure 2-6 Non-electricity fuel consumption in buildings



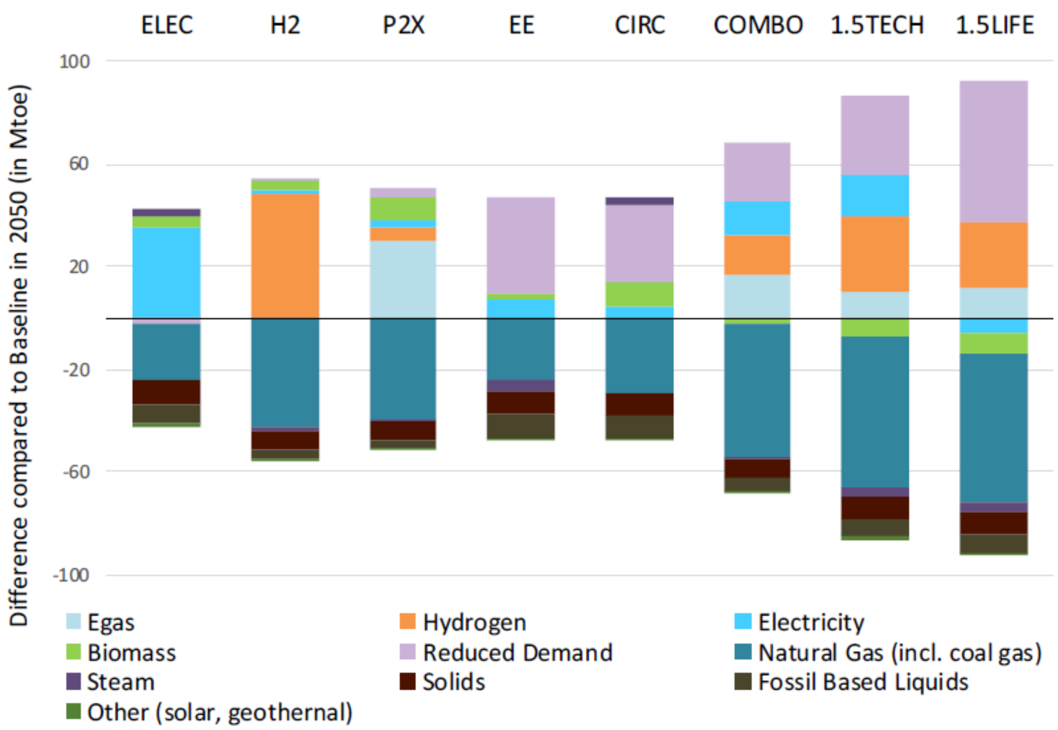
Source: PRIMES.

[26] European Technology Platform on Renewable Heating, Common Vision for the Renewable Heating and Cooling Sector in Europe, 2011
[27] https://heatroadmap.eu/sp_faq/heat-roadmap-europe-4/

Currently, to further decarbonise industry, energy efficiency and electrification of industrial heat and steam production are the most technologically mature options. Electrification of industrial heat (that relies on decarbonised electricity) is a promising solution. There is significant potential to electrify low temperature industrial heat with heat pumps (up to approximately 100° C) or with electric boilers (below 300° C). Other fuel switching options do exist, but at various levels of technological readiness; these would mainly be switching from fossil fuels to mostly biomass, but also to hydrogen and e-fuels.

There are significant changes across the LTS scenarios in the fuel mix used in industry both for heating and for processes (other than combustion). In the PRIMES Baseline, natural gas is the only fossil fuel remaining in the industry final energy fuel mix with a significant share of around 24.5% (61 Mtoe). Solids and other fossil fuels account for an additional 9% (23 Mtoe). About half of the final energy demand comes from electricity and heat. Total final energy demand is 253.5 Mtoe. Compared to the baseline scenario, solid and liquid fossils would decrease by an additional 10-17 Mtoe across all scenarios (up to 9.6 Mtoe for liquids only, as illustrated by Figure 2-7), from the 23 Mtoe. Oil consumption would sharply decrease in industrial sectors.

Figure 2-7 Differences in final energy consumption in industry compared to PRIMES Baseline in 2050



Source: PRIMES.

2.2 Description of considered fuels

Fossil based fuels

Most liquid fuels currently used are derived from **crude oil**. The most notable of these are:

- **Gasoline** is the most widely used liquid fuel (gasoline is made of a mix of alkanes and cycloalkanes with a chain length of between 5-12 carbon atoms. These boil between 40°C and 205°C);

- Conventional **diesel** is in principle easier to refine than gasoline, however it contains more pollutants that emit carbon monoxide-CO, hydrocarbons-HC, particulate matter-PM and nitrogen oxides-NO_x (diesel is made of alkanes containing 12 or more carbon atoms. These have a boiling point between 250°C and 350°C);
- **Kerosene** is used to fuel aircraft jet engines (it is made of carbon chains containing from 12 to 15 carbon atoms);
- **Liquefied Petroleum Gas** is a mixture of propane and butane, both of which are easily compressible gases under standard atmospheric conditions. Commonly used for cooking and space heating, LP gas and compressed propane are seeing increased use in motorised vehicles; propane is the third most commonly used motor fuel globally.

Bioethanol

A biofuel is a fuel produced through contemporary processes from biomass, rather than a fuel produced from fossil fuels, such as oil.

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane, or sweet sorghum. Cellulosic biomass, derived from non-food sources, such as trees and grasses, is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, or after being transformed in ETBE (Ethyl Tertiary Butyl Ether). It is usually used as a gasoline additive to increase octane and improve vehicle emissions.

Biodiesel

Fatty acid methyl ester (FAME) Biodiesel is produced by transesterification of animal fats and plant oils and is the most common biofuel in Europe. It can be used as a fuel for vehicles in its pure form, but it is currently blended with diesel, in compliance with the Renewable Energy Directive, article 25.

HVO biodiesel stands for hydrotreated vegetable oils. In terms of chemical composition, HVOs are straight chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulphur and have high cetane numbers. The different chemical structure also offers some advantages of HVO over the FAME biodiesel fuels, in particular reduced NOx emissions, better storage stability and better cold flow characteristics, as detailed in the case studies.[28]

Next to HVO, the hydro processed esters and fatty acids (HEFA) have similar physical properties and can be used in a similar way. HEFA fuels are mainly used as aviation fuel, although currently only in blends with conventional fossil fuel.

BioLPG

BioLPG is propane produced from renewable and bio-based feedstocks such as plant and vegetable waste material; it is also called renewable propane and/or biopropane. The main production method is the renewable biodiesel production process (or HVO – hydrotreated vegetable oil). This generates a by-product of bioLPG. During the refining process, a variety of waste ‘off-gases’ are produced that contain propane or bioLPG. For every tonne of biodiesel, 50 kg of bioLPG is generated from this off-gas stream. This co-product is then purified to make it identical to conventional propane.

[28] EAFO (2019). Hydrotreated Vegetable Oils: Overview. Available at: https://www.eafo.eu/alternative-fuels/advanced-biofuels/hvo.

There are other routes to bioLPG (pyrolysis, gasification, anaerobic digestion), however, the only commercial process to date is HVO.

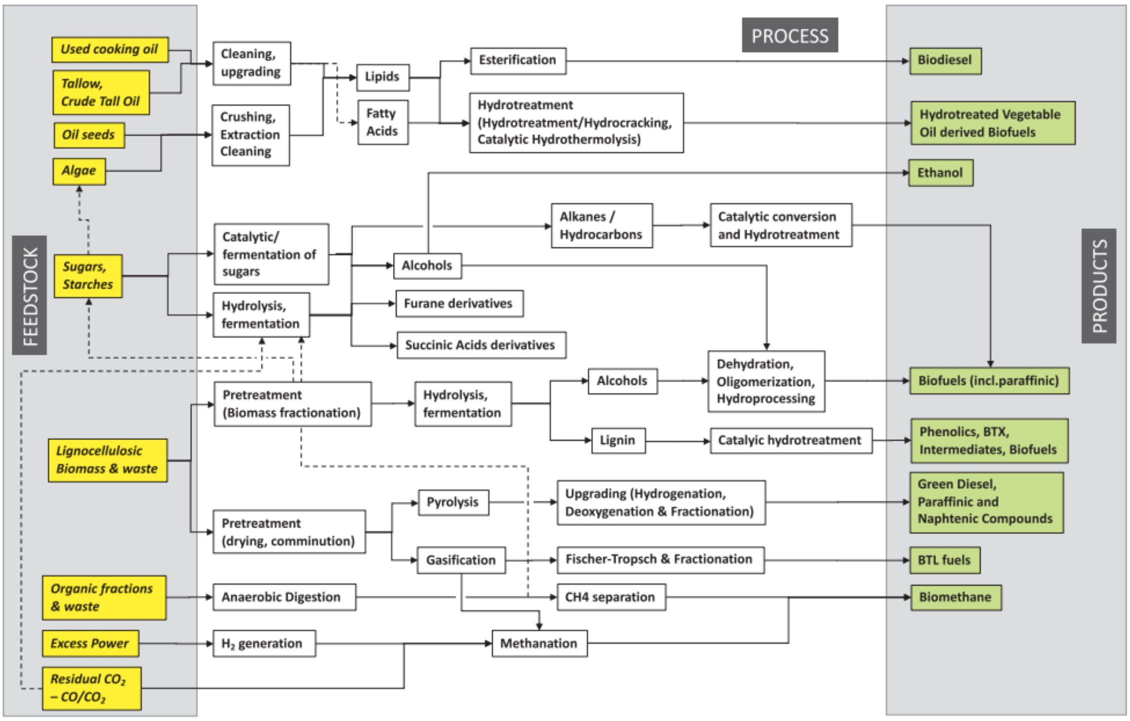
Biomethane

Biomethane is methane that is either separated from biogas in the process of "biogas upgrading", or produced through gasification of solid biomass followed by methanation. Biogas is principally a mixture of carbon dioxide and methane, alongside other gases in trace quantities, produced by anaerobic digestion of organic matter in an oxygen-free environment[29]

Notwithstanding the concrete production pathway, biomethane is the same chemical compound as natural gas and is transported via conventional natural gas supply chains, e.g. injected into the natural gas grid after production. Substitution of natural gas by biomethane therefore does not require any additional adaptations, as long as the "upgrade" of biogas complies with technical requirements.

The overview of different production pathways for the main groups of alternative fuels based on biomass is presented in the Figure 2-8 below.

Figure 2-8 Overview of biomass-based alternative fuels production pathways30



E-fuels: Renewable Fuels of Non-Biological Origin (RFNBOs)

RED defines 'renewable liquid and gaseous transport fuels of non-biological origin' as "liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass" (Article 2(36) RED II).

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[29] IEA. An introduction to biogas and biomethane Available at: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane.

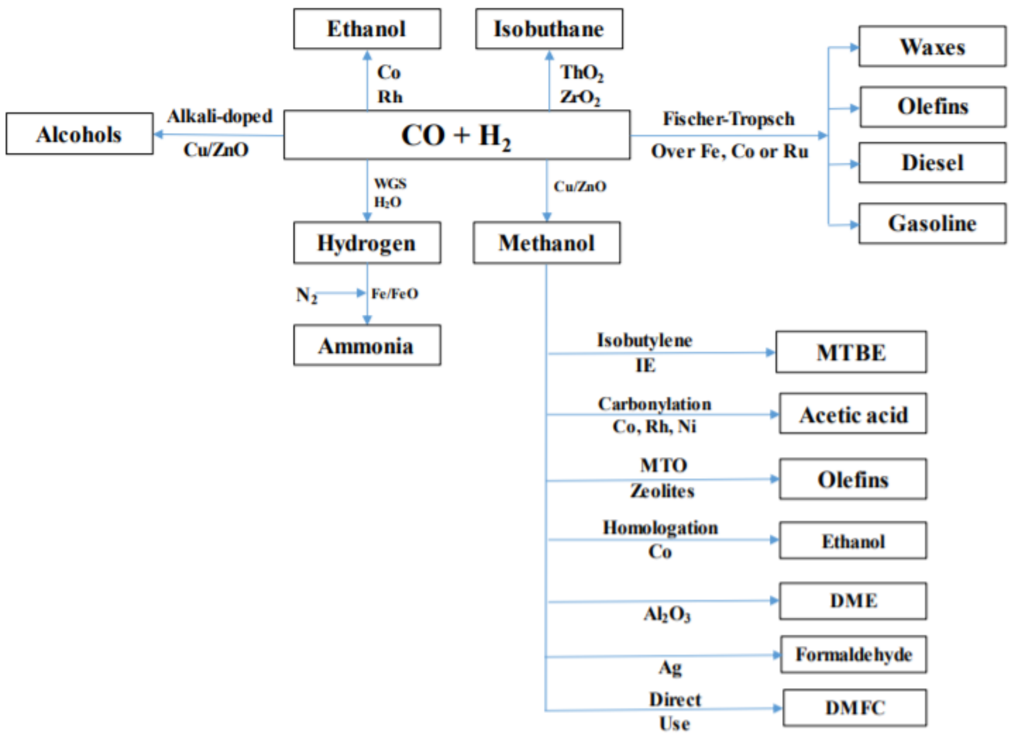
[30] Chiaramonti and Goumas (2019). Impacts on industrial-scale market deployment of advanced biofuels and recycled carbon fuels from the EU Renewable Energy Directive II. Available at: https://doi.org/10.1016/j.apenergy.2019.113351.

The most mature production pathway of fuels identified as RFNBOs is using renewable electricity to produce hydrogen by electrolysis. Hydrogen can then either count directly as a RFNBO (compressed or liquid), or can be used as an input to produce fuels for internal combustion engine vehicles through various chemical synthesis processes, such as methane, ethanol and other alcohols, aromatic compounds (including gasoline, diesel or olefins), methanol or ammonia. The various production pathways of RFNBOs from syngas (mixture of hydrogen and carbon monoxide) are presented in Figure 2-9 below. These renewable electricity-based liquids are sometimes referred to as e-liquids[31].

RFNBOs can be a supplementary solution for low-carbon transition in sectors that are hard to electrify or cannot use other renewable alternative fuels. They can also add to the limited impact potential of biofuels, which is determined by sustainability and resources limitations.

A potential medium term sector for RFNBO (e.g. methanol or ammonia) deployment is long-distance and heavy-goods transport, where hydrogen-derived fuels could provide a low-carbon alternative in the long term. Depending on the source of hydrogen (for example from natural gas or by electrolysis from renewable electricity), these fuels can have significantly differing GHG emissions. Another possible medium- to long-term sector for e-liquid deployment is light commercial vehicles, given the limited changes required to existing infrastructure but also end-use application (car engines). However, fuel price and availability of other alternatives (mainly electric vehicles) may remain an important barrier in the short term.

Figure 2-9 Synthetic fuels produced from hydrogen[32]



Definition of the abbreviations: MTBE - Methyl tert-butyl ether; DME - Dimethyl Ether; DMFC - Direct Methanol Fuel Cell.

[31] They can also be called PtL or Power-to-liquids, or electro liquid fuels.
[32] Santos and Alencar (2020). Biomass-derived syngas production via gasification process and its catalytic conversion into fuels by Fischer Tropsch synthesis: A review. Available at: https://doi.org/10.1016/j.ijhydene.2019.07.133.

2.3 Main implications for conventional fuel supply chains in Europe in the context of the energy transition

2.3.1 Main implications and vulnerabilities for fuel supply chains

The existing fossil fuel supply chains already face many threats, especially given their global interdependent nature. The nature of these threats range from geopolitical, such as manipulations of oil production output, the increased pressure European refiners face from large scale facilities outside Europe, or physical attacks, through the possibility of major technical failure that would stop the fuel flow, to environmental threats such as consequences of short-term extreme weather events and long-term climate change impacts. These threats depend on many local, national and global factors, and have varying intensities and consequences, impacting the resilience of the supply chains.

However, these threats might not apply in the same way to the alternative supply chains. For example, from the global perspective the production of these alternative fuels could be more decentralised and (to a certain extent) located closer to the consumption sites. Therefore, the existing areas of geopolitical conflict or the supply route bottlenecks will not have the same impact on the security of supply. At the same time, the digitalisation trend could seriously increase cyber-related threats.

The focus of this study is on the specific implications that the energy transition poses for these alternative (low-carbon) fuel supply chains in the European geographic area and the specific supply chain weaknesses that might increase in significance in the context of the transition process.

Supply chain implications

Based on the description of the major future trends in the previous sections, the main global implications for the European fossil fuels supply chains are:

1. Decrease in the overall energy demand and electrification of the transport sector, resulting in lower demand for conventional liquid and gaseous fuels, leading to major changes in the supply chain logistic;
2. Decentralisation or re-localisation of alternative fuel production, resulting in the need to reconfigure the existing supply chains to connect them with the new production facilities;
3. Limited supply of sustainable biomass, leading to competition between different end-uses (energy or material), meaning that no alternative fuel solution can cover all the demand. At the same time, it will be necessary to continue supplies of conventional fossil fuels (especially for the transport sector), at least up to the year 2050;
4. Since the adoption of particular alternative fuels depends on political decisions and future technology development, it is not possible to predict their deployment with a high level of certainty.

Supply chain vulnerability

1. Some parts of conventional fossil fuels infrastructure are not suitable for handling alternative fuels substitutes and it will be necessary to invest in adaptations or in building new infrastructure;
2. Since the overall demand for liquid fuels will decline, and the remaining demand will be dispersed among several different energy carriers requiring separate supply infrastructure (over the same geographic area), the unit cost of investment and maintenance will probably be impacted, making the investment in infrastructure adaptation possibly more costly. While

demand for gases might remain at current levels, the dispersion of demand between natural gas and hydrogen will lead to a similar effect;

3. At the same time, this will also become a weakness of the conventional fuel infrastructure, since it will have to keep the same geographical coverage with a higher amount of liquids given the raising amount of emerging low carbon fuels, while the utilisation rate will decline, and therefore additional infrastructure (storage and transport) may be required;
4. Fuel infrastructure has a long economic lifetime in comparison to the time horizon in which it is possible to make robust estimates of future technology and demand development; investments are therefore at risk of becoming stranded assets.

Part of the existing storage infrastructure (such as tanks and caverns) can be reused, converted or adapted to integrate some of the new liquid fuels, such as biofuels, e-liquids and synthetic fuels. Blending some of these fuels with fossil fuels will not require large investments. For other fuels, new additional investments for storage and distribution will be required, such as for the use of SAF, LNG (from fossil gas or from biomethane) and liquid hydrogen-based carriers. Compressed hydrogen (e.g. 350 bar for buses and trucks, and 700 bar for cars) could be handled in the frame of renewable gas infrastructure. In addition, increased safety concerns will also have an impact on the cost of the new infrastructure.

For energy carriers such as hydrogen or LNG the type of infrastructure currently in use for storage would require investment in new facilities, resulting in high investments in new infrastructure and appropriate safety mechanisms.

2.3.2 *Impact on other sectors*

The increasing fuel diversification and declining use of oil will have consequences across the whole supply chain, also impacting other interconnected sectors:

- Modification of the refining industry (restructuring, delocalisation, closure) will have a major impact as the most important stocks (emergency and commercial) are closely linked to the refineries. According to Concawe's European[33] refinery map[34], there were 111 refineries in operation in 2009, while by 2017 there were only 90;
- The refining industry is interlinked with the whole of society and any change will have a significant and, at times, unexpected impact. It is linked to all industrial sectors, supplying raw materials to many different processes, and would therefore indirectly be linked to final consumer's products. One example is the production of sulphuric acid, a product used in many aspects of daily life, which is produced by the desulphurisation of oils;
- The geographical distribution of consumption will evolve (the deployment of low-carbon alternative fuels will be organised along the required infrastructure and may differ from one region to another), storage facilities may be converted to hold liquid low-carbon fuels;
- The geographical distribution of liquid production will evolve, some products like bioethanol will be produced by agri-food industrial plants; e-liquids will probably be produced by large electrolysers combined with renewable electricity farms; bioLPG will be produced by biofuel plants, as by-products; bio-methane will be produced by waste management or agricultural facilities.

[33]Concawe was established in 1963 to carry out research on environmental, health and safety issues relevant to the oil industry. Its membership now includes most oil companies operating in Europe. It covers areas such as fuels quality and emissions, air quality, water quality, soil contamination, waste, occupational health and safety, petroleum product stewardship and cross-country pipeline performance.
[34]https://www.concawe.eu/refineries-map/

2.3.3 *Security of supply*

From the security of supply point of view, the biggest challenge is to prepare the emergency stocks infrastructure for the predicted trends of fuel diversification and declining oil use. The existing oil storage facilities will therefore have to evolve due to the following driving factors:

- Economics of these facilities, as competition would increase due to a decrease in demand, potentially leading to rationalisation, concentration or even closure if their profitability is not high enough;
- Conversion to storage of new products where technically & economically feasible (with the distinction between gaseous and liquids);
- Additional infrastructure (storage and transport) may be required to provide resilience for emerging low carbon alternative fuels in addition to existing hydrocarbons, due to a higher number of final products (liquids);
- In some cases, permitting could be an issue, when these are not consistent with security of supply basics or with the spirit of the Council Directive imposing an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products[35] (e.g. local authorities responsible for delivering permit but strongly opposed to further promote fossil fuels may compromise the way the stocks are spread across countries, impacting indirectly the global accessibility of the required stocks).

As a consequence, a decrease in consumption and a diversification of the fuel can contribute to the concentration of stock facilities into larger facilities due to decreased profitability. Concentration could possibly increase the distance from end-use locations, compromise the "spread" across the territory and delivery capability, which is a public concern. As an example, for energy carriers such as Hydrogen or LNG the type of infrastructure currently in use for storage would require investment in new facilities, resulting in high investments in new infrastructure and appropriate safety mechanisms.

Therefore, a number of existing storage locations could disappear as owners will not be prepared to invest in new infrastructure. As a result, only hubs at strategically important locations may remain which may have a negative impact on the overall network and jeopardise product availability and accessibility, which could also impact the security of supply.

2.4 Description of fuel supply chains

To assess the implications of the energy transition and the changes in fossil-based and alternative fuels consumption for the alternative fuels infrastructure, the study analyses different case studies of infrastructure adaptation to alternative fuels supplies. Each case study will focus on one specific alternative fuel conversion and on the components along all stages of the downstream supply chain. The actual fuel supply chains vary case by case, even for the same fuel, and might cover a broad range of elements such as storage infrastructure (tanks and depots, terminals), of transport modes (barges / trucks / wagons / barges / pipelines), and end-uses. In order to examine the possible pathways in a practical way, model case studies that will focus on a narrow supply chain pathway were selected. The selection of cases was done with attention to their complementarity, so that all the most important supply chain elements (e.g. different transport modes) are represented at least for some fuels.

[35] 2009/119 directive, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0119&from=FR

For each case study, the data and information were gathered via literature review and consultation, to conduct to a robust assessment of:

1. The description of the supply chains of the different liquids (fossil, low-carbon and renewable liquids) and their applications or use;
2. The identification of the implications of the energy transition on each component of the existing chains;
3. The estimated cost of these implications to upgrade and develop new infrastructure, through specific case studies.

The supply chain stages analysed for each case study comprise:

1. Primary storage (import terminal, refinery, processing facility);
2. Transport mode from Primary to Secondary Storage (if applicable);
3. Inland Secondary Storage;
4. Transport mode from secondary Storage to end-use application (if applicable);
5. End-use application (or delivery point).

Each case pre-defines the fuel which is being produced in a specific industry, addresses all stages up to the final consumer, as transport and distribution mode will depend mainly on the end-use sector (industry, small enterprises, building, transport – passenger or goods).

2.4.1 Fossil fuels supply chain

The following section describes in more detail the stages of a fossil fuel supply chain. These stages concern several actors, such as utilities, storage operators, logistics and fuel suppliers, pipeline operators, traders, distributors or fuel station operators. To ensure the resilience of the entire chain, a view of all changes at all stages is required from all players.

Fuel Production

Gasoline, diesel, kerosene and LPG are produced in refineries, within or outside Europe. Refinery production is centralised in circa 90 facilities across the whole of Europe (2017 figures[36]), while import to Europe via import terminals of refined products is increasing. Every refinery has its own short term storage facility of crude oil used for balancing supplies, and is customised for certain types of oil input and has different units for production of different products. Therefore, the flexibility of refinery outputs is limited. This part of the supply chain is out of the scope of this study.

Primary storage

Primary storage comprises fuel import facilities or terminals mainly located in ports, central distribution depots of fuel distributors, and refinery terminals.

Transport of finished products

Product pipelines

Product pipelines are used to transport the final refinished products from refineries or import terminals to the storage depots along the supply chains. They can be short-distance, connecting a single refinery with intermediate storage depots, or develop into a wide-scale distribution system.

[36] https://www.concawe.eu/refineries-map/

The widest systems in Europe are :

- The CEPS[37] system (Central Europe Pipeline System), which was built by NATO in the 50's and spreads through France, Benelux and Germany, but now is primarily used to the benefit of oil industry ;
- CLH system in Spain :
- TRAPIL, DMM, and PMR systems in France ;
- UK and Italy featuring also various private systems.

Rail wagons

Rail wagons[38] are another way to transport refined fuels across a landmass. The fuel is loaded into tank cars and are moved by train across the rails to their destination. Trains can carry a massive amount of refined products by using multiple tank cars, making rail a fairly cost-effective way to transport fuels. These rail wagons, just like the pipelines, can be used to carry a refined fuel from a refinery to a secondary distribution terminal. Rail wagons are a common way to transport fuel over a long distance to areas where they do not already have pipelines.

Tank trucks

Tank trucks are used like rail wagons, but they will usually transport refined fuel to a fuel station or deliver the fuel straight to the final consumer (e.g. heating oil). Trucks are used to carry smaller capacities on short distances. Like rail cars, trucks can carry several different forms of fuels. Tank trucks allow a rational and cost-effective way to deliver the fuel to the consumers on short distance.

Inland shipping[39]

The transport of refined products via inland waterways is done via barges. A barge is a boat built mainly for river and canal transport of bulk goods. Barges are smaller than tankers (transport on a global scale, from one continent to the other, or for seaway transport along coastlines). As barges are very ineffective for transporting fuels over long distances, they are usually used for shorter distances.

Inland secondary Terminal

Inland secondary terminals are located close to important transportation hubs, as their primary purpose is to serve as central storage hubs for fuel suppliers which will then deliver the fuels to the distribution depots close to final consumers.

Transport to distribution depots

Tank trucks are usually used to transport gasoline and diesel from inland secondary terminals or from import terminals (when no secondary storage is used) to distribution depots, while pipelines are used to deliver kerosene to airport.

Distribution depots

Distribution depots are located close to the final user site.
The final point of delivery to the consumer are fuel stations, airports, customer depots or domestic storage (for example in case of gas oil).

[37]https://www.nato.int/cps/en/natolive/topics_49151.htm

[39]Maritime shipping is out of scope, being out of Europe

3 Detailed description per supply chain

This chapter focuses on the identification of the implications of the energy transition on each component of the existing supply chains. In particular, it looks into the adaptation and repurposing of each component to accommodate the large variety of new fuels, such as biofuels/advanced biofuels, e-fuels, synthetic fuels, clean hydrogen and its derivatives. In addition, it assesses the ability of the various storage and fuel distribution infrastructure to deal with these new fuels, taking into account, among others, the chemical composition and petrochemicals characteristics. The following components will be analysed:

- Adaptation, extension, retrofit or dismantling of tanks, depots and terminals (incl. handling material);
- Repurposing, changing or replacement of road material (trucks), of shipping equipment (barges & vessels), rail equipment (wagons);
- Repurposing, changing or replacement of retail stations;
- Changes in daily operation (with a focus on safety procedures and handling techniques) of the storage facilities, the transportation hubs, the distribution equipment (retail stations).

Diversification of fuels and impact on the supply chain (incl. storage facilities, transport & distribution infrastructure) - European level

In the long term, oil consumption is expected to sharply decrease at the European level compared to the current level of consumption (expected global decrease by 90-95% by 2050 according to the LTS and other scenarios). This low level of consumption will be explained on one hand by the electrification of transport, and the shift to other mobility options (public transport, bicycle, walking, …), and on the other hand by the replacement of fossil-based fuels by low-carbon fuels (renewable or synthetic) mainly for heavier transport modes (such as trucks), and also for heating or industrial purposes. These low-carbon fuels can be either gaseous or liquid.

The whole European supply chain will be impacted by a decrease in oil consumption and a diversification of fuels. As discussed under chapter 2, the modification of the refining industry and increased product diversification will have an impact on the European emergency and commercial stocks, on their cost structure and their ability to ensure security of oil supply.

Assuming an important oil consumption development (decrease of use) and diversification of fuel products, the existing oil storage facilities will evolve due to influencing factors such as the economics of these facilities, technical feasibility, and permitting, ensuring the continuity of operation.

As a consequence, a decrease in consumption and diversification of the fuels can contribute to the concentration of stock facilities into larger facilities due to decreased profitability, potentially resulting in a negative impact in the overall network, therefore jeopardising products availability and accessibility.

List of case studies

The following table summarises the 11 case studies addressed under this chapter. It illustrates the different combinations of the different stages of each supply chain.

These case studies together should grasp most of the components of the supply chains, to allow a precise assessment of the consequences of the energy transition.

Table 3-1 List of case studies

	Current Energy carrier	Example replacement energy carrier	Primary storage (import terminal, refinery, processing facility)	Transport mode from Primary to Secondary Storage (if applicable)	Secondary Storage	Transport mode from secondary Storage to delivery point (if applicable)	Delivery point& end-use vehicle (e.g. retail - passenger cars)
1	Diesel	biodiesel 100% (FAME)	(from refinery)	Rail	inland terminal	Tank trucks	Fuel station - heavy duty trucks
2	Diesel	biodiesel 100% (FAME)	import terminal	Tank trucks	inland terminal	Tank trucks	Fuel station - passenger cars; heavy duty trucks
3	gas oil	biodiesel up to 100% (HVO)	import terminal	Barge (inland)	bunkered stock / distributor depot	Tank trucks	domestic heating fuel (domestic tanks)
4	Gasoline	bioethanol up to 100% (e.g. from waste & residues or lignocellulosics	(from bioethanol plant)	Tank trucks	inland terminal	Tank trucks	Fuel station - passenger cars
5	methane / LNG (from scratch)	compressed / liquid hydrogen	import terminal	Pipeline	NA	NA	Fuel station - trucks
6	ship (marine) fuel	e-fuel (methanol)	(from remote large wind farm-H2 production) import terminal	Pipeline	Port fuel depot	NA	bunkering tankers - ship
7	kerosene (Jet A1)	e-fuels (H2 derived)	import terminal	Pipeline	Airport Storage	NA	Filling planes - Aviation turbine
8	LNG	bioLNG	import terminal			Tank trucks	Fuel station - heavy duty trucks
9	Gasoline	e-gasoline	small stand-alone production facility or import terminal	Pipeline	depot	Tank trucks	Fuel station - passenger cars
10	Diesel	e-diesel	small stand-alone production facility or import terminal	Tank trucks	depot	Tank trucks	Fuel station - trucks
11	LPG	bio LPG (biopropane)	(from refinery)	Tank trucks	LPG cylinder filling plant	Tank trucks	household heating (cylinder tanks)

Cost analysis

Cost estimates have been undertaken using the following methodology:

- where available, data from studies have been used (for example: hydrogen pipeline adaptation; hydrogen fuelling station);
- for civils, electrical works, and labour costs SPONS cost estimating handbooks (2021 edition) has been used, which are price estimating books and guides for the mechanical, electrical and construction industries;
- for equipment and soft costs (planning, permitting etc) quantitative survey methodology has been used, based on quotes from suppliers, web research, as well as data from similar projects, run by Challoch Energy.

For the calculation of levelized costs, WACC (Weighted Average Cost of Capital) rate used is 5% and the project lifetime is 20 years.

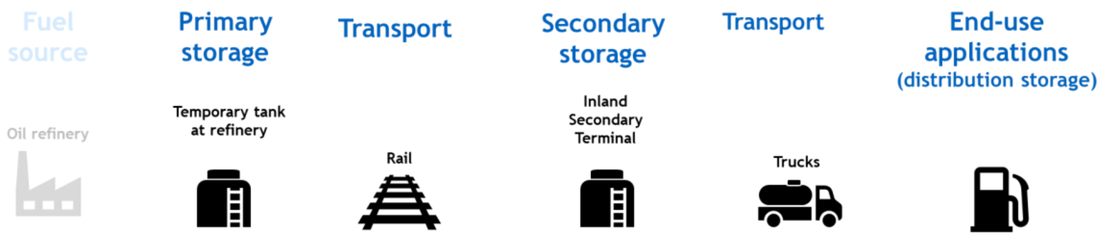
3.1 Diesel to FAME biodiesel supply chain conversion from refinery via truck transport

3.1.1 *Diesel supply chain description*

The supply chain analysed comprises five stages:

- Primary storage: on-site temporary storage tanks (at the refinery);
- Rail transport from primary storage of final product at refineries;
- Secondary storage (bunkered stocks / distributor depots);
- Tank truck transport;
- Delivery equipment to final consumers.

Figure 3-1 Visual representation of conventional diesel supply chain



Components description

Table 3-2 Summary of main diesel supply chains components

Components of Diesel supply chain
Primary storage
On-site temporary storage tank at the refinery
Piping from the refinery tank to the oil rail wagons
Rail loading facility
Pump devices
Meters
Fuel filtration
Rail transport
Rail wagons

Components of Diesel supply chain
Secondary storage
Piping from the oil rail wagons to the secondary storage tanks
Rail unloading facility
Pump devices
Meters
Tanks
Transport to final users
Tank truck loading rack
Tank trucks to distribute to final consumers' on site storage
Delivery to final users
Distributor depots
Fill in devices into truck as end-users

3.1.2 *Scenario - switch to 100% biodiesel*

Table 3-3 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
diesel	biodiesel 100% (FAME)	(from FAME production)	Rail	secondary storage	Tank trucks	Fuel station - heavy duty trucks

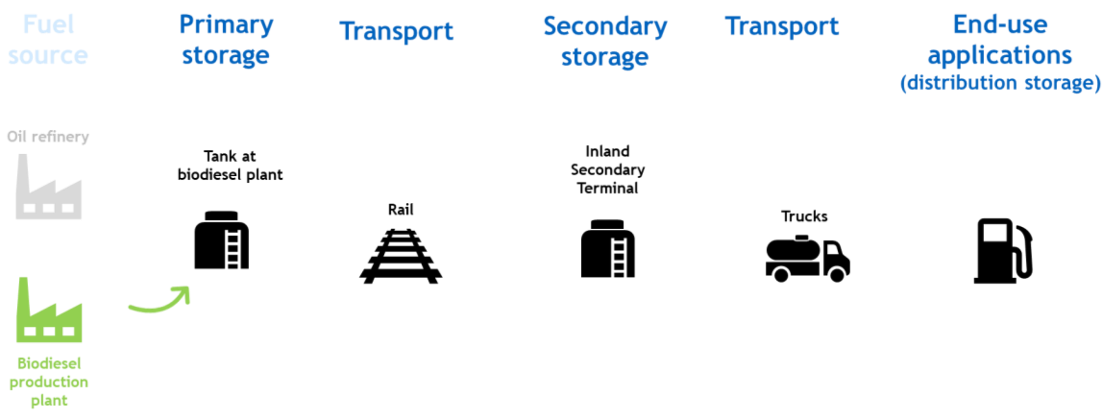
The scenario considers distribution of neat FAME biodiesel (B100) or high-percentage mixtures with conventional diesel (such as B80). Blending biodiesel with diesel (FAME) is currently done up to 7%. Higher rates of blends are possible without changes of equipment, and therefore at no cost. The current study focuses on neat alternative fuels (FAME in this case) requiring the most changes in the equipment and infrastructure. From no cost in the current situation (7% blends) to a maximum cost for 100% alternative product, the adaptation of the infrastructure and equipment will be progressive, and will depend on each supply chain element.[40] The same applies for bioethanol.

The model supply chain for this case starts with primary storage, where the biodiesel is collected from the production facility or admixed to diesel (there are several blending strategies such as in-tank blending or in-line blending at the loading rack, but no FAME-specific equipment is required[41]). From primary storage, the fuel is transported by rail tanks to the secondary storage across the territory closer to final users, for example in logistical hubs. From secondary storage, it is transported to distribution depots, where it is distributed for final consumption in (heavy-duty) road vehicles.

[40] The gradation of the cost incurred by the changes of the supply chain elements is studied in several studies, and is still subject to research

[41] Concawe (2009). Guidelines for handling and blending FAME

Figure 3-2 Schematic representation of biodiesel downstream supply chain



3.1.3 *Adaptation challenges*

Spatial distribution of the supply chain

Since the biodiesel production sites need to be in close proximity to the sources of biomass used for the fuel production, their geographical location is not necessary in line with the existing conventional diesel infrastructure, which is optimised around the oil import routes. Therefore, some adaptation of the supply routes or additional transport steps might be required, such as transport of biodiesel from a production facility to a secondary terminal where it will be blended with the conventional diesel fuel.

General consideration of the differences between fossil-based diesel and diesel of biological origin and their implications on diesel supply chain

In general, biodiesel can be used the same way and with the same equipment as conventional diesel. The use of some materials in the handling and storage equipment should be avoided though, as explained below. Due to a different chemical composition of biodiesel, there are several characteristics of the fuel that differentiate it from conventional diesel.

Biodiesel is a good solvent

As biodiesel is a good solvent, it can dissolve sediments from previous use in tanks or other equipment and subsequently clog filters or pumping devices. This issue is caused mainly by free glycerol in the fuel. The glycerol content has been regulated by the EN14214 norm. The problem of dissolving sediments occurs mainly when there is a change of use from conventional diesel to FAME biodiesel. In the long term, the same biodiesel property can on the other hand help to prevent new material sedimentation.

Biodiesel may degrade certain materials

B100 may soften and degrade certain types of rubber compounds used for hoses and gaskets (buna-N, nitrile, natural rubber). However, according to the stakeholder feedback, these rubber compounds have been replaced in the last two decades and are not used for new equipment.

Problems with biodiesel degradation

Fuel aging and oxidation will degrade the quality of fuel over time. Metals such as copper, brass, bronze, lead, tin, and zinc can accelerate the process of degradation and contribute to the creation of additional sediments that can create problems in handling devices. Acceptable storage tank materials include aluminium, steel, fluorinated polyethylene, fluorinated polypropylene, Teflon and most fiberglass. According to stakeholder feedback, the main problem was with the use of copper, which has been addressed in the technical norms.

Microbial contamination

Microbial contamination might be a more serious problem for biodiesel than for conventional diesel, especially when the fuel contains water, which is dissolvable in biodiesel. The microbial activity, e.g. fungi, yeasts and bacteria growing in the water and feeding on biodiesel, will lead to degradation of fuel quality.

Higher freezing point of biodiesel

B100 freezes at higher temperatures than most diesel fuel. This must be taken into account if handling or using B100, especially in aboveground storage tanks. Most B100 starts to cloud at (2° to 15ºC), so heated fuel lines and tanks may be needed, even in moderate climates, during winter. As B100 begins to gel, the viscosity also begins to rise to much higher levels than most diesel fuel, which can increase the stress on pumps. The high cloud point makes B100 use challenging in colder climates.
However, there are different FAME biodiesels with different qualities on the market (depending on additives, type of feedstock), with cold filter plugging point (CFPP) ranging between +13˚C and -13˚C. Therefore, lower CFPP fuels can be used without additional insulation, but their price is also higher.

Lower energy content

Biodiesel contains 9% less energy per unit of volume than conventional diesel, with some variations depending on the feedstock for biodiesel production. Consequently, larger volume of fuel has to be transported to final consumers.

Safety of use

According to Concawe, FAME Biodiesel contains no hazardous materials and is generally regarded as safe[42]. Better biodegradability of the fuels is a positive in case of environmental accidents such as spills. It has higher flash point than conventional diesel, so it is also slightly less flammable.

Transport of biodiesel to primary and secondary storage

This step is applicable for admixing the biodiesel in conventional diesel. Since biodiesel production facilities are not necessary located at the same location as refineries or existing diesel distribution infrastructures, the transport of biodiesel to primary storage may constitute an additional step. Although blending FAME with diesel is already a current practice in Europe, the volume of transported FAME biodiesel will have to increase, as well as the transported volumes from biodiesel production plants to blending sites. Conventional diesel tank trucks are suitable for the transport, provided the tanks are made from suitable material and are cleaned beforehand to get rid of sediments that might be dissolved in biodiesel and clog filters. According to stakeholder input, most of the tank trucks are already made of FAME compatible materials.

Admixing biodiesel into conventional diesel & primary and secondary storage

FAME biodiesel can be blended in several ways, for example by in-tank blending or in-line blending at the loading rack. Due to differences in viscosity, biodiesel should however not be poured into a tank first (to avoid it remaining at the bottom and not mixing with diesel). Changing the equipment for handling biodiesel might be necessary to avoid unsuitable materials (although in many countries fuel

[42] Concawe (2009). Guidelines for handling and blending FAME

admixture is already necessary so the investment was already made). Refineries, large import terminals and large inland secondary storage might be better equipped to execute the mixing, since better metering equipment (for volumes, as well fuel quality) are available on site. Larger primary and secondary storage sites are usually equipped for biodiesel blending, so in some cases there will be no additional investment needed. According to the stakeholder inputs, smaller depots are however not equipped for this task and currently can handle only prepared biodiesel blends. These storage operators are expecting, that with higher biodiesel demand, adaptations will be necessary.

Transport of final fuel to fuel stations

The bio-component in biodiesel is a surface-active material and FAME can adhere to pipe and tank walls during the transportation of biodiesel. The FAME can contaminate the next product transported in the pipeline.[43]Therefore, the transport of FAME biodiesel via multiproduct pipeline is not advisable, due to risk of cross-contamination of fuels. In cases where the existing diesel supply chain includes pipeline transport, it would have to be substituted by other transport options, such as rail or road tanks. Conventional diesel rail tanks are suitable for the transport, provided the tanks are made from suitable material and are cleaned beforehand to get rid of sediments that might be dissolved in biodiesel and clog filters.

Distribution to final consumers in fuel stations

Existing handling equipment in fuel stations can be used, provided they are made from suitable materials. Additional insulation/heating systems might be necessary to avoid handling problems in cold temperatures. Table 3-4 details the risk exposure and weaknesses of these equipment.

Table 3-4 Summary table of main vulnerabilities and risks for FAME biodiesel supply chains

Supply chain component	Vulnerabilities and risk exposure
Transport by rail from primary storage in refinery	
Piping from the refinery tank to the oil rail wagons	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals. • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Pump devices	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals. • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Meters	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals.
Oil rail tank cars	• Fuel aging and oxidation can accelerate with metals such as copper, brass, bronze, lead, tin, and zinc. • Additional cleaning/maintenance necessary to prevent water contamination and microbial degradation • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Train	• Lower energy content (8%) may require additional train capacity for the same amount of energy transported.

[43] https://www.atmosi.com/en/news-events/blogs/any-fame-in-your-pipeline/

Supply chain component	Vulnerabilities and risk exposure
Secondary storage	
Storage tank - above ground	• Possible degradation of certain metals • Additional insulation to prevent water or microbial contamination might be necessary • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Storage tank - underground	• Possible degradation of certain metals
Piping in the secondary storage facilities	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals. • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Pump devices	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals. • Additional insulation or heating might be necessary since B100 freezes at higher temperatures than most diesel fuel.
Meters	• Softening & degradation of rubber compounds used for hoses and gaskets. Possible degradation of certain metals.

3.1.4 Consequences of risk exposure and required response

The consequences on the equipment & infrastructure can include:

- Equipment or infrastructure can be upgraded via minor additional investments to avoid the risks;
- Equipment or infrastructure is completely inappropriate and should be completely replaced:
  - Becoming stranded assets;
  - Being usable for other purposes.

Table 3-5 Summary table of main consequences and actions needed for FAME biodiesel supply chain

Challenge in supply chain adaptation	Consequences & responses
Adaptation of equipment to prevent fuel contamination	• All vents should be fitted with screens or breathers designed in such a way to minimise the ingress of contaminants; • Above ground storage tanks should be equipped with a low point sump and a drain line with a valve that is suitable for removing water and sediment; • Excessive tank water should not be permitted in product tanks. All tanks should be constructed with adequate water removing capability; • Fill connections and gauge access points should be provided with tightly fitting covers to prevent entry of water or solid contaminants and evaporative loss. When accessing them, care should be taken to prevent further contamination; • These adaptations are not absolutely necessary for handling of biodiesel (contamination issues can be also addressed by specific filtration activities), all new investment and equipment replacements should be fitted with these features.

Adaptation of tanks and storage facilities to prevent material degradation	• Although the most typical materials for tanks and piping are low carbon or mild carbon steel, it is recommended to use epoxy coating on inner surfaces of new tank installations
Additional filtering of the fuel	• Filtration systems are recommended to reduce particulate or other forms of foreign material contamination. They should be designed with the ability to sample the product both pre- and post-filtration. When filtration is used, it is recommended that the system should be appropriately sized for the application utilised, redundant to allow for bypassing a single vessel without interruption to operations, have the ability to monitor differential pressure to ensure system integrity, include air eliminators to reduce risk of internal fire or explosion, be fitted with a pressure or thermal relief valve and include low-point drains for water monitoring and removal.
Additional insulation or heating is necessary to prevent fuel freezing	• In particular for piping, above-ground storage, rail and truck tanks, pumps, in case that fuel with higher CFPP will be handled or stored.
Reconfiguration of supply chain infrastructure to connect the new biodiesel production facilities	• Investment in new transport modes might be required • Existing diesel infrastructure might become a stranded asset if the fuel switch will be to pure biodiesel, but will be still relevant if biodiesel/diesel blends are used, since the blending can happen at the refinery facilities and the resulting fuel blend can be transported through the existing supply chain.

3.1.5 *Cost assessment of the diesel supply chain adaptations*

The supply chain adaptations included in the cost assessment cover primary storage, fuel transport and secondary storage. The modelled case concerns a supply chain with capacity for handling 5 000 m^3 of FAME biodiesel. The Table 3-66 below presents the assessed adaptations and assumptions on the equipment.

Table 3-6 Summary of adaptation actions and assumptions on equipment

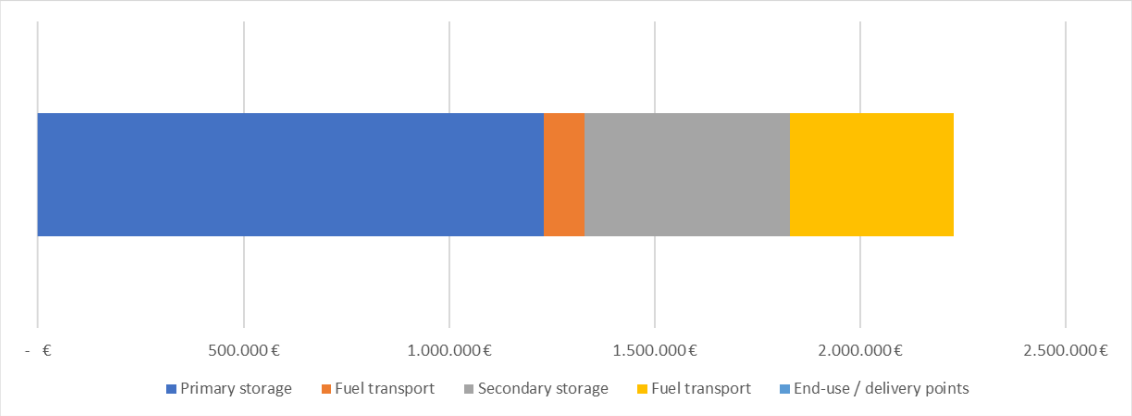
Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage	Supply chain relocation	New storage site at biodiesel production site	Storage tank; meters, pumps; thermal insulation	5 000 m^3
Fuel transport to primary storage	Supply chain relocation	New fuel trucks	Fuel transport truck	4 trucks with capacity of 25 000 l
Fuel transport to secondary storage	Unsuitable materials; high freezing point	Adaptation of rail tanks for FAME transport	Rail tank cleaning	
Secondary storage	Unsuitable materials; high freezing point	Adaptations in distributor depot	new meter, pump, filter + new coating and insulation for existing storage tank	Coating for 5 000 m^3 tank

Cost estimate

The cost assessment shows that for adaptations of the model supply chain for 5 000 m^3 of 100% FAME biodiesel, a total investment of 2 227 971 EUR would be necessary. While primary storage would represent 55% of the sum, rail transport adaptation from primary to secondary storage 4.5%, secondary storage adaptation 22.5% (additional epoxy coating of inner tank surfaces) present another substantial cost item), and fuel transport from secondary to final use 18%.

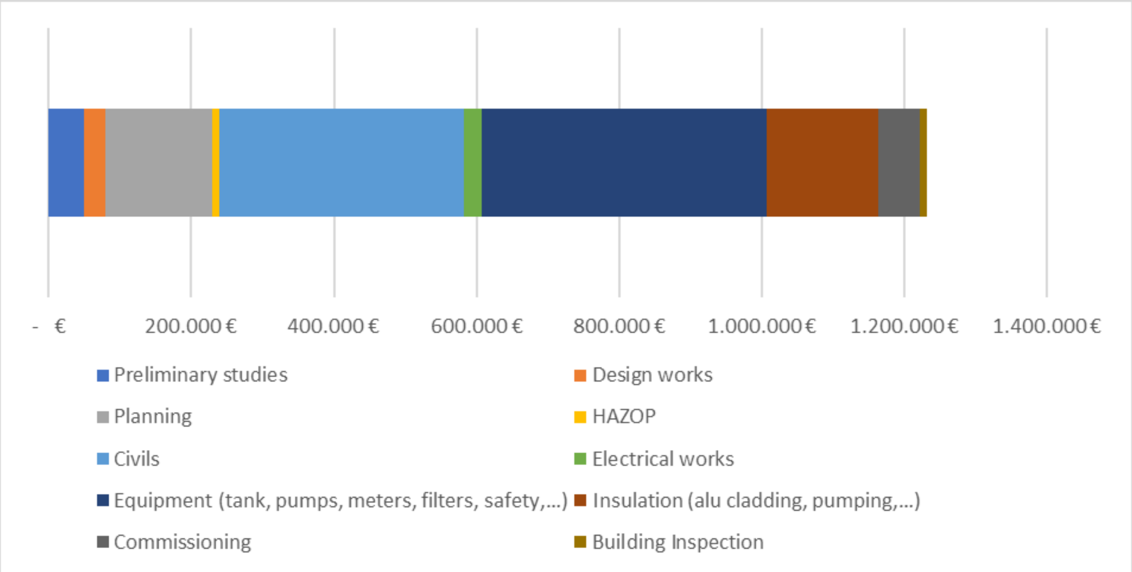
Considering a transition period to 100% biodiesel supply, the current low percentage of blends (7%) can be used without major adaptations, while higher blends (and pure biodiesel) can be problematic without adaptation. According to several studies, most EU infrastructure (and fleet[44]) could already accommodate the use of B10 and E10. Therefore, these adaptations are only required above a certain threshold of blending, which is currently expected to be 10%.

Figure 3-3 Adaptation costs of diesel supply chain



As presented in the Figure 3-4 below, the largest portion of the primary storage would be the civil works & equipment such as tanks, pumps, meters, filters, safety material, epoxy coating.

Figure 3-4 Breakdown of equipment and installation costs for primary storage (biodiesel supply chain adaptations)



[44] Cf the List of ACEA member company passenger cars, light commercial vehicles (vans) and heavy-duty vehicles (or heavy-duty engine models) that are compatible with using 'B10' diesel fuel, available at https://www.acea.auto/uploads/publications/ACEA_B10_compatibility.pdf. And the MVaK vehicles lists, available at https://www.mvak.eu/wp-content/uploads/2020/11/mvak_approval_list_b10_v07.pdf
Cf also the "Engine tests with new types of biofuels and development of biofuel standards" funded by Horizon 2020, and carried out by the European Standardization Committee (2019), available at https://www.cen.eu/work/Sectors/Energy/Pages/Biofuels.aspx

Size variation

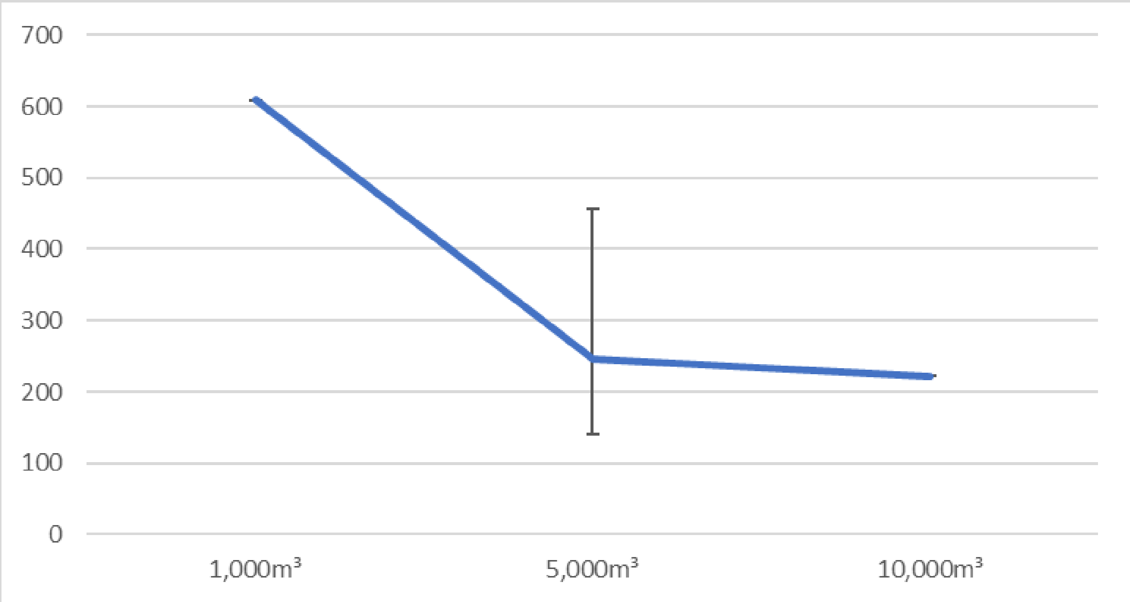
To address the influence of fixed costs on the final estimate, the Table 3-7 presents the cost estimates for three model primary storage with different fuel handling capacity, ranging from 1000 m^3 to 10 000 m^3. As can be expected, the unit cost of new equipment cost installation decreases with the volume of handled fuel, from 609 EUR/m^3 for the smallest tank to 222 EUR/m^3 for the largest tank.

Table 3-7 Primary storage adaptation cost variation for different fuel volumes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m^3)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
1 000 m^3	608.520 €	36.000 €	609 €		
5 000 m^3	1.230.689 €	60.000 €	246 €	923.017 €	1.846.034 €
10 000 m^3	2.216.967 €	120.000 €	222 €		

Figure 3-6 presents the decreasing unit cost per m^3 of installed storage. For the central case of supply chain for 5 000 m^3 of fuel, the estimated error margin shows that the unit cost could reach between 185 EUR and 369 EUR.

Figure 3-5 Unit cost for different storage sizes



Levelised cost of primary storage adaptation

Assuming the project lifetime of 20 years, the levelised cost of investment in new tank storage for biodiesel at the biorefinery site or an independent storage facility will reach 0.027 EUR per m^3.

Table 3-8 Levelised cost of adaptation measures

Total investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/m^3)
1.230.689 €	60.000 €	20	1314 (15%)	0,016 €/m3

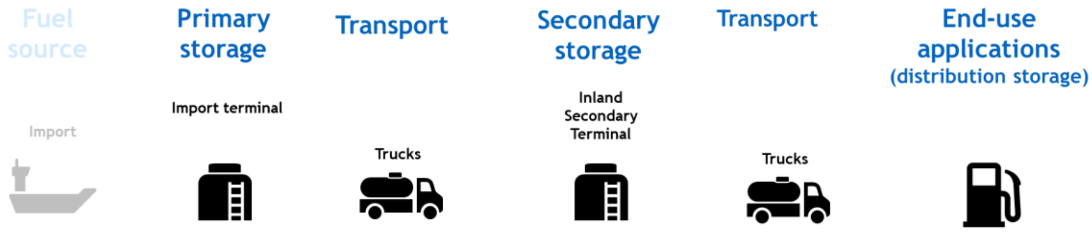
3.2 Diesel to FAME biodiesel supply chain conversion from import terminal

3.2.1 *Diesel supply chain description*

The supply chain comprises four stages:

- Import terminal / primary storage;
- Truck transport from primary storage;
- Secondary storage;
- Tank trucks transport;
- Delivery equipment to final consumers.

Figure 3-6 Visual representation of conventional diesel supply chain



Transport from primary to secondary storage is more frequently done by barges, pipelines or rail than by trucks. However, the changes assessed to transport the fuel by trucks remain representative of what would be required for other transport mode.

Components description

Table 3-9 Summary of main diesel supply chains components

Components of Diesel supply chain
Primary storage - Import terminal
Offloading equipment / ship unloading gantry
Storage tanks
Tank trucks loading facility
Pump devices
Meters
Fuel filtration
Truck transport
Tank trucks
Secondary storage
Tank truck unloading facility
Piping from the tank trucks to the secondary storage tanks
Pump devices
Meters
Tanks
Transport to final users
Tank trucks loading facility
Tank trucks to distribute to final consumers’ on site storage
Delivery to final users
Distributor depots
Fill in devices into truck as end-users

3.2.2 Scenario - switch to biodiesel

Table 3-10 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
diesel	biodiesel 100% (FAME)	Import terminal	Tank trucks	secondary storage	Tank trucks	Fuel station - heavy duty trucks

The scenario considers distribution of neat FAME biodiesel (B100).

The model supply chain for this case starts at the import terminal and primary storage. From primary storage, the fuel is transported by road trucks to the secondary storage in fuel stations, where it is also distributed for final consumption in road vehicles.

3.2.3 Adaptation challenges

There are no spatial adaptations necessary for the part of FAME biodiesel supply chain that starts at the import terminal. The same conclusions on the impacts of FAME biodiesel on supply chain components apply as in the first case including the two differing supply chain elements, e.g. import terminal and rail transport.

Table 3-11 Summary table of main consequences and actions needed for FAME biodiesel supply chain

Supply chain element	Consequences & responses
Import terminals	• Stocktaking of the materials in equipment to see if they are compatible with FAME biodiesel; • Adding epoxy coating on inner surface to prevent material degradation; • Adding thermal insulation if storage in cold temperatures is envisaged.
Rail tanks	• Cleaning the tanks before using for transport of biodiesel to prevent water and sediment contamination.

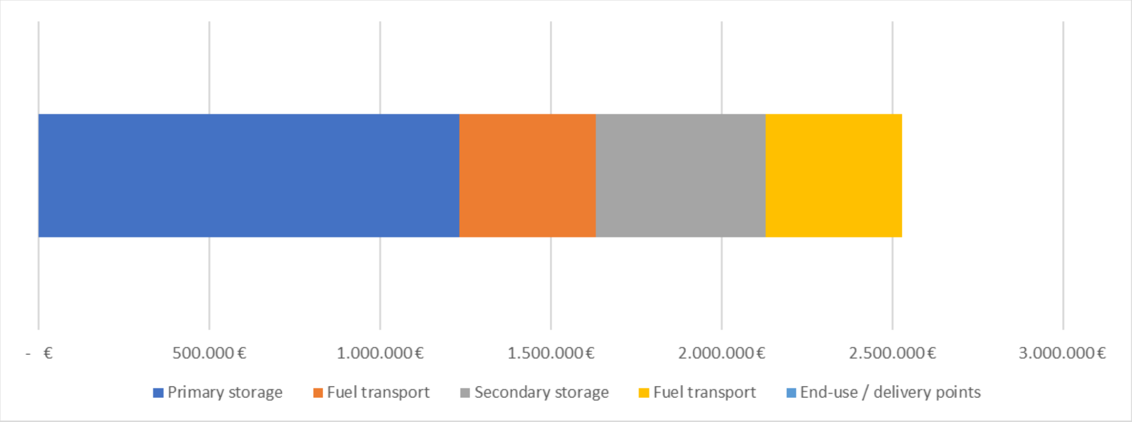
3.2.4 Consequences of risk exposure and required response

No direct risks for the analysed part of supply chain were identified, therefore no direct adaptations are necessary and the existing infrastructure and equipment can be used.

3.2.5 Cost assessment of the gas oil supply chain adaptations

The cost assessment shows that for adaptations of the model supply chain for 5 000 m^3 of 100% FAME biodiesel, a total investment of 2 529 891 EUR would be necessary. While primary storage would take 48% of the sum, truck transport adaptation from primary to secondary storage 16%, secondary storage adaptation 20% (additional epoxy coating of inner tank surfaces) present another substantial cost item), and fuel transport from secondary to final use 16%.

Figure 3-7 Adaptation costs of diesel supply chain



The costs of primary storage adaptation are of the same nature as the estimate in the previous case.

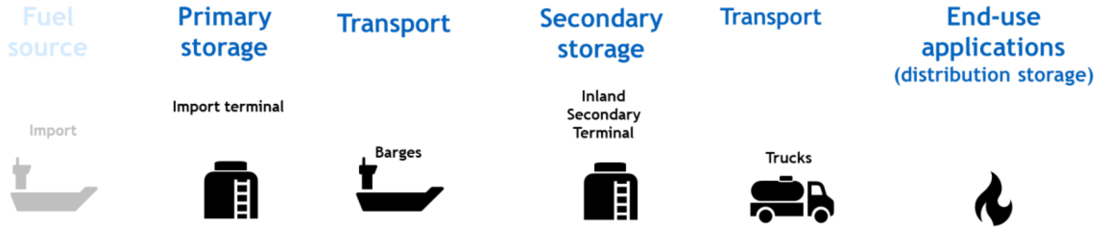
3.3 Gas Oil to Hydrotreated Vegetable Oil Biodiesel supply chain conversion

3.3.1 Gas oil supply chain description

The supply chain comprises the following stages:

- Central seasonal storage depot (in a port import terminal, to be suitable for barge transport);
- Barge transport;
- Secondary storage;
- Truck transport to final consumers;
- Domestic storage

Figure 3-8 Visual representation of conventional gas oil supply chain



Components description

Table 3-12 Summary of main gas oil supply chain components

Components of gas oil supply chain
Central (seasonal storage) at import terminal
Storage tanks
Pumps, metering equipment
Barge loading equipment (loading arm)
Barge transport
Barge tanks
Valves, pressure gauges, screens high-level alarm and flowmeters
Cargo pumps
Secondary storage (inland port)

Components of gas oil supply chain
Barge offloading equipment
Storage tanks
Truck loading equipment
Truck transport to domestic storage
Tank truck
Offloading equipment

3.3.2 *Scenario - switch to biodiesel*

Table 3-13 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
gas oil	biodiesel up to 100% (HVO)	import terminal	Barge (inland)	inland secondary terminal	Tank truck	domestic tank - heating fuel

In the case of switching from gas oil to HVO biodiesel, the biodiesel would be imported via an existing import terminal at the port. The entire existing supply chain would be therefore utilised for biodiesel transport as well. The alternative method of domestic production would also likely utilise the existing fossil fuel infrastructure, as converting existing refineries (for biodiesel production) is possible.

3.3.3 *Adaptation challenges*

Spatial distribution of the supply chain

The HVO fuels can be produced in standalone facilities or by adapting the existing hydrotreating equipment in conventional refineries. The biggest HVO production facilities are currently located in ports (for example Rotterdam, Singapore).[46]

Stockpiling heating fuels for winter

Since heating oil is a distillate fuel that is produced together with other main oil products such as gasoline and diesel, the production rate is limited and heating oils have to be stored to meet the increased seasonal demand in winter.[45]Although production of biodiesel is not dependent on the conventional fuel production, the need to stockpile fuels to cover the increased seasonal consumption remains unchanged.

General consideration of the differences between fossil-based heating oils and HVO biodiesel and their implications on the gas oil supply chain

Unlike the FAME biodiesels, HVO biodiesel offers better storage stability and better cold flow characteristics.[46] Low sulphur and oxygen content also means that the negative effects of FAME fuels on infrastructure materials degradation are avoided.

[45] U.S. Energy Information Administration (2020). Heating oil explained: Where our heating oil comes from. Available at: https://www.eia.gov/energyexplained/heating-oil/where-our-heating-oil-comes-from.php
[46]EAFO (2019). Hydrotreated Vegetable Hydrotreated Vegetable Oils: Overview. Available at: https://www.eafo.eu/alternative-fuels/advanced-biofuels/hvo.

Cold condition properties

Cold condition properties of HVO fuels are the most problematic element of HVO use in comparison with conventional diesel.[47] Unlike the FAME biodiesel, the cloud point of HVO biodiesel is not dependent on the feedstock origin. The cold flow properties can be regulated in the production facility by adjusting hydro-isomerisation reactor severity, tailoring the production to seasonal variation.[48]

Summary of HVO biodiesel challenges

In summary, HVO biodiesel should be suitable for use with current infrastructure without adaptation to the existing infrastructure. Since the production of HVO fuels seems to be centralised to existing refineries of major infrastructure hubs such as ports, the required spatial adjustments of supply chains also seem to be limited. However, HVO can also be upgraded to Sustainable Aviation Fuels, and therefore would be transported to airports (this use is addressed in a separate chapter).

3.3.4 Consequences of risk exposure and required response

No direct risks for the analysed part of the supply chain were identified, therefore no direct adaptations are necessary and the existing infrastructure and equipment can be used.

3.3.5 Cost assessment of the gas oil supply chain adaptations

As no changes are needed, no additional costs are expected when switching from fossil gas oil to Hydrotreated Vegetable Oil Biodiesel.

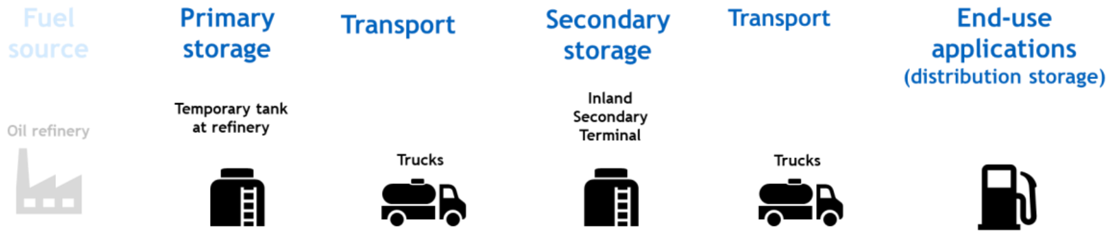
3.4 Gasoline to Bioethanol supply chain conversion

3.4.1 Gasoline supply chain description

The supply chain comprises the following stages:

- Primary storage: on-site temporary storage tanks (at the refinery);
- Tank trucks transport from primary storage of final product at refineries;
- Secondary storage;
- Tank trucks transport;
- Fuel station: distribution storage and fuelling equipment.

Figure 3-9 Visual representation of conventional gasoline supply chain



Transport from primary to secondary storage is more frequently done by barges, pipelines or rail than by trucks. However, the changes assessed to transport the fuel by trucks remain representative of what would be required for other transport mode.

[47] Soo-Young (2013). Application of hydrotreated vegetable oil from triglyceride based biomass to CI engines – A review. Available at: https://doi.org/10.1016/j.fuel.2013.07.001.
[48]Kalnes et al (2011). Green diesel production by hydrorefining renewable feedstocks. Available at: https://www.honeywell-uop.cn/wp-content/uploads/2011/01/UOP-Hydrorefining-Green-Diesel-Tech-Paper.pdf.

Components description

Table 3-14 Summary of main gasoline supply chain components

Components of gasoline supply chain
Primary storage
Storage tank
Rail loading facility
Pump valves
Tank truck transport
trucks
Secondary storage
Offloading equipment
Pump valves
Transport to final user
Tank truck loading rack
Tank trucks
Fuel station
Fuel tank
Fuel dispensers (including pump, filters, meters)

3.4.2 *Scenario - switching up to 100% bioethanol supply*

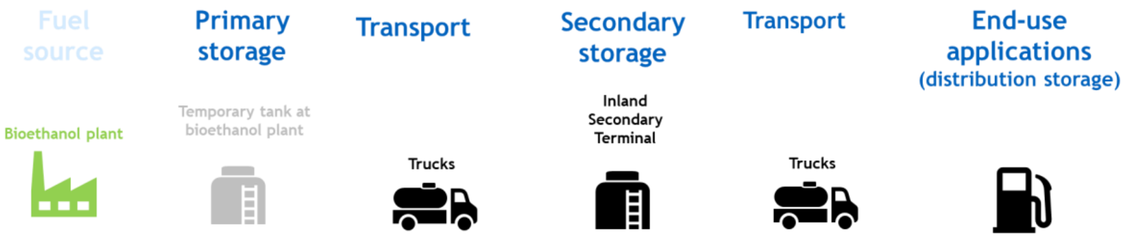
Table 3-15 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
gasoline	bioethanol up to 100% (e.g. from cereal and sugar crops)	(from bioethanol plant)	tank trucks	secondary storage	Tank trucks	fuel station - passenger cars

The scenario considers distribution of neat bioethanol (E100) or high-percentage mixtures with conventional gasoline (such as E85). Blending bioethanol with gasoline is currently done up to 10%. Higher rates of blends are possible without changes of equipment, and therefore at no cost. The current study focuses on neat alternative fuels (bioethanol) requiring the most changes in the equipment and infrastructure. From no cost in the current situation (10% blends) to a maximum cost for 100% alternative product, the adaptation of the infrastructure and equipment will be progressive, and will depend on each supply chain element.[49] The same applies for biodiesel.

[49] The gradation of the cost incurred by the changes of the supply chain elements is studied in several studies, and is still subject to research

Figure 3-10 Bioethanol supply chain



3.4.3 *Adaptation challenges*

General consideration of the differences between fossil-based gasoline and bioethanol

In general, bioethanol can be transported the same way and with the same equipment as conventional gasoline. For higher volume ethanol/gasoline blends and pure ethanol, specially adapted engines have to be used, so the end user equipment is not interchangeable (e.g. standard gasoline ICE vehicles cannot use pure ethanol as fuel). Furthermore, the use of some materials in the handling and storage equipment should be avoided, as explained below. Another problem is the affinity of ethanol for water, which can potentially lead to greater water contamination of the fuel.

Ethanol is a good solvent

Because ethanol is a good solvent, it can dissolve sediments from previous use in tanks or other equipment and subsequently clog filters or pumping devices. The problem of dissolving sediments occurs mainly when there is a change of use from conventional gasoline to bioethanol or bioethanol blend. In the long term, the same ethanol property can, on the other hand, help to prevent new material sedimentation.

Ethanol may degrade certain materials

Some materials, such as metals and polymers that are suitable for handling gasoline do react with ethanol, leading to material degradation and loss of functionality. For that reason, facilities handling ethanol blends have to be inspected and some parts have to be outright replaced as they would not be suitable for handling ethanol.

Figure 3-11 below summarises the impacts of ethanol blends on different hardware parts of fuel terminals and filling stations.

Figure 3-11 Recommended terminal and filling station hardware inspections and modifications

Ethanol content in the fuel	Petrol fuel grade	Nitrile rubber (seals and gaskets)	Fluoroelastomer (seals and gaskets)	Polyethylene pipes (nylon protective layer)	Polyethylene pipes (Fluroeslastomer protective layer)	Carbon steel tanks	Stainless steel (Tank gauge probes)	Aluminium (Tank gauge probes)	Aluminium (Fill pipe adapters)	Aluminium (Under pump valves etc.)	Brass valves (Vapour containment systems)	Non-ferrous fittings (Vapour recovery systems)
≤ 5 %	E0 – E5	Monitor/maintain	Monitor/maintain	Monitor/maintain	Monitor/maintain	Monitor/maintain	Monitor/maintain	Inspect/replace	Monitor/maintain	Monitor/maintain	Monitor/maintain	Monitor/maintain
5 % – 10 %	E10	Inspect/replace	Monitor/maintain	Inspect/replace	Monitor/maintain	Monitor/maintain	Monitor/maintain	Inspect/replace	Monitor/maintain	Monitor/maintain	Inspect/replace	Inspect/replace
10 % – 25 %	E10+	Inspect/replace	Monitor/maintain	Inspect/replace	Monitor/maintain	Monitor/maintain	Monitor/maintain	Inspect/replace	Inspect/replace	Inspect/replace	Inspect/replace	Inspect/replace
85 %	E85	Inspect/replace	Monitor/maintain	Inspect/replace	Monitor/maintain	Monitor/maintain	Monitor/maintain	Inspect/replace	Inspect/replace	Inspect/replace	Inspect/replace	Inspect/replace

Monitor/maintain   Inspect/replace

Source: EI/DFA[50]

Solubility in water

Since water is fully soluble in ethanol, any free water in the fuel facilities will be dissolved in the solution, potentially leading to overreaching the 0.3% water limit in fuel grade ethanol. Moreover, if enough water is dissolved with ethanol, it might separate from the fossil-based gasoline into two separate phases, which cannot be reblended back together without further processing (thus potentially devaluating the fuel). However, with the higher volume of ethanol, the amount of water contamination necessary to cause phase separation also increases, reducing the risk for higher-volume blends. Phase separation is also not a risk for 100% bio-ethanol storage or transport. Increased water content can also react with materials of the handling equipment, leading to material degradation. This is due to higher electric conductivity of water (in comparison to gasoline), which can lead to galvanic corrosion of metals. Water also carries corrosive chlorides, salts and other ions that can cause further corrosion.

Transport of bioethanol

Risks associated with water affinity of ethanol have impacts on the fuel distribution. In particular, tank trucks may face issue of sediments from previous use contaminating the fuel, and of water leaks able to dissolve in the fuel, lowering its quality. Barge and ship transport is under risk of water and salt contamination from the surrounding environment. It could be also more effective to mix bioethanol and gasoline in later stages of the supply chain, just before distributing to the point of final consumption. That way, all the required adaptations of the gasoline supply chain would be avoided, although additional supply chains for ethanol transport would have to be established.

Transport via multiproduct pipeline should not be an issue, as appropriate transmix would completely remove potential residual water content which is normally dissolved in ethanol (the concentration of water would not reach any substantial level with pure ethanol).

According to one stakeholder, there could be a problem of cleaning and drying pipelines which could be expensive. This could probably be solved with adequate transmix.

[50] EI/DFA (2014). Compatibility of materials used in distribution handling systems with ethanol and gasoline/ethanol blends.

Storage at a fuel station

Besides the necessary adaptations of equipment due to material compatibility, there are limited possibilities for storage at fuel stations. A typical fuel station might for example have three storage tanks, for storing diesel, regular gasoline and premium gasoline. If one of the gasoline storage tanks were to be converted to bioethanol storage, the capacity of the fuel station to distribute gasoline to conventional ICE vehicles would be reduced, since they are not suitable for bioethanol above a certain blending rate, which should increase over time.[51] Therefore, a new storage tank might be needed to address the situation.

Table 3-16 Summary of main adaptation risks and challenges

Supply chain component	Vulnerabilities and risk exposure
Fuel transport	
Aluminium and rubber parts (valves, gauges)	• Material degradation
Truck Tanks	• Sediments from previous use can contaminate the fuel; • Water leaks can dissolve in the fuel, lowering its quality
Fuel station	
Storage tanks	• Material degradation in certain parts (aluminium, rubber, brass); • Limited storage possibilities - bioethanol would replace some other stored fuel; • Sediments from previous use can contaminate the fuel;
Fuel dispensers	• Material degradation in certain parts (aluminium, brass); • Swelling of elastomers (in case of low-volume ethanol blends)

3.4.4 *Consequences of risk exposure and required response*

Table 3-17 Summary of main adaptation measures

Challenge in supply chain adaptation	Consequences & responses
Contamination of bioethanol with sediments from previous use of infrastructure; Preventing water contamination	• Inspect and clean tanks before injecting ethanol • All vents should be fitted with screens or breathers designed in such a way to minimise the ingress of contaminants; • Above ground storage tanks should be equipped with a low point sump and a drain line with a valve that is suitable for removing water and sediment; • Excessive tank water in the bottom should not be permitted in product tanks. All tanks should be constructed with adequate water removing capability; • Fill connections and gauge access points should be provided with tightly fitting covers to prevent entry of water or solid contaminants and evaporative loss. When accessing them, care should be taken to prevent further contamination.
Material degradation	• When switching to high volume ethanol blends or pure bioethanol, inventory of component materials should be made and those incompatible with ethanol should be replaced:

[51]NREL (2014). Increasing Biofuel Deployment and Utilization through Development of Renewable Super Premium: Infrastructure Assessment. Available at: https://afdc.energy.gov/files/u/publication/increasing_biofuel_deployment.pdf

	○ Inspect and replace rubber seals – replacing nitrile rubber (NBR) by fluoroelastomers (FKM); ○ Upgrade plastic pipes from nylon inner barriers to FKM or Polyvinylidene fluoride (PVDF) materials; ○ Tank gauges: upgrade to stainless steel probes and floats (from aluminium and nitrile rubber materials); • Monitor any other non-ferrous components, valves and other fittings for evidence of degradation (corrosion).

3.4.5 Cost assessment of the gasoline supply chain adaptations

The assessment of adaptation costs cover actions in the primary storage, fuel transport, secondary storage and in fuel stations distributing the fuel to the end consumers. The modelled case assumes a supply chain with capacity for handling 5 000 m^3 of bioethanol. Table 3-18Table 3-18 below presents the modelled adaptations and assumptions regarding equipment.

Table 3-18 Summary of adaptation actions and assumptions regarding equipment

Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage	Supply chain relocation	New storage site at bioethanol production site	Storage tank; meters, filters	5 000 m^3
Fuel transport	Unsuitable materials	New fuel trucks		4 fuel trucks
Secondary storage	Supply chain relocation	New blending equipment		Blending tank 5 000 m^3
Fuel transport	Unsuitable materials	New fuel trucks		4 fuel trucks
Fuel station	Unsuitable materials	New fuel station for higher blend and neat bio fuel		New equipment

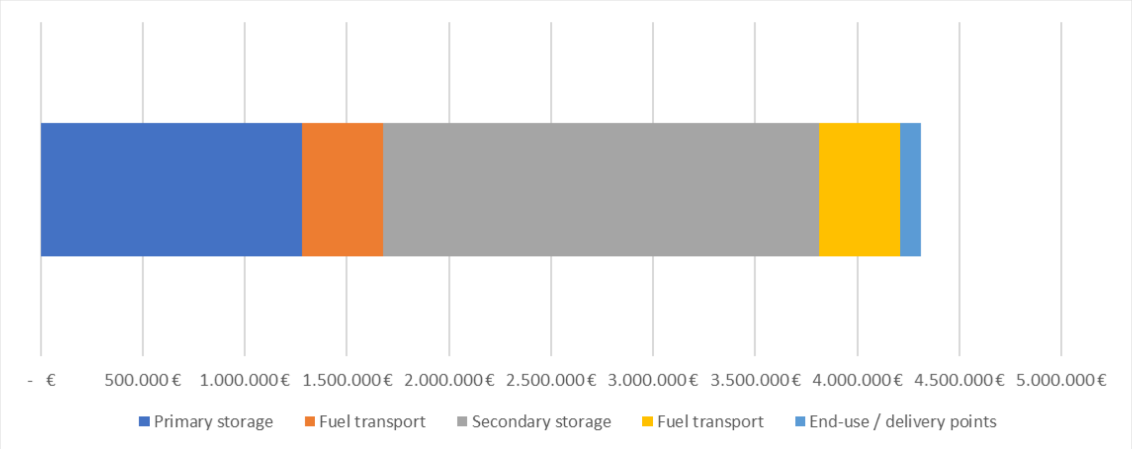
Cost estimate

The results of the cost assessment are presented in Figure 3-12.

The cost assessment shows that for adaptations of the model supply chain for 5 000 m^3 of 100% FAME biodiesel, a total investment of 4 311 983 EUR would be necessary. While primary storage would comprise 30% of the sum, truck transport from primary to secondary storage 9%, secondary storage adaptation 50%, fuel transport from secondary to final use 9%, and finally end-use adaptation at fuel stations 2%.

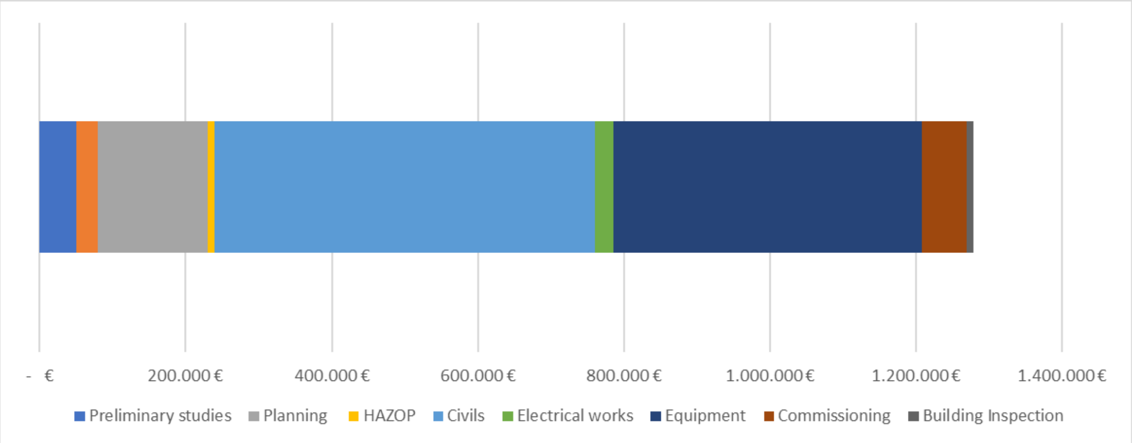
As presented in the Figure 3-4 below, the largest portion of the primary storage would be the civil works & equipment.

Figure 3-12 Adaptation costs of gasoline supply chain



As shown in Figure 3-13,the biggest items on in the equipment and installation costs are the storage tanks (at primary and secondary storage sites) and the required transport trucks. The other substantial cost item is the adaptation of the fuel station.

Figure 3-13 Equipment and installation costs for primary storage adaptation (ethanol supply chain)



Size variation

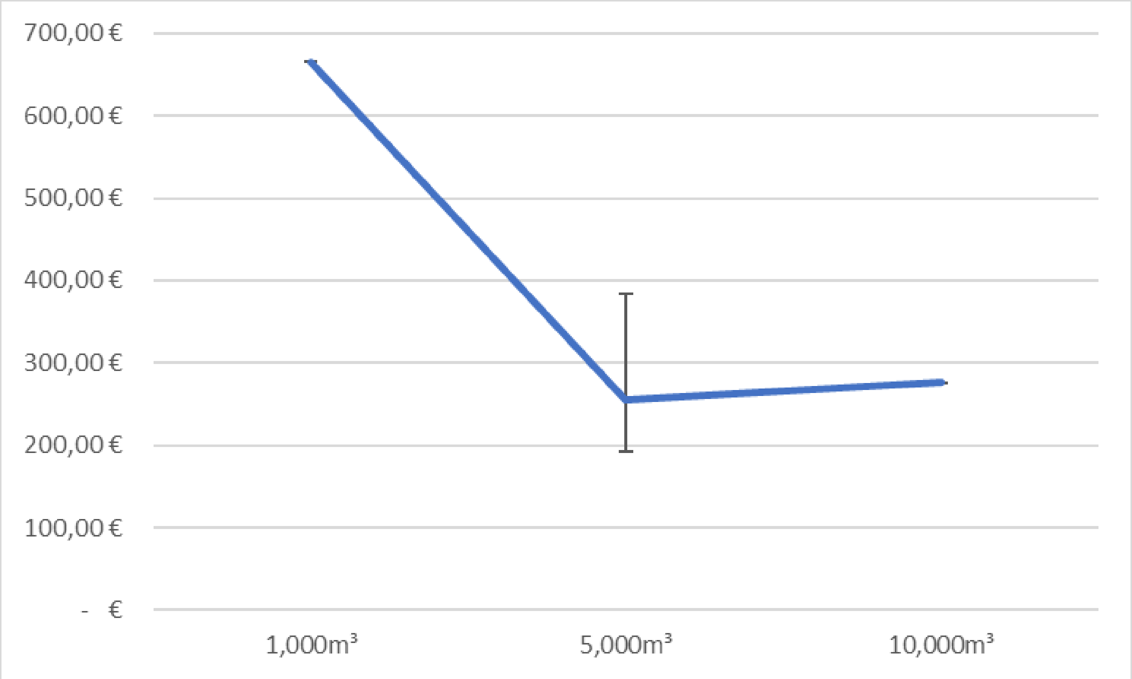
To address the influence of fixed costs on the final estimate, Table 3-19 presents the cost estimates for three model supply chains with different fuel handling capacity, ranging from 1000 m^3 to 10 000 m^3. As can be expected, the unit cost of new equipment cost installation decreases with the volume of handled fuel, from 666 EUR/m^3 for the smallest tank to 276 EUR/m^3 for the largest tank.

Table 3-19 Primary Storage adaptation costs variation for different tank sizes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m^3)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
1 000 m^3	665.860 €	36.000 €	666 €		
5 000 m^3	1.279.163 €	60.000 €	256 €	959.372 €	1.918.744 €
10 000 m^3	2.762.821 €	120.000 €	276 €		

Figure 3-14 presents the decreasing unit cost per m³ of installed storage. For the central case of supply chain for 5 000 m³ of fuel, the estimated error margin shows that the unit cost could reach between 192 EUR and 384 EUR.

Figure 3-14 Unit cost for different storage sizes



Levelised cost of adaptation

Assuming the project lifetime of 20 years, the levelised cost of investment in adaptations of gasoline supply chain for bioethanol handling will reach 0.016 EUR per m³.

Table 3-20 Levelised cost of adaptation measures

Total investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/m³)
1.279.163 €	60.000 €	20	1314 (15%)	0,016 €/m3

3.5 Natural gas (LNG) to hydrogen supply chain conversion

The supply chain comprises three stages

- LNG import terminal and bulk storage at port;
- Pipeline transport (no secondary storage);
- Distribution storage and fuelling equipment at the refuelling station.

3.5.1 Natural gas supply chain description

Figure 3-15 Visual representation of natural gas supply chain

Component description

Table 3-21 Summary of main LNG supply chain components

Components of Natural Gas supply chain
Import terminal
Unloading berth: unloading arms, vapour return arm
Cryogenic tank, boil off compressors, recondensing unit
Regasification unit: pumps, vaporiser
Meters
Pipeline compressors
Pipeline transport
Pipeline
Compressors
Metering equipment
Delivery to final users - fuel station
Storage vessel
CNG compressor
CNG dispenser

3.5.2 Scenario - switch to hydrogen

Table 3-22 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
methane / LNG (from scratch)	compressed / liquid hydrogen	import terminal	Pipeline	NA	NA	fuel station

In this scenario, the natural gas infrastructure, supplying imports of natural gas in liquid state to CNG vehicles is adapted to handle imports of liquid hydrogen. Due to differences in handling liquefied hydrogen and liquefied natural gas (in particular the much lower temperature of LH2), it is not possible to adapt existing the LNG infrastructure for handling liquefied hydrogen (more details are in the next section), so this option is not taken further as a proposed case.

For pipeline transport, it is mostly safe and possible to blend hydrogen with natural gas in the existing infrastructure up to 10% of volume (and probably even more) with only small modifications.[52] However, for the purpose of final consumption in fuel cells, the hydrogen would have to be separated again. A conversion of pipeline to pure hydrogen transport is therefore investigated.

As can be seen in Figure 3-16 below, low-volume hydrogen admixture in natural gas (up to 5%) can be used in CNG vehicle engines. This blend ratio can be also transported via the existing natural gas infrastructure and therefore this case is not investigated further.

3.5.3 *Adaptation challenges*

Spatial distribution of the supply chain

While hydrogen production can be dispensed in locations with abundant renewable energy availability, it is estimated that the level of demand for green hydrogen in Europe will necessitate imports from third countries. It is therefore justified to expect that hydrogen infrastructure can develop in parallel with the existing NG import routes (e.g. from main ports by pipeline to consumption centres).

General consideration of hydrogen and its implications on LNG supply chain

Hydrogen leakage and safety of use

The smaller size of hydrogen molecules (in comparison to methane) means that it permeates more easily through materials, leading to potential leaks. For example, permeation rates of hydrogen can be four to five times higher than methane through polymer pipes and three times higher through steel and iron pipes. With polymer pipes leakage occurs primarily through the pipe walls, whilst in steel pipes (and potentially other equipment) leakage occurs in particular in welds and threads.[53] This also means that hydrogen can leak at much a faster pace through defects, leading to risk of gas accumulation in confined spaces.

Pipeline integrity

Hydrogen also enters and diffuses more easily (than NG) into steel materials, leading potentially to weakening of the material and increased speed of propagation of defects. This effect is called hydrogen embrittlement. The sensitivity of steel pipelines depends on variety of factors, especially:

- Diameter of the pipeline – larger transmission pipelines seem to be more sensitive to hydrogen;
- Impurities in hydrogen, such as hydrogen sulphide or water;
- Operating pressure – the sensitivity increases with higher pressures.

Given the impact of higher pressures, hydrogen embrittlement can be a significant issue in case of LNG infrastructure conversion. The adaptation measures are under research, but involve primarily surface coating to prevent hydrogen absorption. Other materials, such as polyethylene, are not affected by hydrogen, but on the other hand they have higher permeability (leading to hydrogen losses) and are less suitable for higher pressures than steel.

[52]Marcogaz (2019). Overview of available test results and regulatory limits for hydrogen admission into existing natural gas infrastructure and use.
[53]Myers Jaffe et al (2017). The Potential to Build Current Natural Gas Infrastructure to Accommodate the Future Conversion to Near-Zero Transportation Technology.

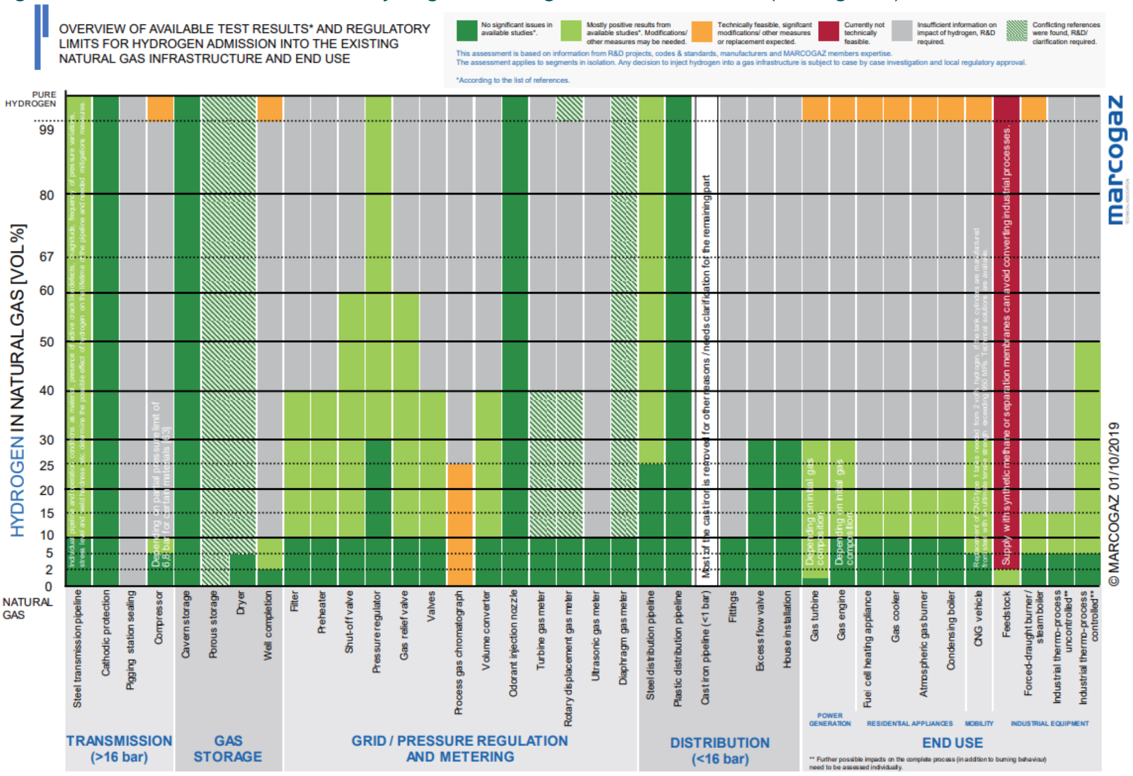
Import terminal and regasification facilities

A crucial difference between liquid hydrogen and natural gas is the storage temperature of the liquid. While LNG is stored at temperature around -160 °C, the temperature for storing liquid hydrogen is -253 °C. The receiving, storage and gasification equipment of an LNG terminal is therefore unsuitable for hydrogen handling and it is not possible to adapt it for this task. There might however be possibility of utilising some elements of the existing facilities that are not directly handling the energy carrier. For example, the import terminal for liquid hydrogen might be built in the existing LNG import terminal[54], which could lower the overall costs.

Pipeline transport

While it is currently accepted that low-volume hydrogen blends in natural gas infrastructure are possible, its compatibility with pure hydrogen use has not been fully researched yet. An overview of existing research by Marcogaz is presented in Figure 3-16. The research suggests that use of existing transmission and distribution pipelines is possible with only minor adaptations, although "individual pipeline and operation conditions as material, presence of active crack like defects, magnitude, frequency of pressure variations, stress level and weld hardness etc. determine the possible effect of hydrogen on the lifetime of the pipeline and necessary mitigation measures". Compressor units and most end-use equipment can be technically adapted to pure hydrogen use, but it would require significant efforts. For grid regulation and metering equipment, more research is necessary in most cases.

Figure 3-16 Overview of research on hydrogen blending in NG infrastructure (Marcogaz52)



[54] RWE (2021). H2 Brunsbüttel. Available at: https://www.group.rwe/en/our-portfolio/innovation-and-technology/hydrogen/h2-brunsbuettel.

Deblending of hydrogen

One pathway that would enable the use of existing natural gas pipelines without much adaptation is transporting hydrogen blended with natural gas and deblending the two substances before delivery to end use. There is mature technology available (cryogenic or membrane separation combined with pressure swing absorption) that can deblend high purity hydrogen. However, an additional purification step of hydrogen is required for transport uses (e.g. getting rid of sulphur based odorant).[55] The cost competitivity of this option is however not clear and in the long term view of decreasing natural gas consumption, it is not clear whether this investment would not become a stranded asset if hydrogen-only supply chains were to be established.

Refuelling stations

The equipment of hydrogen refuelling station is analogous to a CNG station. The biggest difference is that hydrogen handling equipment operates at much higher pressures between 350 -700 atm, while CNG typically operates at pressure of 200 – 250 atm. The higher operating pressure is required since hydrogen has lower volumetric energy content. To prevent material degradation, steel hydrogen storage vessels also require polymer coating of the surfaces.

Because of the higher operating pressures and also due to different physical properties of hydrogen, a different compressor design is required, rendering the CNG compressors useless.

Table 3-23 Summary of main adaptation risks and challenges

Supply chain component	Vulnerabilities and risk exposure
Import terminal	
LNG infrastructure: Unloading arms; Cryogenic storage; pumps, boil off compressor, vaporization unit	• LNG infrastructure incompatible with liquid hydrogen due to difference in storage/handling temperatures
Gas pipeline	• Steel embrittlement
Gas compressors	• Steel embrittlement
Metering equipment	• Steel embrittlement
Pipeline infrastructure	
Transmission pipelines	• Steel embrittlement
Compressors	• Compressor not compatible with hydrogen without significant adaptation effort; • Steel embrittlement
Metering units	• Steel embrittlement
Distribution pipelines	• Higher level of hydrogen leakage in polymer pipes (additional safety risk
Refuelling station	
Storage vessel	• Higher operational pressure of hydrogen; • Steel embrittlement
CNG compressor	• Physical properties of hydrogen require different compressor design; • Higher operational pressure of hydrogen; • Steel embrittlement
CNG dispenser	• Higher operational pressure of hydrogen; • Steel embrittlement

[55] Koller and Green (2020). Hydrogen Deblending. GGG Workshop on 17 July 2020. Available at: https://www.energynetworks.org/industry-hub/resource-library/gas-goes-green-2.2-webinar-slides.pdf.

3.5.4 Consequences of risk exposure and required response

The main natural gas infrastructure element suitable for conversion to pure hydrogen supply is the pipeline network. On the other hand, LNG infrastructure, including facilities in import terminal as well as in refuelling stations, is not suitable for handling liquid hydrogen. These supply chain elements would become stranded assets if LNG were to be completely substituted by hydrogen, but might still be utilised for e.g. liquid biomethane handling.

CNG supply chain infrastructure is more suited for conversion to hydrogen transport, but would still require replacement of major infrastructure components.

Table 3-24 Summary of main adaptation measures

Challenge in supply chain adaptation	Consequences & responses
Adaptation of LNG import terminal	• The equipment for handling and storing LNG is cannot be used for hydrogen. In the long term (depending on the demand for NG), this might become a stranded asset. Parallel infrastructure for hydrogen will have to be constructed.
Adaptation of pipeline network	• The suitability of NG networks for pure hydrogen transport is still being investigated, but some components such as compressors will definitely have to be upgraded .
Adaptation of storage facilities	• Steel vessels without polymer coating will have to be replaced to prevent material degradation; storage facilities also have to withhold higher operating pressures.
Replacing fuel dispensers and compressors in refuelling stations	• The equipment has to be replaced to be able to handle higher operational pressure

3.5.5 Cost assessment of the natural gas supply chain adaptations

Assumptions regarding the equipment

The supply chain adaptations included in the cost assessment cover primary storage at the import terminal, fuel transport via adapted natural gas pipeline system and converted fuelling station. The modelled case concerns a supply chain with capacity for handling 10 000 m^3 of hydrogen. Table 3-25 below presents the assessed adaptations and assumptions regarding the equipment.

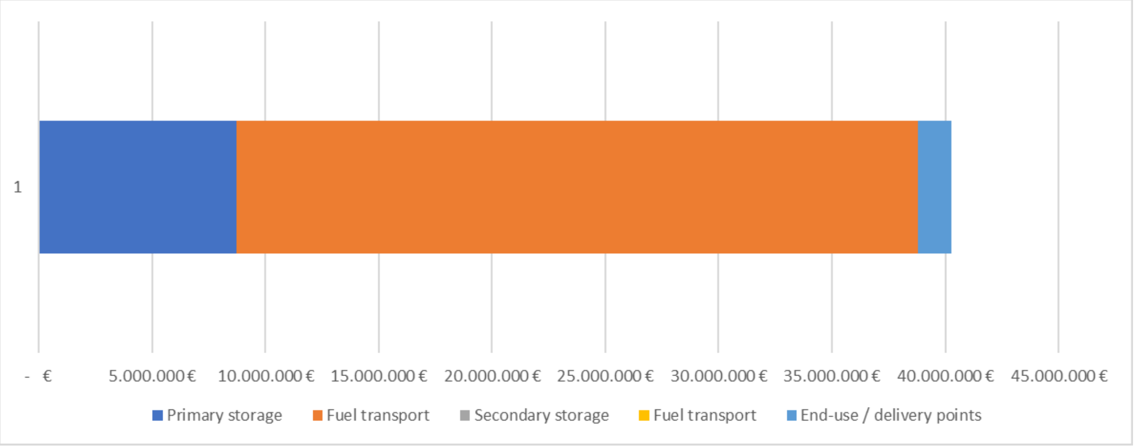
Table 3-25 Summary of adaptation actions and assumptions on equipment

Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage at import terminal	Unsuitable materials and tank design	New storage tank	New storage tank, compressors, pumping system, etc.	10 000 m^3
Fuel transport by pipeline	Unsuitable materials	Pipeline adaptation	Steel pipes adaptation; new compressors, valves, meters, etc.	100 km of pipeline
Fuelling station	Unsuitable materials; different operational pressure	Upgrading station equipment	New storage tank, compressors, fuel dispensers, etc.	

Cost estimate

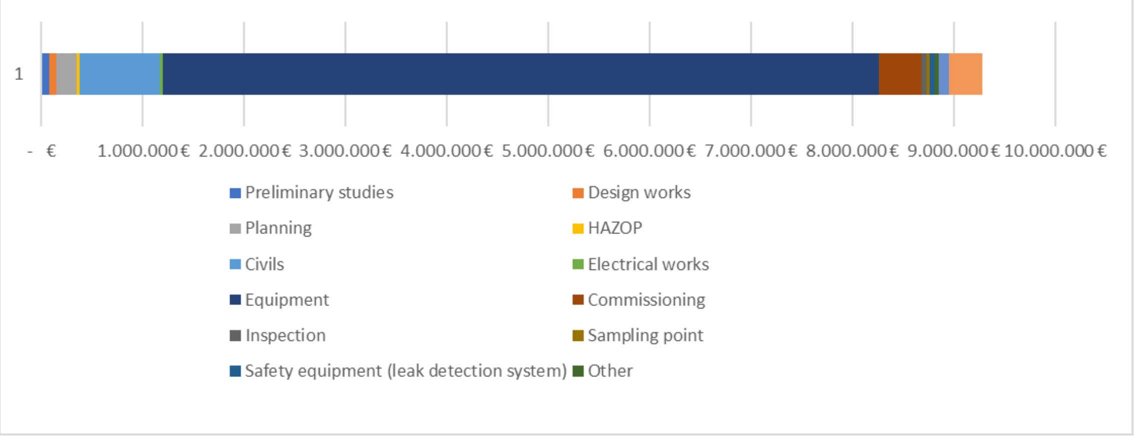
The cost assessment shows that for adaptations of the model supply chain for hydrogen (10 000 m^3 storage tank, 100 km of pipeline and 1 refuelling station), an investment of 38 335 375 EUR would be necessary. Fuel transport via pipeline represents 74.5% of the sum and the primary storage 21.5%, only 4% for the fuel station adaptation.

Figure 3-17 Adaptation costs of hydrogen supply chain elements



As presented in the Figure 3-18 below, the largest part of the primary storage investment is related to tank and equipment.

Figure 3-18 Investment cost breakdown per primary storage



Primary storage tank size variation

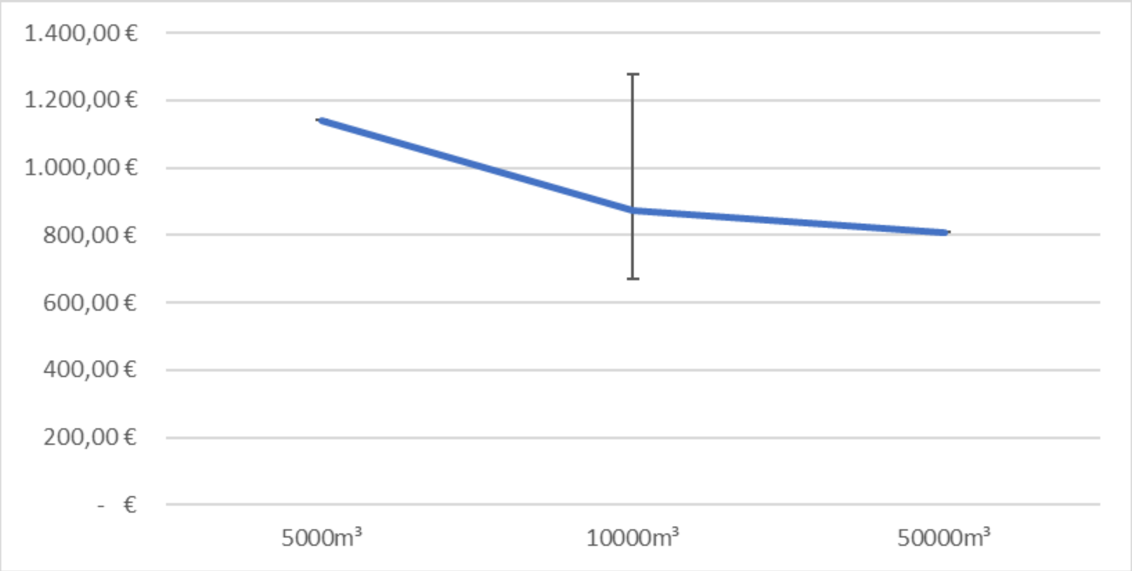
To address the influence of fixed costs on the final estimate, Table 3-26 presents the cost estimates for three different import terminal storage tanks capacity, ranging from 5 000 m^3 to 50 000 m^3 of storage in the import terminal. As can be expected, the unit cost of new equipment cost installation and adaptations decreases with the increased storage volume, from 1 140 EUR/m^3 for the smallest volume to 8095 EUR/m^3 for the largest volume.

Table 3-26 Supply chain adaptation costs variation for different import terminal storage sizes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m³)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
5 000 m³	5.700.474 €	36.000 €	1.140 €		
10 000 m³	8.733.401 €	60.000 €	873 €	6.550.051 €	13.100.102 €
50 000 m³	40.426.969 €	120.000 €	809 €		

Figure 3-19 presents the decreasing unit cost per m³ of installed storage. For the central case with import terminal storage tank for 10 000 m³ of fuel, the estimated error margin shows that the unit cost could reach between 655 EUR and 1 310 EUR.

Figure 3-19 Unit cost for different storage sizes



Levelised cost of adaptation

The table below presents the levelised cost of supply chain adaptation for hydrogen, broken down by each assessed supply chain element. Assuming the equipment lifetime of 20 years, the levelised cost of primary storage investment will reach 0.045 EUR per kg, mostly due to investment in pipeline adaptations.

Table 3-27 Levelised cost of adaptation measures

Supply chain element	Investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/kg)
Import terminal storage	8.733.401 €	120.000 €	20	1 314 (15%)	0,002 €
Pipeline	33.883.605 €	120.000 €	20	2 628 (30%)	0,042 €
Fuel station	1.451.363 €	12.000 €	20	1 752 (20%)	0,003 €
Total	**44.068.369 €**	**252.000 €**			**0,047 €**

3.6 Conventional fuel to renewable ship fuels supply chain conversion

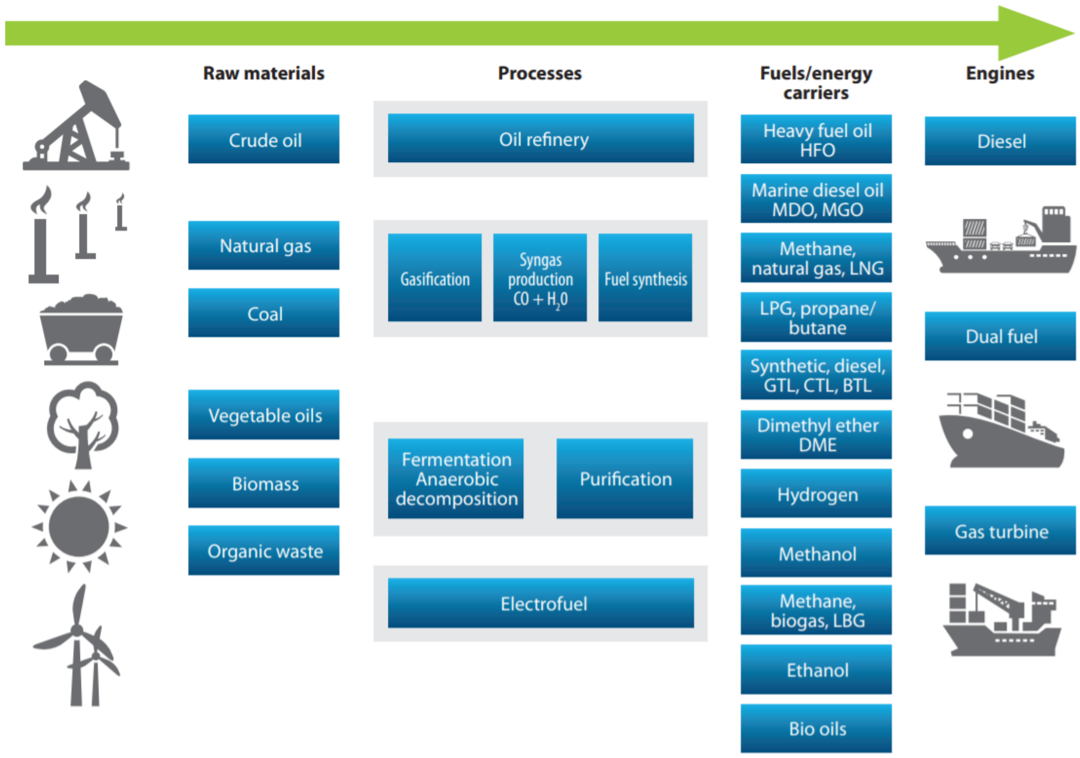
3.6.1 Ship fuel supply chain description

The focus of this case study is the infrastructure for seafaring vessels, supplied via maritime port.

Conventional shipping fuels encompass: gasoil (10ppm), marine gasoil, marine diesel oil, sulphur fuel oils (ultra-low, very low, high). In this case **Heavy Fuel Oil** (HFO) is considered, given that it is still currently the main type of bunker oil for ships, derived as a residue from crude oil distillation[56], although the use of gasoil is increasing.

Alternative fuels in shipping are still at an early stage (demonstration projects), and there is a long list of fuels or energy carriers that can be used in shipping[57], illustrated by Figure 3-18. The most commonly considered today are Liquefied Natural Gas (LNG[58]), electricity, biodiesel, methanol, and ammonia. E-fuels for the maritime sector comprises hydrogen, methanol, ammonia, and other power-to-liquids[59]. For this case, we consider **e-methanol**, although ammonia remains a good option[60], and could also be further explored given the fact it is considered a high health hazard because its corrosivity (to the skin, eyes and lungs), and flammability characteristics.

Figure 3-20 examples of pathways to marine fuels



Source: FCBI-Methanol-Marine-Fuel-Report-Final-English.pdf[61]

[56] https://www.ing.be/assets/nuid/documents/GREEN%20SUPPLY%20CHAINS%20-%20IMPLICATIONS%20AND%20CHALLENGES%20FOR%20RHINE-SCHELDT%20DELTA%20SEAPORTS_DIGITAL.pdf
[57] https://www.eafo.eu/shipping-transport/shipping-overview/af-for-shipping
[58] https://www.transportenvironment.org/sites/te/files/LNG_as_a_marine_fuel_in_the_EU_UMAS_2018.pdf
[59] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_Shipping_Sep_2019.pdf
[60] https://www.lr.org/en/insights/articles/the-complexities-of-the-fuel-supply-chain-as-maritime-moves-towards-zero-carbon/
[61] http://www.methanol.org/wp-content/uploads/2018/03/FCBI-Methanol-Marine-Fuel-Report-Final-English.pdf

Visual representation of the complete supply chain

Usually for HFO, onshore extraction occurs abroad (e.g. Russia[62]) and transport occurs via pipeline or ship on a long distance (several thousands of km) up to a refinery. It is assumed that HFO is then distributed by barge, pipeline or rail.

For the purpose of this study we consider the supply chain comprises four stages:

- Import Terminal receiving final product (from HFO to H2/methanol) with bunkering infrastructure;
- Transport via pipeline;
- Stored in bunker depots (secondary storage);
- Finally transported/delivered by bunkering tankers to final users (maritime ships).

Components description

Table 3-28 Summary of main marine fuel supply chain components

Components of Marine fuels supply chain
Import terminal
Terminal Tanks
Pump devices
Meters
Pipeline
Pipeline
Pump devices
Meters
Fuel filtration
Secondary storage
Tanks (port depots)
Pump devices
Meters
Bunkering tankers
Hoses
Valves, level gauges
Pump devices
Bunkering tanks

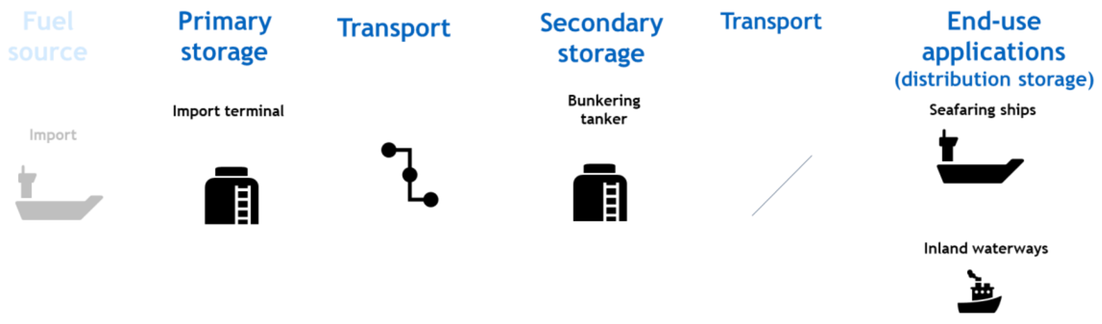
3.6.2 *Scenario - switch to e-methanol (and bio-methanol)*

Table 3-29 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
ship (marine) fuel	e-fuel (methanol)	(from remote large wind farm-H2 production) import terminal	Pipeline	Bunker depot	NA	ship

[62]https://www.mdpi.com/1996-1073/13/11/2739

Figure 3-21 HFO bunkering pathways for maritime and inland waterways



The majority of methanol production today is based on a mixture of hydrogen and carbon monoxide produced from natural gas or coal.

As methanol is widely available and extensively used in other industries, there is a lot of industrial experience on the best transport, handling and operation practices (ITF, 2018). Methanol also offers advantages in terms of bunkering requirements, when compared to LNG – a fuel frequently considered by the industry to be a feasible option to replace oil-based marine fuels. At ambient temperature, methanol is liquid and therefore more compatible with existing bunkering infrastructure, as it can be stored in regular, non-pressurised tanks. However, the fact that methanol occupies more than twice the space of Marine Gas Oil (and HFO) must be taken into account as this affects both onshore and shipping infrastructure.

Renewable (and bio)-methanol are compatible with current methanol dual-fuel engine technology, without future investment or compatibility issues.[63] To hedge the risk of fuel price volatility, shipping companies may choose to diversify their fuel mix to operate on flex-fuel methanol/diesel engines. Consequently, there would have to be double storage and transport infrastructure to handle both products at the same time.

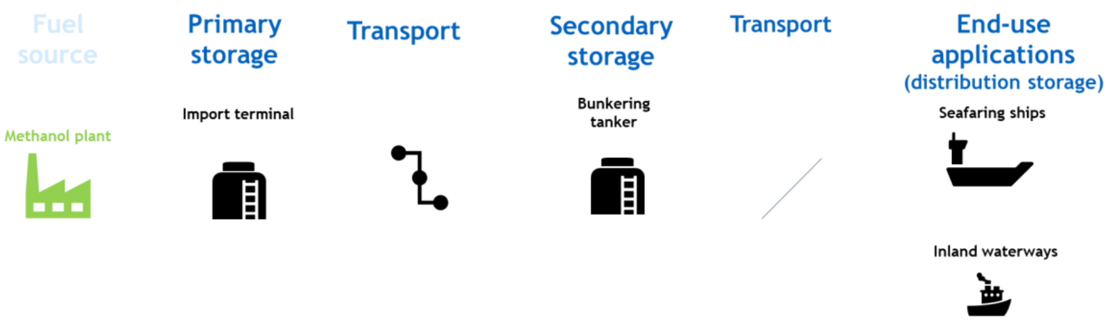
Methanol also offers improved fuel efficiency over conventional fuels.

As a liquid fuel, methanol does not require expensive cryogenic equipment and is more economical to convert to and operate compared with other fuels that require cooling or pressurisation.

E-methanol can be produced using CO2 captured from renewable sources such as bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC), plus green hydrogen (hydrogen produced with renewable electricity).[64]

[63] https://www.methanex.com/sites/default/files/about-methanol/Methanol%20as%20a%20Marine%20Fuel_Final_2021-03-02.pdf
[64] https://ihsmarkit.com/research-analysis/methanol-production-capacity-may-quintuple-on-decarbonized-ind.html

Figure 3-22 Schematic representation of e-methanol downstream supply chain



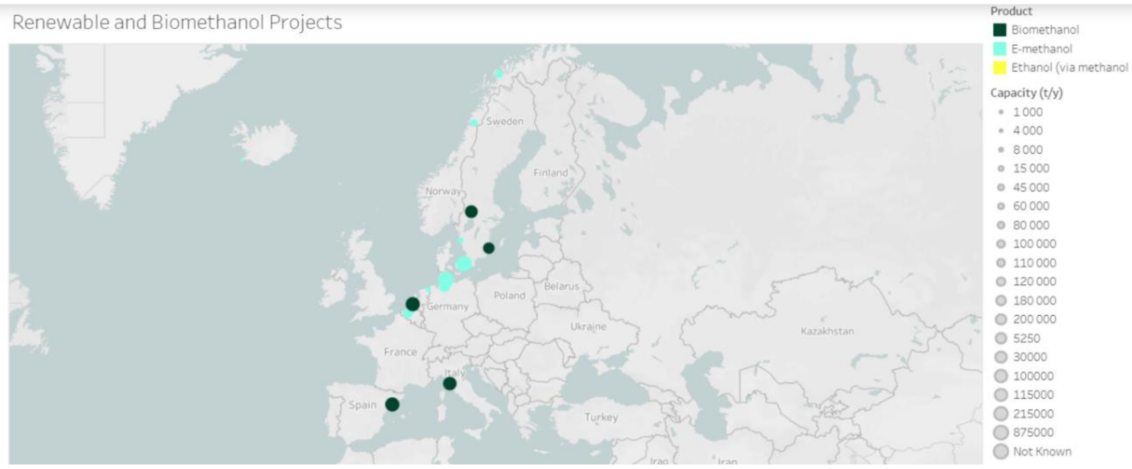
3.6.3 *Adaptation challenges*

Spatial distribution of the supply chain

Since e-methanol production sites need to be in close proximity to the sources of hydrogen and carbon dioxide used for the fuel production, their geographical location is not necessarily in line with existing conventional Heavy Fuel Oil (or any petroleum product) infrastructure, which is optimised at the refinery and around the oil import routes. Therefore, some adaptations of the supply routes or additional transport steps might be required, such as transport of e-methanol from a methanol production facility to a collection point where it will be distributed along the more conventional supply routes.

There are currently 9 e-methanol plants, and 5 bio-methanol projects under development in EU, according to the Methanol Institute.[65]

Figure 3-23 European Renewable and Biomethanol projects



General considerations & implications of existing supply chain elements

Methanol is the world's most commonly shipped chemical commodity and more than 95 billion litres are manufactured every year. It has been stored, transported and handled safely for over 100 years. Since it remains liquid at ambient temperature and pressure, the infrastructure required to deploy it as a fuel is largely in place: combustion engines, fuel cells and power blocks could quite easily and affordably be adapted to methanol.[66]

[65] https://www.methanol.org/renewable/
[66] https://www.methanol.org/wp-content/uploads/2019/01/MethanolReport.pdf

Supply infrastructure is often in place for methanol, as it is already available and shipped through many ports around the world. Although methanol is less energy dense than traditional fuels, requiring more storage space on board, it's a liquid fuel, so it can be stored in ballast and "slop" tanks.

Methanol degradation via microbial degraders

An active microbial community of methanol degraders can become established within a few days after a surface water release. Dissolved oxygen concentration in water is the limiting factor for the biodegradation rate. In surface water, a typical degradation rate is 10 mg/l per day. At concentrations less than 3,000 mg/l, methanol is readily degraded in a wide range of subsurface conditions.[67] However, methanol concentrations above 10,000 mg/l can inhibit the microbial population and lower the degradation rate. Handling and storage should respect safe procedures when using this product.

Microbial contamination

Microbial contamination is not an issue for methanol.

Freezing & boiling temperatures of methanol

Methanol is liquid at ambient temperatures and pressures with liquid freezing point at -97C, and liquid boiling point at 65C.

Lower energy content

A drawback of alcohol fuels such as methanol is that energy contents are lower than for traditional fuels, therefore the space needed for storing methanol in a tank will be approximately twice that of traditional diesel fuels. Methanol and LNG are similar in terms of energy density.[68]

Safety of use

In November 2020, the Maritime Safety Committee of the International Maritime Organization (IMO) adopted interim guidelines on the use of methanol as a marine fuel, making ethyl and methyl alcohols safe ship fuel options for shipowners and operators[69]. Twelve methanol powered ships are already in operation, with another 10 on order.[70]

Environmental impact

From an environmental point of view, methanol performs well. Methanol readily dissolves in water and is biodegraded rapidly, as most micro-organisms have the ability to oxidise methanol. In practice, this means that the environmental effects of a large spill would be much lower than from an equivalent oil spill. In addition, marine methanol fuel produces no sulphur emissions and very low levels of nitrogen oxide emissions. It is therefore compliant with the main emissions reduction measures and regulations.[71]

Corrosion

Methanol is a conductive polar solvent (while gasoline is a non-conductive, non-polar solvent). Galvanic and dissimilar metal corrosion in methanol service may be high if incompatible materials are placed in

[67] http://www.methanol.org/wp-content/uploads/2016/06/Methanol-Safe-Handling-Manual-Final-English.pdf
[68] http://www.methanol.org/wp-content/uploads/2018/03/FCBI-Methanol-Marine-Fuel-Report-Final-English.pdf
[69] https://www.rivieramm.com/news-content-hub/news-content-hub/imo-approves-methanol-as-a-safe-ship-fuel-62055
[70] https://www.marinelink.com/news/abs-publishes-guidance-methanol-marine-485573
[71] http://www.methanol.org/wp-content/uploads/2018/03/FCBI-Methanol-Marine-Fuel-Report-Final-English.pdf

electrical contact with one another. Cathodic protection, and regular inspection of methanol storage tanks and trim hardware is vitally important to avoid corrosion failure.

The use of some materials in the handling and storage equipment may require some slight adaptation, as explained below. Due to a completely different chemical composition of methanol, there are several characteristics of the fuel that differentiate it from conventional oil liquids (incl. HFO), leading to minor equipment changes.

Toxic emissions

When methanol is combusted, the hydrocarbon emissions are composed primarily of unburned methanol and aldehydes, with formaldehyde being dominant.[72] Testing has shown that neat methanol will produce about twice the level of aldehydes as gasoline (in car engines), while gasoline produces additional toxics such as 1,3-butadiene, benzene, hexane, toluene, and xylene. When methanol is added to gasoline, production of these toxics is correspondingly reduced. Tests of neat methanol vehicles have shown that formaldehyde is the predominant toxic emission from methanol combustion.

Flammability range

Methanol is classified by the International Code Council as a class IB flammable liquid (like ethanol, hydrocarbon fuels such as gasoline and kerosene, and reactants such as benzene, acetone, and toluene).

As the upper flammability limit of methanol is 36 percent by volume (vol%) compared to that of gasoline which is 6-7 vol%, methanol vapor can ignite and burn inside tank vapor space.

Methanol can be classified a flammable liquid and a toxic substance. Protective safeguards should be developed for both hazards which may be present near tanks and within spill impoundment areas. This includes protection of workers during normal operation and maintenance, and safeguarding fire fighters and first responders during accidental releases.

Safeguards for gasoline tank fires are not necessarily sufficient to prevent methanol tank fires.[73] During tank filling, methanol vapor is displaced through tank vents to atmosphere thereby creating potential flammability and toxicity hazards in the ambient air which surrounds the tank.

Transport of methanol by pipeline

Methanol is typically shipped via railroad tank car, barge, and truck tanker, depending on volume and distance.[74] Usually, only a small amount of methanol is sent through pipelines, and only over short distances.

Existing pipelines may be diverted to dedicated methanol use but using these pipelines to transport methanol faces several hurdles. Once these pipelines are cleaned, they will not have the problems associated with intermittent use in petroleum pipelines, and water pick-up and residue removal should not be problems. However, potential material compatibility issues with existing pipelines still require research.

[72] http://methanolfuels.org/wp-content/uploads/2013/05/Bechtold-ATS-Methanol-Use-in-Transportation.pdf
[73] http://www.methanol.org/wp-content/uploads/2018/03/atmosphericabovegroundstorage.pdf
[74] http://methanolfuels.org/wp-content/uploads/2013/05/Bechtold-ATS-Methanol-Use-in-Transportation.pdf

Methanol may corrode and shorten the lives of pipelines. Further testing is required but, if corrosion is a problem, pipes could be coated with special materials, although with some disruption and, according to industry sources, at some undetermined but probably large cost.[75]

Blending methanol into conventional gasoline (not applicable as maritime fuel)

The use of methanol-gasoline blends requires some modifications in the existing distribution system. Blending could take place at oil refineries, bulk storage terminals, or in blending pumps at service stations. For gasoline, blending pumps are already widely used[76], and blending at refineries and storage terminals presents no critical barrier. Some slight cost may be incurred by the logistics of blending. A more important drawback to blending is the need to deter water intrusion into the storage and transportation vessels of the distribution system. The "wet" characteristics of the petroleum product distribution system may be a major barrier to the use of methanol-gasoline blends. Currently, water is allowed to intrude into storage tanks, pipelines, and other tank vessels. If methanol is used straight, water is not a problem. It becomes a problem, however, if methanol is blended with gasoline. Even the presence of 0.1 percent water may cause the liquids to separate.[77]

Storage tank

Guidelines for designing, fabricating, constructing, repairing, and safeguarding above-ground methanol storage tanks is essentially the same as that for liquid transportation fuels such as ethanol and gasoline, and flammable liquid feed stocks such as benzene, acetone, and toluene. However, physical and chemical properties of methanol are unique to methanol and are not the same those of other bulk-stored flammable liquids.[78]

Principal considerations of tank storage of methanol are siting, liquid and vapour containment, electrical grounding, cathodic protection, protection from stray currents, in-tank vapour control, vapour space fire suppression, and management of inhalation, ingestion, and dermal contact.

Methanol tanks can be constructed of either carbon steel or stainless steel. Carbon steel has the advantage of lower capital cost, but the disadvantage of higher life cycle cost due to increased maintenance and costs associated with corrosion protection. Because methanol is a polar solvent, galvanic corrosion is more prevalent with methanol than with other commonly-used motor fuels. Because of its very high affinity to form mixtures with water, methanol is hygroscopic and extracts moisture from ambient air that enters tank vapour space during normal liquid level cycling. In the presence of neat or technical grade methanol, the small amount of water added by desiccation of atmospheric air does not substantially increase the rate of general corrosion. Nevertheless, because of the relatively high conductivity of liquid methanol, corrosion induced failures of carbon steel tanks have been reported. Efforts to coat interior tank surfaces with epoxy resin have met with limited success. Typical coating life is less than seven years, and the coatings tend to form an electrically non-conductive barrier between the methanol and the tank, thereby complicating bonding and grounding. Recent reports indicate progress is being made in developing more suitable electrically conductive spray-on tank liner coatings.[79]

[75] http://onlinepubs.trb.org/Onlinepubs/trr/1982/870/870-012.pdf
[76] Ibid.
[77] ibid.
[78] http://www.methanol.org/wp-content/uploads/2018/03/atmosphericabovegroundstorage.pdf
[79] ibid.

Galvanic corrosion of dissimilar trim materials may be accelerated in methanol service, particularly trim materials of aluminium, lead, magnesium, copper, zinc and platinum alloys. An example of this resulted in a methanol tank fire when the aluminium alloy flame arrester corroded to the point of being non-functional. Galvanised steel seems not to be suitable for methanol service.

Carbon steel is more likely to corrode and cause methanol contamination than stainless steel, particularly in the presence of moist air and/or water in coastal environments. This can be mitigated by padding tank freeboard space with dry inert gas such as nitrogen. Stainless steel has higher capital cost than carbon steel but offers the advantage of lower life cycle maintenance cost, and reduced likelihood of methanol contamination.

According to the stakeholder input, the main actions needed for conversion of HFO storage tanks for the methanol use are cleaning of the tank, removing thermal insulation, switching to a floating roof and changing pumps and metering equipment.

Distribution to final consumers

Handling equipment to fill in ships can be used, provided they are from suitable materials, which is the usually the case as a large number of metals and alloys are suitable.

Table 3-30 Summary table of main vulnerabilities and risks for marine fuels supply chains

Supply chain component	Vulnerabilities and risk exposure
Receiving terminal & intermediate storage	
Tanks	• Deep cleaning of HFO storage tanks needed before using them for methanol storage • Removing thermal insulation from HFO storage tanks is required for the conversion • Galvanic and dissimilar metal corrosion in methanol service may be high if incompatible materials are placed in electrical contact with one another • Possible corrosion of certain metal alloys (and galvanised metals) • The space needed for storing methanol in a tank will be approximately twice that of traditional fossil fuels • Methanol can be classified a flammable liquid and a toxic substance
Floating roof	• Adding floating roof
Pump devices	• new pumps needed due to change of tank construction
Meters	• New metering equipment needed due to change of tank construction
Transport by pipeline	
Pipeline	• Methanol may corrode and shorten the lives of pipelines
Pump devices	• No apparent issue, as a large number of metals and alloys are suitable
Meters	• No apparent issue, as a large number of metals and alloys are suitable
Fuel filtration	• No apparent issue
Bunkering tankers	
Hoses	• Methanol may corrode and shorten the lives of hoses
Valves, level gauges	• No apparent issue, as a large number of metals and alloys are suitable
Pump devices	• No apparent issue, as a large number of metals and alloys are suitable
Bunkering tanks	• Same issues as for tanks

3.6.4 Consequences of risk exposure and required response

The consequences on the equipment & infrastructure can be at various levels

- Equipment or infrastructure can be upgraded via minor additional investments to avoid the risks;
- Equipment or infrastructure is completely inappropriate and should be completely replaced:
  - Becoming stranded assets;
  - Being usable for other purposes.

Table 3-31 Summary table of main consequences and actions needed for marine fuels supply chain

Challenge in supply chain adaptation	Consequences & responses
Adaptation of tanks and storage facilities to prevent material corrosion	• Above ground storage tanks should be equipped with a Cathodic protection • Regular inspection of methanol storage tanks and trim hardware is vitally important to avoid corrosion failure • Tanks should be constructed with adequate water removing capability; • Fill connections and gauge access points should be provided with tightly fitting covers to prevent entry of water • Although the most typical materials for tanks and piping are carbon steel, it is recommended padding tank freeboard space with dry inert gas such as nitrogen, in order to mitigate the risk of corrosion • As alternative, stainless steel has higher capital cost than carbon steel, but offers the advantage of lower life cycle maintenance cost, and reduced likelihood of methanol contamination

Adaptation of operation to prevent fire and explosion	• Tank storage of methanol requires strict and rigorously-enforced provisions to prevent over filling and tank overflow. Tank maximum allowable working volume must always allow additional volume for liquid expansion. The volumetric coefficient of thermal expansion for methanol is greater than that of gasoline. A general rule of thumb is to allow 20% of tank working volume for liquid expansion
	• Flammability (and toxicity) hazards can be controlled using either of two strategies:
	    • Eliminating ignition sources and recognizing toxicity hazards in the proximity of the tank by classifying the area surrounding the tank as a hazardous location
	    • Excluding air from tank vapor space by inerting or gas blanketing

Reconfiguration of supply chain infrastructure to connect the new e-methanol production facilities	• Investment in new transport modes might be required • Existing upstream HFO infrastructure (e.g. supply from Russia) might become a stranded asset if the fuel switch will be to pure e-methanol.

3.6.5 Cost Assessment

Assumptions on the equipment

The supply chain adaptations included in the cost assessment cover primary storage and fuel transport to the primary storage of standard fuel supply chain. The modelled case concerns a supply chain with capacity for handling 5 000 m^3 of methanol. The Table 3-32 below presents the assessed adaptations and assumptions on the equipment.

Table 3-32 Summary of adaptation actions and assumptions on equipment

Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage	Unsuitable materials and tank design	Adapting storage tank	Cleaning the tank; Removing thermal insulation; new meters, pumps	50 000 m^3
Fuel transport	Unsuitable materials and tank design	Repurposed pipeline from production site to primary storage	Internal coating, equipment (valves, flowmeters, filters, pumping set)	100km
Secondary storage	Unsuitable materials and tank design	Adapting storage tank	Cleaning the tank; Removing thermal insulation; new meters, pumps	5 000 m^3

Cost estimate

The cost assessment shows that for adaptations of the model supply chain for 5 000 m^3 of methanol, an investment of 8 552 082 EUR would be necessary. While primary storage comprises 32.5% of the sum, repurposed pipeline (~100km) transport from primary to secondary storage 62.5%, and secondary storage adaptation 5%.

Figure 3-24 Adaptation costs of ship fuels supply chain

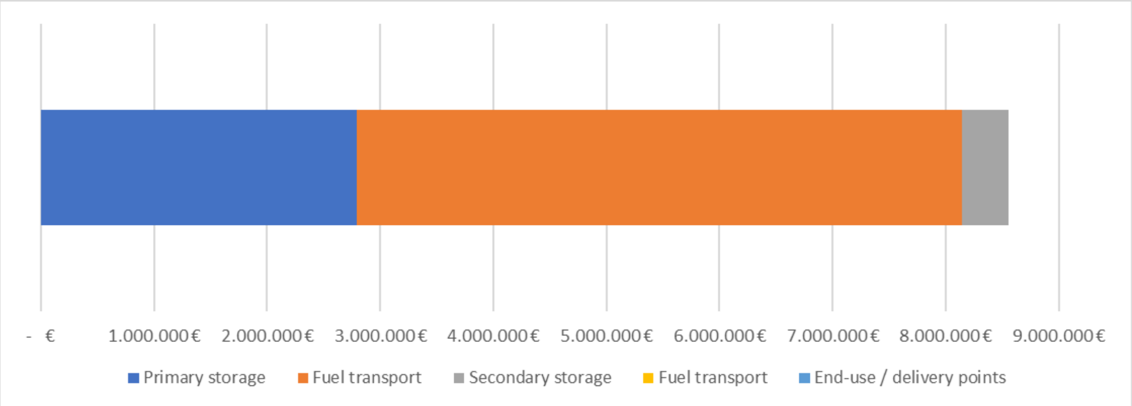
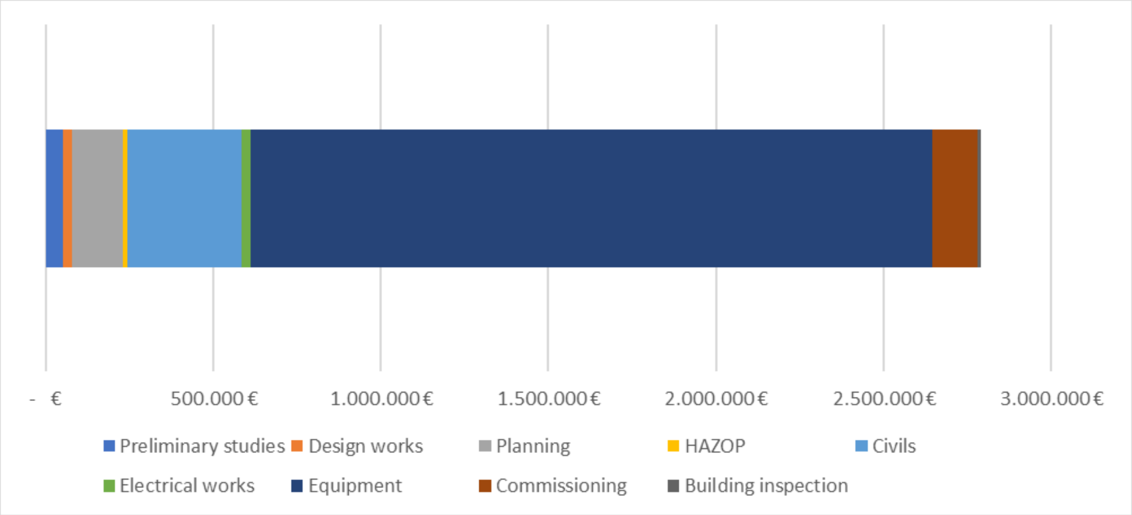


Figure 3-25 below shows the breakdown of cost of investment and its installation. The largest investment item (46%) is the storage tank at the primary storage site as well as the cathodic protection (12%).

Figure 3-25 Breakdown of equipment and installation costs for primary storage for ship fuel



Size variation

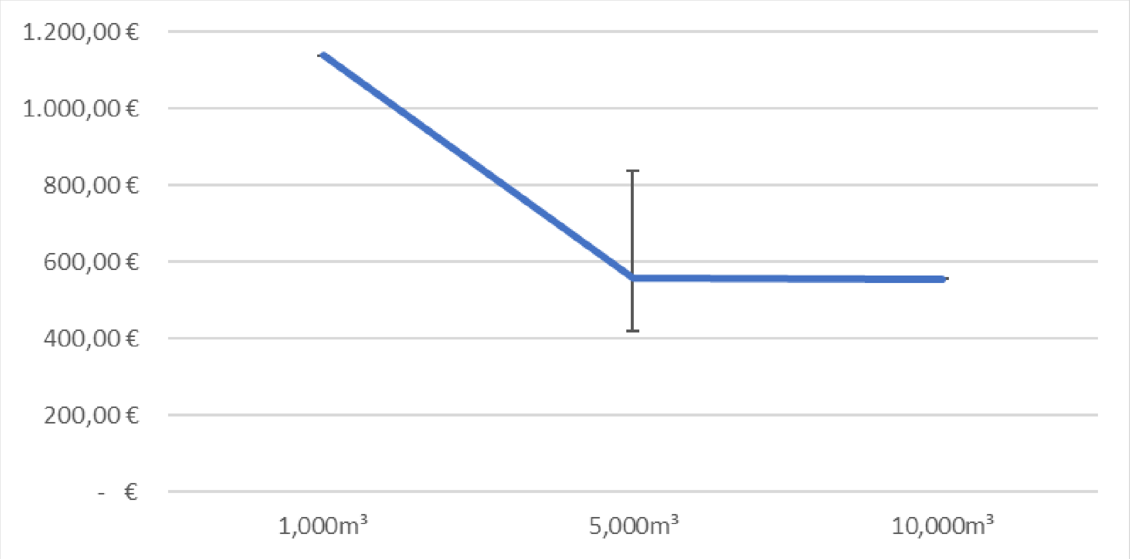
To address the influence of fixed costs on the final estimate, Table 3-33 presents the cost estimates for three model supply chains with different fuel handling capacity, ranging from 1000 m^3 to 10 000 m^3. As can be expected, the unit cost of new equipment cost installation decreases with the volume of handled fuel, from 1 321 EUR/m^3 for the smallest volume to 631 EUR/m^3 for the largest volume.

Table 3-33 Supply chain adaptation costs variation for different tank sizes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m^3)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
1 000 m^3	1.138.629 €	90.000 €	1.139 €		
5 000 m^3	2.789.499 €	120.000 €	558 €	2.092.125 €	4.184.249 €
10 000 m^3	5.556.618 €	180.000 €	556 €		

Figure 3-26 presents the decreasing unit cost per m^3 of installed storage. For the central case of supply chain for 5 000 m^3 of fuel, the estimated error margin shows that the unit cost could reach between 418 EUR and 837 EUR.

Figure 3-26 Unit cost for different storage sizes



Levelised cost of primary storage adaptation

Assuming the equipment lifetime of 20 years, the levelised cost of investment in adaptations of ship fuel supply chain for methanol handling will reach 0.042 EUR per m^3.

Table 3-34 Levelised cost of adaptation measures

Total investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/m^3)
2.789.499 €	120.000 €	20	1314 (15%)	0,036 €

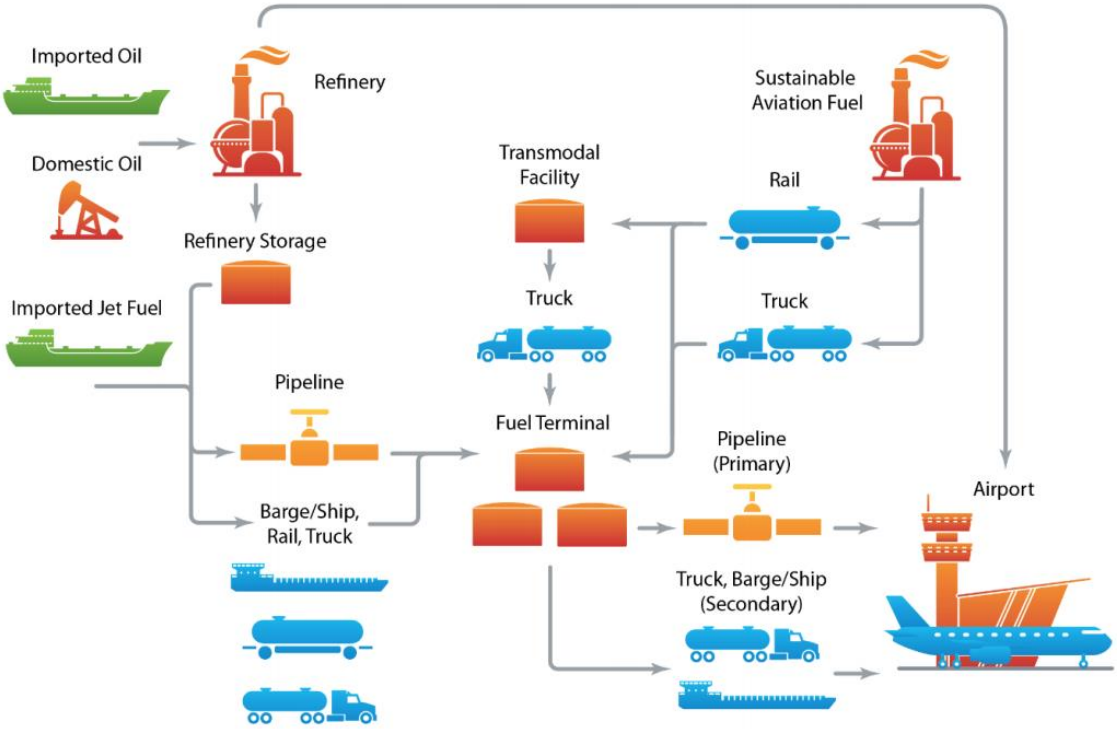
3.7 Kerosene to Sustainable Aviation Fuels (SAF) supply chain conversion

3.7.1 Kerosene supply chain description

The term SAF covers a group of different renewable fuels which have also different qualities. However, by blending with conventional jet fuels, they are designed to be compatible with the existing aviation fuel infrastructure (more detailed information is provided in next section).

Figure 3-26 illustrates different potential pathways for the supply of kerosene and Sustainable Aviation Fuels (SAF).

Figure 3-27 Examples of pathways to kerosene & SAF supply



Source: Moriarty and Kvien (2021)

The scenario considers that SAF would be produced in a standalone production facility and then moved directly to the central storage (secondary terminal), where it would be blended with conventional jet fuel. From there, the blend would be transported via existing pipeline infrastructure to the airports.

The kerosene supply chain comprises five stages:

- Primary storage;
- Product pipeline system;
- Secondary storage: distributor central tank;
- Product pipeline system;
- Airport tank farm and fuelling equipment at airport.

Figure 3-28 Visual representation of conventional jet fuel supply chain

Components description

Table 3-35 Summary of main kerosene supply chains components

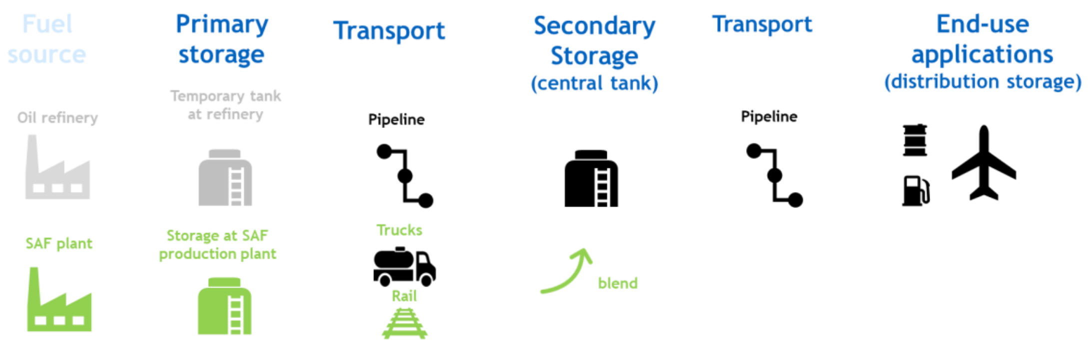
Central storage (secondary storage)
Kerosene storage tank
Blending equipment
Pipeline transport
Pipeline
Compressors
Metering equipment
Airport facilities
Fuel tanks
Pipelines
Fuel flow and vapor regulators
Filters
Metering equipment
Pumps
Safety equipment (preventing and detecting leaks from the system)
Offloading racks
Hydrant systems
Fuelling equipment (hydrant dispenser or fuel bowser)

3.7.2 Scenario - blending SAF with JET fuel

Table 3-36 Supply chain stages

Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
kerosene (Jet A1)	e-fuels (H2 derived)	NA	pipeline	central Storage	pipeline	Airport facility Aviation turbine

Figure 3-29 Visual representation of SAF supply chain blended in secondary storage



3.7.3 Adaptation challenges

General consideration of the differences between fossil-based jet fuel and SAF

Blending SAFs with jet fuel

Currently available sustainable aviation fuels are designed to be used by existing aviation fuel infrastructure and airplane engines[80]. According to existing international standards (ASTM D7566 and ASTM D1655), alternative fuels can be used only in blends with conventional fossil-based Jet A1 fuel, meaning that the distribution infrastructure also only needs to transport fuel blends. The standards set maximum blend percentages based on the chemical composition of the fuel. The two main groups of SAFs are fuels based on synthetic paraffinic kerosene (SPK) and synthetic kerosene with aromatics (SKA), but there are currently 7 different fuel groups recognised by the norms[81]:

- Hydrogenated esters and fatty acids (HEFA) fuels (HEFA-SPK), 50% maximum blend;
- Fischer–Tropsch fuels (FT-SPK), 50% maximum blend;
- Fischer–Tropsch fuels with aromatics (FT-SKA), 50% maximum blend;
- Synthetic iso-paraffin (SIP) from fermented hydroprocessed sugar, formerly known as direct-sugar-to-hydrocarbon fuels (SIP-SPK), 10% maximum blend;
- Alcohol-to-jet (ATJ-SPK) fuels produced from isobutanol and ethanol, 50% maximum blend;
- Catalytic hydrothermolysis jet (CHJ) produced from esters and fatty acids at a 50% maximum blend concentration;
- HEFA with hydrocarbons (HC-HEFA) produced from esters and fatty acids at a 10% maximum blend concentration.

Blending facilities for SAF

Currently, SAF are blended with conventional jet fuel either directly by the producer in its production facility, or in a central terminal that can be owned by the fuel distributor supplying the airport. In the first case, no additional requirement for distribution infrastructure would be needed. There are two possibilities in the second case, either blending the SAF directly to a tank with jet fuel or offloading SAF into a dedicated storage tank, from where it would be blended to a separate tank designed for fuel blending. For storage of neat SAF, specific requirements on the tanks might be necessary similarly to other FAME- or ethanol-based fuels[82]. The blending procedure might also require additional equipment for fuel mixing to address potential differences in fuel characteristics.[81]

After blending the conventional and renewable fuels, the resulting mixture is tested and certified for use by aviation infrastructure. The certification is done also in the same way as for standard fuel consignments (and essentially it tests the same fuel qualities), therefore the upgrades in certification procedures should be minimal. After this step of the supply chain, no additional changes in the infrastructure are needed.

Transport of SAF to blending facilities

The current practice within Europe is that SAF are blended in the production facility and the final blend is shipped via existing infrastructure.

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[80] NESTE (2020). What is NESTE MY Renewable Jet Fuel?. Available at: https://www.neste.com/sites/neste.com/files/attachments/aviation_downloadable_brochure_what_is_29012020.pdf.

[81] Moriarty and Kvien (2021). U.S. Airport Infrastructure and Sustainable Aviation Fuel. Available at: https://www.nrel.gov/docs/fy21osti/78368.pdf

[82] These are investigated in detail in other case studies (for example FAME and HVO biodiesel and bioethanol).

However, examples from the United States show that SAFs can also be either imported (by ship) and blended with jet fuel in import terminal, or, in case of domestic production, shipped from the standalone production facility by trucks or rail transport.[81] The truck and rail transport might require specific equipment, depending on the physical qualities of the particular SAF.

Table 3-37 Summary of main adaptation risks and challenges

Supply chain component	Vulnerabilities and risk exposure
Fuel blending at the central terminal	
SAF storage tank	• Specific materials additional maintenance might be necessary for SAF storage, depending on concrete physical qualities
Blending equipment	• Additional mixing equipment might be necessary
Fuel quality testing	• Adjustment of certification process might be necessary
SAF transport to central terminal	
Tank truck and rail wagon	• Additional supply chain step to be established; • Specific materials additional maintenance might be necessary for SAF storage, depending on concrete physical qualities.

3.7.4 Consequences of risk exposure and required response

SAF are currently designed to be compatible with existing aviation fuel infrastructure, the necessary adaptations are therefore limited to blending of SAF with conventional fuel and establishing the supply chain from SAF production facilities to the central distribution terminal. Given the role of SAF in the European decarbonisation scenarios, it is unlikely that dedicated infrastructure for SAF would be needed in the short to mid-term.

Table 3-38 Summary of main adaptation measures

Challenge in supply chain adaptation	Consequences & responses
Adaptation in central terminal	• Dedicated storage tanks with specific materials and maintenance procedures might be needed
Establishing SAF transport to distribution storage	• Specific tanks might be needed for rail/road transport

3.7.5 Cost Assessment

Assumptions regarding the equipment

The supply chain adaptations included in the cost assessment cover primary and secondary storage and fuel transport to the secondary storage. The modelled case concerns a supply chain with capacity for handling 5 000 m^3 of e-kerosene. The table below presents the assessed adaptations and assumptions regarding the equipment.

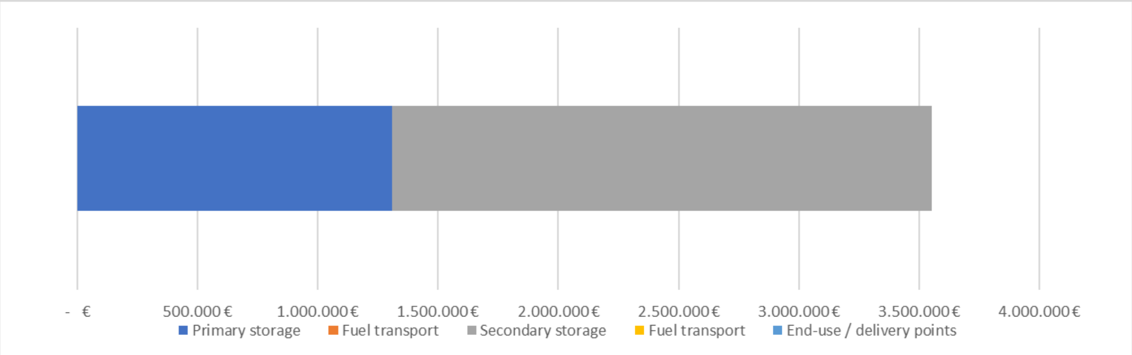
Table 3-39 Summary of main adaptation actions and equipment assumptions

Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage	Supply chain relocation	New storage site at SAF production site	Storage tank; meters, filters	5 000 m^3
Secondary storage	Supply chain relocation	New blending equipment		Blending tank 5 000 m^3
Fuel transport by pipeline	No risk	No changes required	NA	NA

Cost estimate

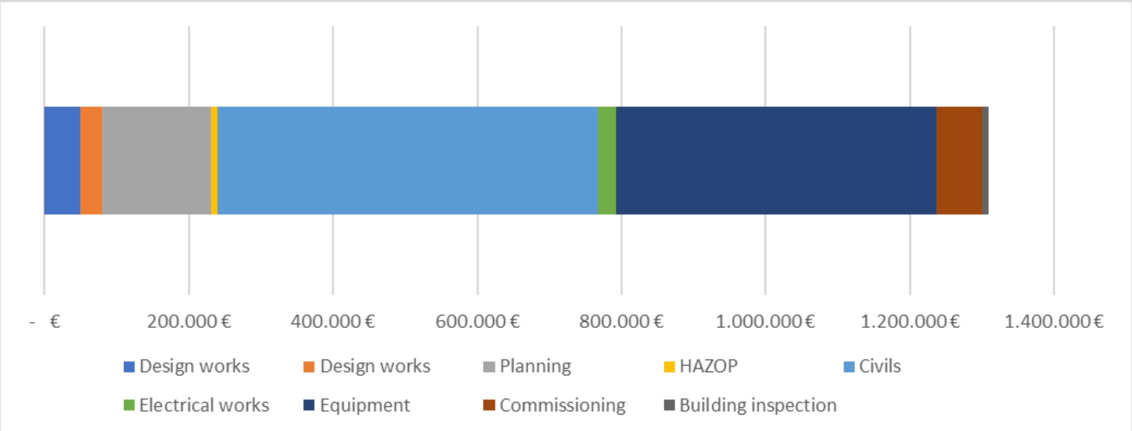
According to the cost assessment, the adaptations in the kerosene supply chain for handling of 5 000 m^3 of SAF would require an investment of 3 550 321 EUR. The largest portion of the investment is the secondary storage (63% of the budget), followed by the primary storage cost (37%). No changes are required for pipelines, which can be used directly.

Figure 3-30 Adaptation costs of kerosene supply chain



The breakdown of primary storage costs is presented in Figure 3-31 below. The largest investment item are, according to the assessments, civil works and new equipment.

Figure 3-31 Breakdown of equipment and installation cost for kerosine primary storage



Size variation

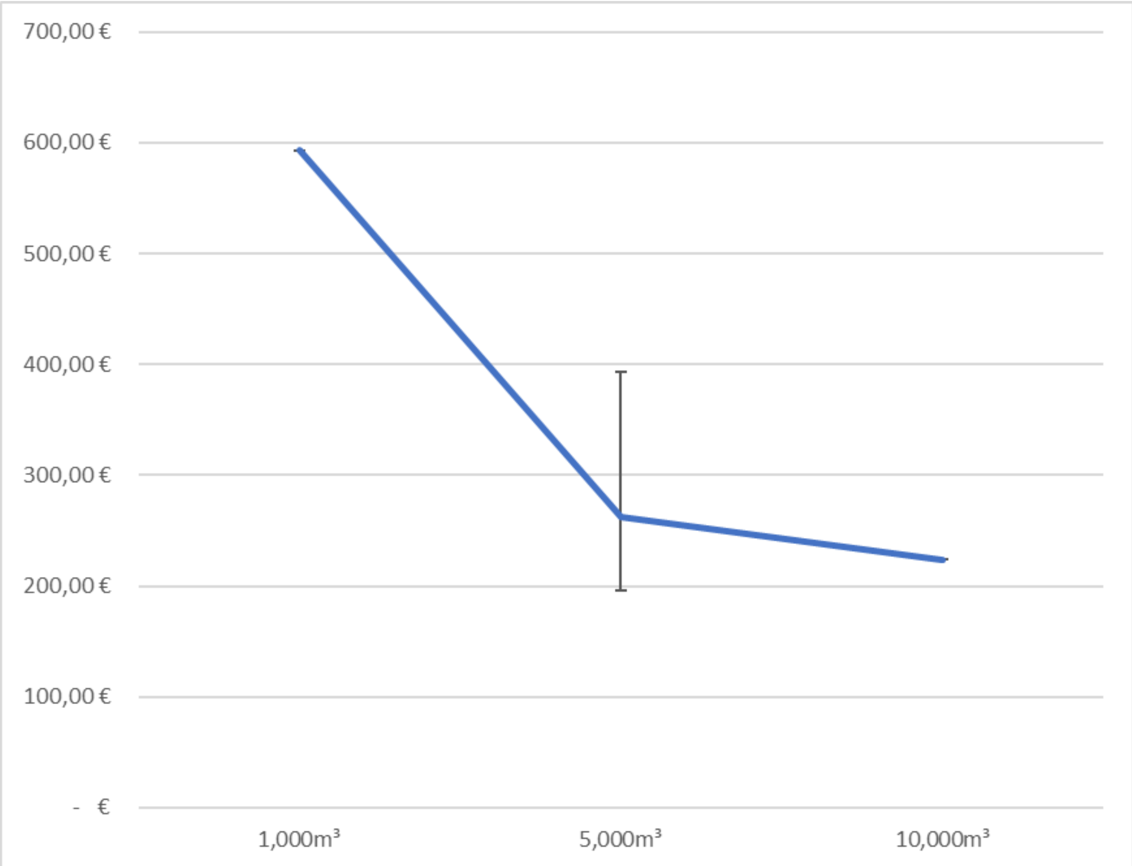
To address the influence of fixed costs on the final estimate, Table 3-40 presents the cost estimates for three model supply chains with different fuel handling capacity, ranging from 1 000 m^3 to 10 000 m^3. As can be expected, the unit cost of new equipment cost installation decreases with the volume of handled fuel, from 593 EUR/m^3 for the smallest volume to 224 EUR/m^3 for the largest volume.

Table 3-40 Supply chain adaptation costs variation for different tank sizes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m^3)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
1 000 m^3	593.200 €	45.000 €	593 €		
5 000 m^3	1.309.508 €	60.000 €	262 €	982.131 €	1.964.261 €
10 000 m^3	2.240.813 €	90.000 €	224 €		

Figure 3-32 presents the decreasing unit cost per m^3 of installed storage. For the central case of supply chain for 5 000 m^3 of fuel, the estimated error margin shows that the unit cost could reach between 196 EUR and 393 EUR.

Figure 3-32 Unit cost for different storage sizes



Levelised cost of adaptation

Assuming the equipment lifetime of 20 years, the levelised cost of investment in adaptations of kerosene supply chain for handling of SAF will reach 0.017 EUR per m^3.

Table 3-41 Levelised cost of adaptation measures

Total investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/m^3)
1.309.508 €	60.000 €	20	1314 (15%)	0,017 €

3.8 LNG to liquefied biomethane supply chain conversion from import terminal

As explained in section 2.2, biomethane consists of the same chemical substance as natural gas (methane). Therefore, liquefied biomethane imports can use the existing LNG import infrastructure as well. Furthermore, biomethane is (within the EU) shipped using the mass balance system[83], meaning that the physical consignment of biomethane can be injected into the natural gas grid, and the same volume of methane can be taken out of the network in any other point regardless of the origin (biological or fossil) of the particular molecules. Since the renewable quality of the fuel is decoupled from the qualities of the physical matter, it does not make sense to investigate adaptations of supply chain infrastructure.

3.9 Gasoline to e-gasoline supply chain conversion

E-gasoline is produced by Fisher-Tropsch (FT) synthesis of syngas, e.g., mixture of carbon monoxide and hydrogen[84] that is produced ideally by electrolysis using renewable electricity. The FT synthesis produces straight-chain hydrocarbons in the paraffin series. This compound is subsequently distilled into gasoline, diesel, jet fuel and other equivalents of petroleum products.[85]

The resulting products have higher purity than conventional fuels, missing for example sulphur or aromatics traces. This results in differences in certain qualities of the fuels. However, these differences do not necessarily have an impact on the fuel distribution infrastructure, but rather on the end uses. The absence of sulphur and aromatics leads for example to lower GHG emissions during combustion. FT gasoline has also lower octane number and needs to be further processed to reach quality of conventional gasoline required for combustion in the conventional engine.[86]

3.10 Diesel to e-diesel supply chain conversion

The production pathway of e-diesel via FT synthesis is shared with that of e-gasoline, explored in section 0. Similarly as for e-gasoline, e-diesel has very similar chemical composition to fossil-based diesel and can be used with the existing infrastructure, as well as in conventional diesel engines.[87]

Therefore, it can be concluded that no adaptations in the diesel downstream supply chain infrastructure are needed for the use of e-diesel.

[83] As defined in the Renewable Energy Directive (2018/2001).
[84] More detail is provided in section 2.2
[85] Andrews and Logan (2008). Fischer-Tropsch Fuels from Coal, Natural Gas, and Biomass: Background and Policy. CRS report for Congress. Available at: https://www.everycrsreport.com/files/20080327_RL34133_5320447491700d8c35c78624a956317f1baa8401.pdf.
[86] Ibid.
[87] Dieterich et al (2020). Power-to-liquid via synthesis of methanol, DME or Fischer–Tropsch-fuels: a review. Available at: https://doi.org/10.1039/D0EE01187H.

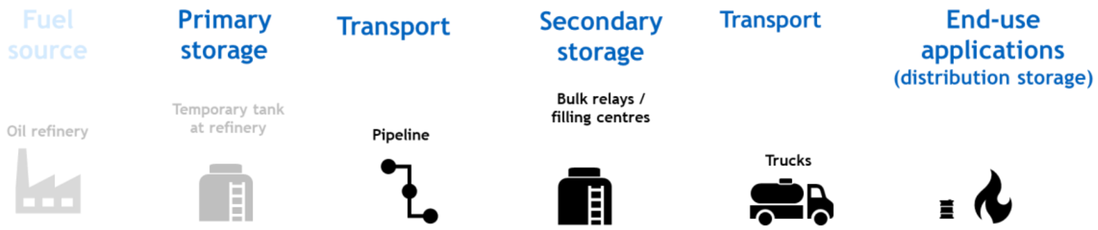
3.11 LPG to bio-LPG supply chain

3.11.1 LPG supply chain description

The supply chain comprises the following stages:

- Primary transport by pipeline from refineries;
- Tank truck transport from primary to secondary storage;
- Reception of bulk products in secondary storage (bulk repays/filling centres), LPG cylinder filling plants;
- Secondary transport by cylinder delivery trucks from bulk relays/filling centres to consumers;
- Individual tank for household heating.

Figure 3-33 Visual representation of conventional LPG supply chain



Transport from primary to secondary storage is more frequently done by barges, pipelines or rail than by trucks. However, the changes assessed to transport the fuel by trucks remain representative of what would be required for other transport mode.

Components description

Table 3-42 Summary of main LPG supply chain components

Components of LPG supply chain
Primary storage
Piping from on-site biorefinery tank to the bioLPG tank
Pumping system
Metering devices
Storage tanks
Transport from primary
Tank trucks
Secondary storage
No changes
Terminal transport
Cylinders/bottles
LPG transport by road trucks to final consumer

3.11.2 Scenario - switch to bioLPG

Table 3-43 Supply chain stages

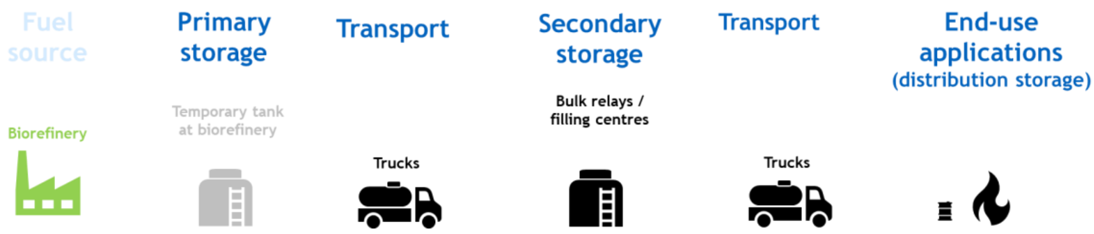
Current Energy source	Example replacement energy source	Primary storage	Transport mode from Primary to Secondary Storage	Secondary Storage	Transport mode from secondary Storage to delivery point	Delivery point& end-use vehicle
LPG	bio LPG (biopropane)	On-site bio-refinery tank	Tank trucks	LPG cylinder filling plant	cylinder delivery truck	Individual tank household heating

The case addresses a full switch to 100% bioLPG, and all consequences.

Bio LPG is chemically identical to conventional LPG and can be blended and used by all existing appliances suitable for use with LPG.

The model supply chain for this case starts with primary storage at bio-refinery where bioLPG is produced. From primary storage, the fuel is transported by road trucks to the secondary storage in the vicinity of households, where it is also distributed for the final consumption.

Figure 3-34 Schematic representation of biodiesel downstream supply chain



3.11.3 Adaptation challenges

Spatial distribution of the supply chain

BioLPG is a co-product of biodiesel production, and since biodiesel production sites need to be in close proximity to biomass sources, their geographical location is not necessarily in line with existing conventional LPG infrastructure, which is usually around oil import routes. Therefore, some adaptations might be required for bioLPG primary storage and additional transport, such as transport of bioLPG from a production facility to a collection point where it will be mixed with conventional LPG.

General consideration of the differences between fossil-based diesel and diesel of biological origin and their implications on diesel supply chain

BioLPG is identical in chemical structure, appearance, performance and application to conventional LPG and is transported and stored in the same tanks and used for the same applications and equipment, making the transition from LPG to bioLPG seamless.[88]

Transport of bioLPG to primary storage

This step is applicable for blending bioLPG with fossil LPG. Since bioLPG production facilities are not necessarily located at the same location as refineries or existing LPG distribution infrastructure, the transport of bioLPG to primary storage constitutes an additional step, raising the operational expenditure.

Blending bioLPG with fossil LPG & primary storage

There is no special procedure for blending bioLPG with conventional LPG, both fuels having the same chemical structure, hence the same characteristics (density, freezing point etc.).

Truck transport of final fuel to fuel stations

Conventional LPG transport trucks and pipelines are suitable for bioLPG transport.

Secondary storage and distribution to final consumers in fuel stations

Existing storage and handling equipment in fuel stations can be used.

[88]Liquid Gas Europe BioLPG2050 pathway studyhttps://www.liquidgaseurope.eu/what-is-biolpg

Summary

As LPG and bioLPG are identical in chemical structure (same molecule – propane – C_3H_8), there is no risk identified for switching from conventional LPG to bioLPG.

The only risk may occur in terms of additional costs when blending the two fuels.

Table 3-44 Summary table of main vulnerabilities and risks for bioLPG supply chains

Supply chain component	Vulnerabilities and risk exposure
Transport by road from primary storage in refinery	
Piping from the refinery tank to the oil tanker	• Relocation/potential stranded asset
Pump devices	• Relocation/potential stranded asset
Metering devices	• Relocation/potential stranded asset
LPG transport by tank trucks	• No change
Secondary storage	
Piping from the LPG tankers to the secondary storage tanks	• No change
Pumping system	• No change
Metering devices	• No change
Cylinder (LPG bottles) refilling tank – above ground	• No change
(Storage tank – under ground)	• No change
Secondary and final transport	
Pumping system	• No change
LPG transport by road trucks to final consumer	• No change

3.11.4 Consequences of risk exposure and required response

The consequences on the equipment & infrastructure can be at various levels:

- Equipment or infrastructure can be upgraded via minor additional investments to avoid the risks, or
- Equipment or infrastructure is completely inappropriate and should be completely replaced:
  - Becoming stranded assets;
  - Being usable for other purposes.

Table 3-45 Summary table of main consequences and actions needed for bioLPG supply chain

Challenge in supply chain adaptation	Consequences & responses
Reconfiguration of supply chain infrastructure to connect the new bioLPG production facilities	• Investment might be required in new storage tanks at production sites and additional transport in case of fuel blending. • Existing LPG infrastructure at refineries might become stranded asset if the fuel switch will be to pure bioLPG, but will be still relevant if LPG/bioLPG blends are used, since blending can happen at the refinery facilities, and the resulting fuel blend can be transported through the existing supply chain.

3.11.5 Cost estimate

Since there are no major adaptations of infrastructure expected, the cost estimate focuses on the relocation of the supply chain from conventional refinery to biorefinery in a new location. In that case, new storage tanks for bioLPG will be needed, and new transport to secondary storage.

It is also possible to consider the option of reusing old LPG tanks at refineries instead of having them as stranded assets. However, this option will not be possible for older tanks. The transportation cost also needs to be taken into account and compared with the delivery of new tanks. Dismantling and disposal of older tanks installed at refineries can be cost neutral given their value as metal.

Assumptions regarding the equipment

New storage tanks

The storage tanks at the new bioLPG production site are assumed to have a volume of 900 m^3.

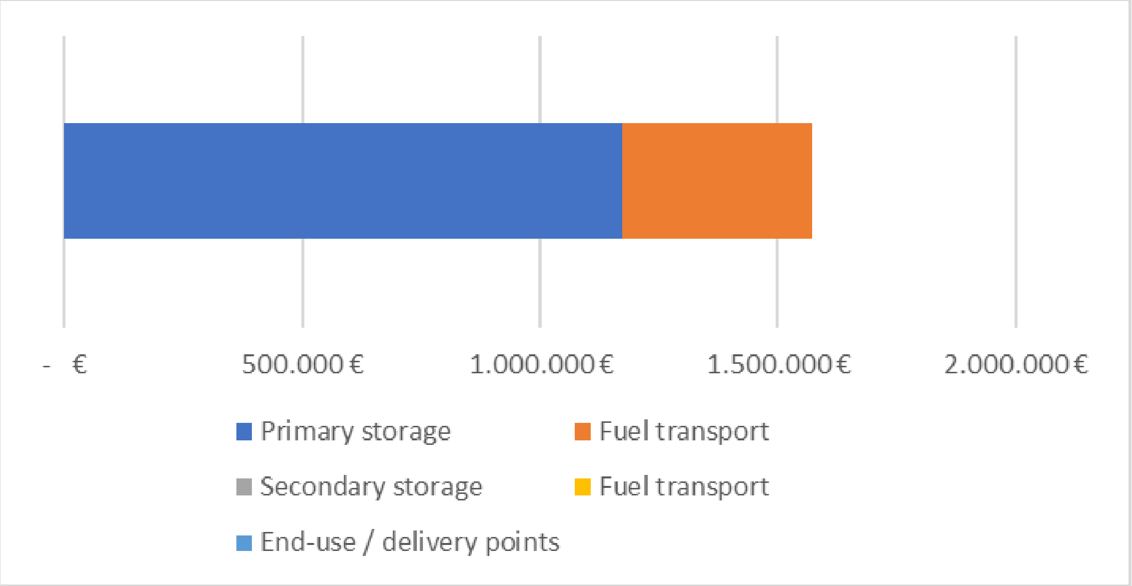
Table 3-46 Main assumptions regarding the technical equipment

Supply chain component	Related risk	Changes needed	Adapted equipment	Size assumption
Primary storage	Supply chain relocation	New storage site at biorefinery	Storage tank	900 m^3

Cost estimates - new tank storage

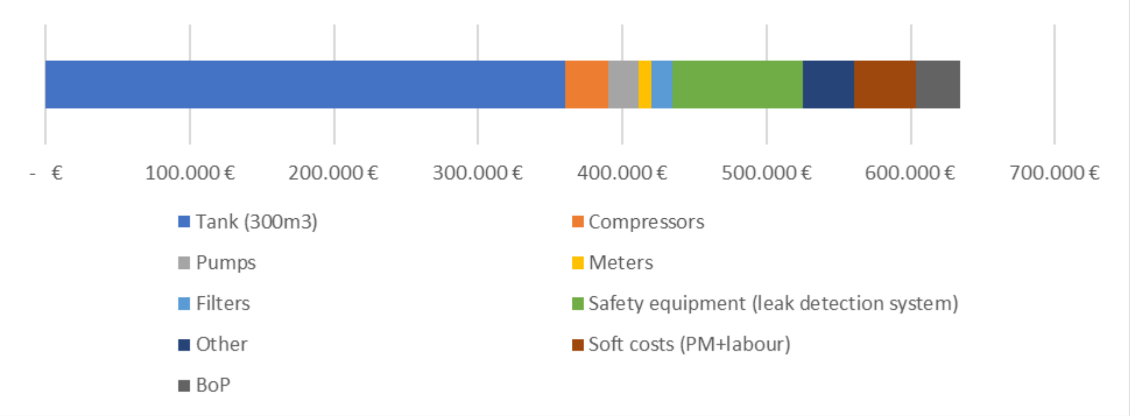
The cost analysis shows that the installation of 900 m^3 storage tank at the new biorefinery site and the purchase of tank trucks to deliver to secondary storage will cost 1 265 975 EUR. The cost of primary storage represents around 68% and cost of tank trucks the remaining 32%.

Figure 3-35 Installation cost of new LPG storage supply



According to the estimates, the most costly part of equipment is the tank vessel, representing 57% of equipment installation costs. The other parts with significant costs are meters (14% of total equipment installation cost) and safety equipment (5%). The labour costs, including project management, represent 7% of equipment installation cost.

Figure 3-36 Breakdown of equipment installation costs for new LPG tank



Size variation

To address the influence of fixed costs on the final estimate, Table 3-47

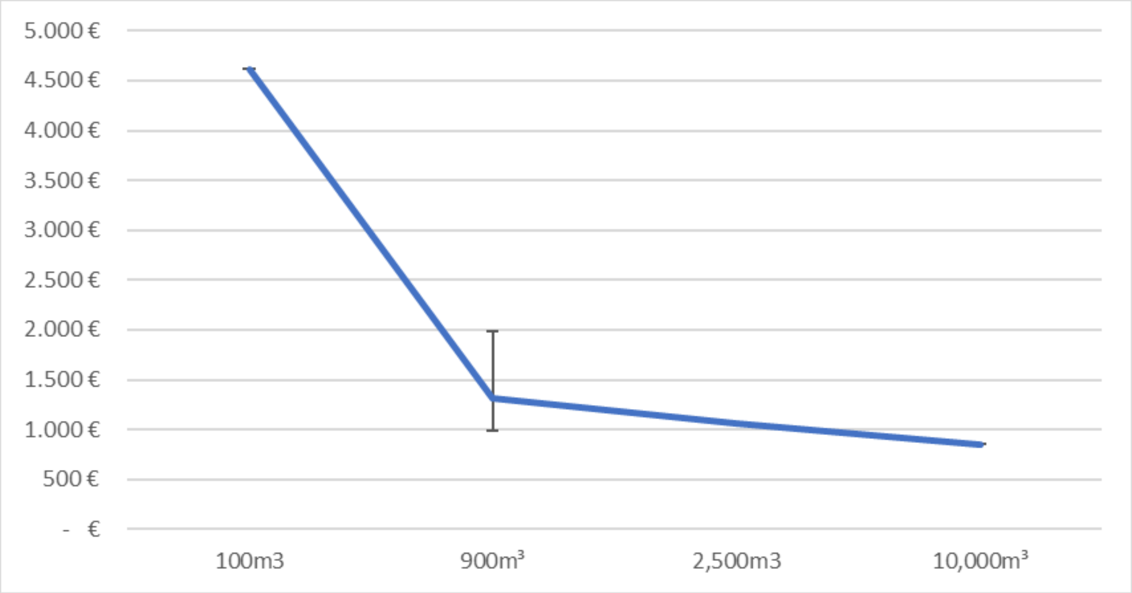
Table 3-47 presents the cost estimates for four storage tank sizes, ranging from 100 m^3 to 10 000 m^3. As can be expected, the unit cost of new equipment cost installation decreases with the size of storage tank, from 4 391 EUR/m^3 for the smallest tank to 816 EUR/m^3 for the largest tank.

Table 3-47 New storage costs variation for different tank sizes

Tank size	Total cost (EUR)	OPEX (EUR/year)	Unit cost (EUR/m^3)	Cost error margin -25% (EUR)	Cost error margin +50% (EUR)
100 m^3	461.331 €	42.000 €	4.613 €		
900 m^3	1.171.774 €	60.000 €	1.302 €	878.830 €	1.757.661 €
2 500 m^3	2.557.564 €	120.000 €	1.023 €		
10 000 m^3	8.534.348 €	240.000 €	853 €		

Figure 3-37 presents the decreasing unit cost per m^3 of installed storage. For the central case of 900 m^3 storage tank, the estimated error margin shows that the unit cost could reach between 976 EUR and 1 953 EUR.

Figure 3-37 Unit cost for different storage sites



Levelised cost of adaptation

Assuming the project lifetime of 20 years, the levelised cost of investment in new tank storage for bioLPG at the biorefinery site will reach 0.126 EUR per m^3.

Table 3-48 Levelised cost of adaptation measure

Adaptation measure	Total investment (EUR)	OPEX (EUR/year)	Equipment lifetime (years)	Annual Utilisation time (h)	Levelised cost (EUR/m^3)
New storage site at biorefinery (900 m^3)	1.171.774 €	60.000 €	20	876 (10%)	0,126 €

3.12 Summary of supply chain adaptations

Generally, the changes required to ensure continuity of supply of low-carbon and renewable fuels can be categorized in three broad groups. These are based on two main parameters, which are a) the substituting alternative fuel characteristics and b) the geographic distribution of alternative fuel production facilities (in cases when the fuel is produced on European territory, rather than imported)[89]:

- No changes at all for some products which would be produced and distributed along the same logistic chain;
- Limited changes, such as replacing some parts of fuel handling equipment, minor adjustment of supply chains;
- Important changes due to different alternative product characteristic, which would be produced and distributed along the same logistic chain but still would require complete replacement of some infrastructure elements ;
- Complete change of the existing supply chain assets, given the production certainly does not happen at the same place and the existing equipment is not suitable for handling the substitute alternative fuel. However, no such case was identified.

[89] The substituting fuel characteristics may require changes in e.g. fuel handling or replacement of some infrastructure elements, while the location of production facilities can require spatial adaptations of the supply chain.

Table 3-49 Summary table illustrating the importance of the supply chain elements adaptation

		Geographic/spatial reconfiguration of supply chain	Primary storage	Fuel transport	Secondary storage	Fuel transport	Fuel distribution
1	FAME biodiesel 100%	No	Import terminal	Rail	Inland terminal	Tank trucks	Fuel station - heavy duty trucks
2	FAME biodiesel 100%	Yes	Import terminal	Tank trucks	Inland terminal	Tank trucks	Fuel station - passenger cars; heavy duty trucks
2.a	FAME biodiesel <100%						
3	HVO biodiesel	No	Import terminal	Barge (inland)	bunkered stock / distributor depot	Tank trucks	Domestic heating fuel (domestic tanks)
4	bioethanol	Yes	(from bioethanol plant)	Tank trucks	Inland terminal	Tank trucks	Fuel station - passenger cars
5	hydrogen	No	Import terminal	Pipeline	NA	NA	Fuel station - trucks
6	Methanol		Import terminal (from large H2 prod)	Pipeline	Port fuel depot	NA	Bunkering tankers - ships
7	SAF	Partial	Import terminal	Pipeline	Airport storage	NA	Filling planes - aviation turbines
8	liquefied biomethane	No	Import terminal			Tank trucks	Fuel station - heavy duty trucks
9	e-gasoline	No	(small stand-alone prod facility)	Pipeline	Depot	Tank trucks	Fuel station - passenger cars
10	e-diesel	No	(small stand-alone prod facility)	Tank trucks	Depot	Tank trucks	Fuel station - trucks
11	bioLPG	Yes	BioLPG tank at refinery	Tank trucks	LPG cylinder filling plant	Tank trucks	household heating (cylinder tanks)

Legend

(orange)	Important changes required
(yellow)	Limited changes required
(green)	No changes required
(white)	Not included

The following table summarises the cost to adapt existing infrastructure, or to invest in new assets.

Table 3-50 Summary table of the supply chain costs

	Short description	Primary storage	Fuel transport	Secondary storage	Fuel transport	End-use / delivery points	Levelised cost of primary terminal	Levelised cost (unit)
FAME 100% biodiesel	5000m3 storage, 4 rail wagons (cleaning of wagons, epoxy coating, insulation+cladding), adaptation secondary terminal (cleaning of existing storage tanks, insulation and cladding, epoxy coating), tank trucks	1.230.689	98.080	499.202	400.000	-	0,016	eur/m3
FAME 100% biodiesel	5000m3 storage, tank trucks, adaptation secondary terminal (cleaning of existing storage tanks, insulation and cladding, epoxy coating), tank trucks	1.230.689	400.000	499.202	400.000	-	0,016	eur/m3
HVO biodiesel								
bioethanol	5000m3 storage, tank trucks, adaptation secondary terminal (10000m3 new tanks for blending + all necessary equipment (meters, filters etc) + civils to install the new tank), tank trucks	1.279.163	400.000	2.132.821	400.000	100.000	0,016	eur/m3
hydrogen	10000m3 tanks, pipeline 100km, fuel station	8.733.401	30.079.100	-	-	1.451.363	0,002	eur/kg
Methanol	2*5000m3 storage, pipeline adaptation 100km + equipment, adaptation secondary storage (incl. cleaning of storage tanks, floating roof, old thermal insulation removal, new equipment (pumps, meters, filters)), tank trucks	2.789.499	5.350.958	411.625	-	-	0,036	eur/m3
SAF	5000m3 storage, pipeline (existing infrastructure is compatible for SAF), 10 000m3 secondary terminal (incl. new blending tank+all necessary equipment (meter, filter, pump)+civils work)	1.309.508	-	2.240.813	-	-	0,017	eur/m3
liquefied biomethane								
e-gasoline								
e-diesel								
bioLPG	3*300m3, tank trucks to secondary storage, then the existing infrastructure can be used without adaptation	1.171.774	400.000	-	-	-	0,126	eur/m3

4 Conclusions & takeaways

4.1 Conclusions and main takeaways from the case studies

- The oil infrastructure is globally more widely spread and distributed than other infrastructure, therefore offering a high level of flexibility and adaptability to supply alternative and conventional fuels. Flexible and adaptable infrastructure can contribute to the clean energy transition by allowing to deliver an increasing number of alternative low carbon fuels while ensuring their security of supply;
- Depending on the product, most parts of the existing fossil fuel infrastructure can be used for alternative fuels supplies as well, without any changes or with minimal modifications, notably for e-fuels, which have the same characteristics as the fossil-derived fuels they would replace;
- Even in the case when the components that directly handle the fuels are not suitable for the alternative use, the surrounding facilities can be used to minimise the necessary investment (e.g. using the existing fuel stations, import terminals), depending on the fuels to be replaced and its alternative low carbon fuels and applications;
- Since there will be only limited supply of sustainable biofuels, it is necessary to find specialised applications where biofuels offer the most viable decarbonisation option. These might be used for heating in rural and low-density population areas, or heavy-duty road transport, in the shipping and aviation sectors, and in industry, although many uncertainties remain regarding the geographic areas and applications to be impacted and switch the fastest. It is necessary to work with national governments to determine these areas. This relates to infrastructure planning for transport, heating and cooling decarbonisation;
- The indigenous production of alternative fuels may become decentralised and more geographically dispersed, moving, for example, closer to biological feedstock places of origin or to remote large renewable electricity plants coupled with hydrogen production. The spatial distribution of existing fuel supply chains will have to be adjusted and new local infrastructure introduced;
- In some cases, the alternative fuels are not a direct substitute that can be used by the same end-users without any adaptations – for example bioethanol substituting gasoline (in high-percentage blends) or hydrogen substituting natural gas. In these cases, the supply of both conventional and alternative fuels will have to be maintained (at least temporarily) to satisfy all consumers.

4.2 Summary of main challenges & opportunities resulting from the case studies

Opportunities

- Large part of the conventional fossil fuel infrastructure can already be used for alternative fuel transport, storage and distribution;
- The existence of the oil infrastructure is more widespread and less dense, therefore it should provide important and real opportunities for the transition given its flexibility to adapt to fast and important changes in the supply of alternative fuels, from decentralised production, to smaller storage or an increasing number of products to be delivered.

Challenges

- Due to substantial electrification, especially of transport sector, the increase of energy efficiency (in all sectors), and the shift to emerging low-carbon and renewable fuels, the demand for liquid fuels will decrease in the future and the associated fuel infrastructure will have to be re-purposed accordingly after 2030 and some assets may become stranded;
- The production of alternative fuels will be decentralised and more geographically dispersed. The spatial distribution of existing fuel supply chains will have to be adjusted;
- Disruptions along the supply chains may occur, given the above-mentioned threats, with consequences in supplying to end-consumers;
- It is necessary to ensure that vulnerable consumers, who do not have the resources to switch fuel, are not left behind by supply chain changes – both in case of supply chain downgrading and fuel switching;
- Most of the emerging fuels, except biofuels (bioethanol & biodiesel), which have been blended for several years, are still at an early stage of development and there is limited experience with their handling and use. Therefore, further research may be required regarding their characteristics and impacts on equipment;
- The diversification of fuels will have implications all along the supply chain, especially at fuel stations which will become multi-fuel due to a wider range of products used by drivers. Adaptations will be required in terms of space (more tanks and dispensers), safety requirements, as well as a broader range of services to be offered at fuel stations.

4.3 Main takeaways

4.3.1 Takeaways for policymakers

Objective

To address the above-mentioned challenges, policymakers should address the following key areas:

- Building a clear pathway and trajectory for renewable and low carbon fuels up to 2050, and assessing the needed infrastructure to supply these fuels and the conventional fuels in a transitory period;
- Involve the oil infrastructure and supply chain sector in the design of the pathway to carbon neutrality, for the adequate consideration of the adaptation of their assets;
- Increasing awareness about the challenges faced by existing infrastructure (storage, transport, distribution) and the new infrastructure to be deployed, but also the potential opportunities for the emergence of these alternative fuels;
- Raise awareness of the fact that some existing infrastructures belong to regulated markets (all gas infrastructure, e.g. large storage in salt caverns), while others belong to non-regulated markets (which is the case for liquids), which could lead to discrepancies in fast moving markets. Large investments may be required for the transition. The lack of a level playing field with existing fossil-based carriers could jeopardise or postpone investments;
- Assessing the risks of disruption and stranded assets due to major changes;
- Taking the appropriate measures to secure the supply and provide a stable framework;
- In the framework of the Oil Stocks Directive and the IEA stockholding regime, anticipating the evolution of fossil-based liquids consumption & emergency storage needs and adapt national regulatory framework accordingly to a low carbon/decarbonised energy system;
- Ensuring a level playing field for all types of energies and energy carriers, providing they comply with the decarbonisation goals and pathways;

- Supporting industrial operators and investors to adapt existing assets;
- Removing existing alternative fuel deployment barriers, such as blending walls in the Fuel Quality Directive;
- Mandating Standardisation bodies to develop the missing standards;
- Supporting RD&I efforts to further explore the technical impacts of emerging fuels.

Although some of these policies can be better addressed at the national level, it is also important to set up a unified regulatory approach at the European level.

Existing EU policy instruments and gaps

Unlike natural gas and electricity, there is no comprehensive European framework that would cover the entire oil supply chain (as defined in the project).The following regulatory frameworks partially address the supply of oil:

- The Directive on the deployment of Alternative Fuels Infrastructure (AFID[90]) covers CNG and LNG, hydrogen and electricity; moreover, it mostly concerns the fuelling/charging infrastructure and, indirectly, storage infrastructure and fuel transport and distribution. The directive also requires MSs to develop National Policy Frameworks that assess all alternative fuels deployment;
- The Council Directive imposing an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products[91], regulating emergency storage of liquids;
- The Fuel Quality Directive (FQD[92]), with regards to alternative fuels:
    - Reduce GHG intensity of fuels by 6% by 2020;
    - Sets a maximum share of 7% of FAME in biodiesel blend;
    - Sets threshold values for vapour pressure waivers for low-percentage bioethanol blends (1-10%);
- The Renewable Energy Directive II (RED II[93]), mandating Member States to oblige fuel suppliers to ensure a share of at least 14% of renewables[94] (with a maximum of 7% for the feed & food crops-based fuels[95]) within the final consumption of energy in the transport sector by 2030.

Other policy frameworks and planning should or could also address the supply of oil:

- All instruments (EU & national) supporting the shift from fossil-based to low carbon and sustainable fuels, such as support schemes, taxation and fiscal incentives, carbon pricing (Emission Trading System or ETS[96], Energy Taxation Directive or ETD[97] and national schemes), quota and mandates, or even ban;

[90] Dir 2014/94/EU available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN
[91] 2009/119 directive, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0119&from=FR
[92] Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (Text with EEA relevance), available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0030&from=EN
[93] Dir 2018/2001, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=fr
[94] Article 25 RED II
[95] Article 26 RED II
[96] https://ec.europa.eu/clima/policies/ets_en
[97] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12227-EU-Green-Deal-Revision-of-the-Energy-Taxation-Directive_en

- National Energy & Climate Plans comprise a section on energy security (chapter 3), which focuses more on electricity and gas security of supply than on oil. Storage and transport of oil are only addressed in the frame of securing energy supply in the current framework, without considering the evolution of fuel demand, nor the emergence of new low carbon fuels;
- The Trans-European Transport Network (TEN-T) policy addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports and railroad terminals. The ultimate objective is to close gaps, remove bottlenecks and technical barriers, as well as to strengthen social, economic and territorial cohesion in the EU[98];
- TEN-T Recital 31 recalls : (…)"In order to achieve those objectives, the availability of alternative clean fuels should be improved throughout the trans-European transport network. The availability of alternative clean fuels should be based on demand for those fuels and there should not be any requirement to provide access to each alternative clean fuel at each fuel station". Even if it is expected to address the availability of fuels, there is limited concern to ensure the full availability of the entire supply chain of these fuels, from their production, to their delivery, via primary storage, transport, secondary storage, and final distribution.➔ to improve the availability, each supply chain should be assessed to mitigate disruption risks.

Globally, the oil supply chains are more or less included in all planning and measures expected to address security of supply. However, in practice, some elements along the chain are not fully considered.

Europe should build a clear view or pathway for renewable and low carbon fuels by 2050. Europe should include an assessment of the existing oil infrastructure of the transition scenarios which are used to design decarbonisation policies (such as in the Clean Target Plan), and factor in the cost impact assessment all benefits of repurposing the existing infrastructure (compared to building new infrastructure). However, this would remain very general and should be passed on to the MS for more detailed assessment, taking into account national circumstances. Additional costs, or on the inverse decreased costs, due to infrastructure adaptation (more or less insulation, coating, protection, specific material,…), should be assessed.

For the next National Energy & Climate Plans (NECP) revision (draft mid-2023, final mid-2024), MSs could:

- More precisely indicate in their NECPs which alternative liquid fuels will be considered for 2030 & 2050, complementing other carriers (gas and electricity, but also heat in district heating);
- Increasing the share of alternative/renewable fuels (incl. liquids), include all infrastructure elements along the whole supply chain, including storage, within their impact assessment.

In the framework of the Oil Stocks Directive, MSs could anticipate the evolution of their fossil-based liquids consumption & emergency storage needs and adapt their legal framework accordingly. In this framework, close coordination would be required between MSs, to understand national developments at a more global scale and allow anticipation of changes along the entire supply chain.

In the frame of the Fuel Quality Directive, which currently sets a maximum share of 7% of FAME in biodiesel blend, the impact of going beyond the current threshold should be assessed. Several studies

[98] The current TEN-T policy is based on Regulation (EU) No 1315/2013

show that most EU infrastructure (and fleet[99]) could already accommodate the use of B10 and E10. There is also a need to ensure all standards and safety regulations are in place for all new fuels (and applications).

Some MSs may have to provide support to investments in new storage and transport assets and equipment to investors, infrastructure operators, and other concerned market actors. The Guidelines on State Aid for Environmental Protection and Energy (2014-2020) should be revised accordingly.

Europe could play a role in supporting the research of the technicalities of infrastructure adaptation. RD&I efforts could be dedicated to further explore the impacts of emerging fuels on different equipment, due to different operating conditions and chemical characteristics.

National frameworks

Since the right to determine its own energy mix lies with the Member State (based on TFEU), the EU is not in a position to define what alternative fuels and in which sectors they will be used. It is therefore mainly in the hands of national governments to indicate to industry what role the alternative fuels are expected to play for a cost effective transition to a low carbon economy (e.g. which fuels and in which sector). However, the EU/EC can coordinate actions to ensure compatibility with the Internal Market.

Since European countries are the ones that have the right to determine national energy mix, they should clearly indicate in their national policy frameworks which alternative fuels are preferred, or how they would set up technology-neutral frameworks for the deployment of the most competitive fuels. This will give infrastructure operators a more precise picture of what level of demand can be expected. Based on this, more qualified investment decisions can be made on whether it makes sense to convert existing infrastructure and which assets should be phased out.

Although the concrete policy framework might differ from country to country, the EU regulation includes at least two basic instruments: the NECPs and the national policy frameworks mandated by the AFID. The NECPs should include targets for the use of alternative fuels in all sectors (transport, heating, industry and others) and also present policy measures to support deployment. According to the AFID, the NPFs for alternative fuel infrastructure focus mainly on deployment of electricity, natural gas (LNG and CNG) and hydrogen charging points for the transport sector. However, according to Article 3 of AFID, the NPFs should also include a wider assessment of future development of alternative fuel markets (in the transport sector) including other alternative fuels.

In the frame of these instruments, MSs should plan decarbonisation of the liquid fuel applications by consulting the sector, based on impact assessments and considering:

- Geographic coverage of the different fuel uses, and their related infrastructure;
- Loss of value and stranded assets where dismantling is required due to decrease in global consumption;
- New specific threats and risks of disruption;

[99] Cf the List of ACEA member company passenger cars, light commercial vehicles (vans) and heavy-duty vehicles (or heavy-duty engine models) that are compatible with using 'B10' diesel fuel, available at https://www.acea.auto/uploads/publications/ACEA_B10_compatibility.pdf. And the MVaK vehicles lists, available at https://www.mvak.eu/wp-content/uploads/2020/11/mvak_approval_list_b10_v07.pdf
Cf also the "Engine tests with new types of biofuels and development of biofuel standards" funded by Horizon 2020, and carried out by the European Standardization Committee (2019), available at https://www.cen.eu/work/Sectors/Energy/Pages/Biofuels.aspx

- Permitting delivery or renewal of existing assets.

Such planning should be transparent and provide visibility to all concerned stakeholders.

4.3.2 Takeaways for infrastructure owners

Infrastructure owners and operators should also anticipate these global trends, by considering the following measures:

- Prepare business continuity plans based on realistic scenarios of future fuel demand to avoid investing in stranded assets;
- The most cost-effective way is to replace equipment at the end of lifetime; consider using materials and equipment that will be suitable for alternative fuels use;
- Consider spatial differences of alternative fuel supply chains to existing fossil fuel chains;
- Support research for equipment to assess compatibility with new fuels (valves, pumps, pipes, noses, ….);
- Support the development of standards for the use of (neat) alternative fuels or hi-percentage blends;
- Take all required measures to work with national regulators in developing guidance, standards and plans to meet emerging safety requirements for future energy sources';
- Assess the needed skills and knowledge in handling alternative fuels and infrastructure adaptation, in order to adopt the required training strategies;
- Consider creating partnerships along the whole supply chain, from production to end-use, to construct resilient energy supply chains in close collaboration with all concerned parties.

5 Annexes

5.1 List of consulted stakeholders

Stakeholders	chain	feedback received
NeriDepositiCostieri	SC2 (biodiesel 100% FAME)	yes
Unem	SC2 (biodiesel 100% FAME)	yes
Assopetroli- Assoenergia	SC2 (biodiesel 100% FAME)	yes
ePure	SC4 (bioethanol 100% from waste)	yes
TSA	SC4 (bioethanol 100% from waste)	yes
Eurogas	SC5 (LNG to hydrogen)	yes
Rotterdam Port	SC6 (ship fuel to e-fuel)	yes
M&B	SC7 (Kerosene by SAF)	yes
Votob	SC7 (Kerosene by SAF)	yes
Primagaz	SC11 (Bio LPG)	yes
USI	SC11 (Bio LPG)	yes

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