Sustainable Marine Biofuel for the Dutch Bunker Sector

Assessing the extent to which current policies lead to achieving shipping sector targets

Final Report

August 2018

Author:
Peter Grijpma –Master student Utrecht University

Supervisors:
Eric van den Heuvel – Netherlands Platform Sustainable Biofuels
Martin Junginger – Utrecht University

Platform Duurzame Biobrandstoffen
KvK: 66963850
Triodos bank: NL40 TRIO 0338 4321 24
BIC TRIONL2U
BTW: 8567.72.999.B01

Kosterijland 15, 3981 AJ Bunnik
contact@platformduurzamebiobrandstoffen.nl
twitter: @PlatfDuurzBiobr
www.platformduurzamebiobrandstoffen.nl

Sustainable Marine Biofuel for the Dutch Bunker Sector

Assessing the extent to which current policies lead to achieving shipping sector targets

Final Report

Date:	August 2018
Written by:	Peter Grijpma, Master Student University Utrecht
Context:	Internship project

Platform Duurzame Biobrandstoffen, 2018
Kosterijland 15
3981 AJ Bunnik
the Netherlands

Contact:
06-83223098
contact@platformduurzamebiobrandstoffen.nl
www.platformduurzamebiobrandstoffen.nl

Platform Duurzame Biobrandstoffen

Acknowledgements

I would like to thank Eric van den Heuvel and Loes Knotter for their undying support throughout this project, their supervision and for always being willing and available to address my questions. I would like to thank Martin Junginger for his supervision from the University of Utrecht. I would like to thank Tijs Lammens and Sjors Geraedts for making time available for me to interview them as well as their prompt and thorough replies to all my follow-up questions.

Finally, I would like to extend a special word of gratitude to Joost van Stralen, who devoted dozens of hours to performing model simulations and responding to my questions and without whom this research would not have been possible.

Peter Grijpma

Platform Duurzame Biobrandstoffen

Table of content

Platform Duurzame Biobrandstoffen

Platform Duurzame Biobrandstoffen

1 Introduction

1.1 Context

In the 2015 Paris climate agreement 195 signatories recognized climate change as an urgent threat and agreed to the need to hold the increase in global average temperature to below 2^0 C above pre-industrial levels (UNFCCC, 2015). In order to meet this objective, it is imperative that society transition away from fossil fuels as its primary energy source and move increasingly towards alternatives with low GHG emissions. Accordingly, in the 2017 Dutch coalition agreement the Dutch government has expressed the ambition to reduce GHG emissions by 49% relative to 1990 levels by 2030, with the intention of realising further reductions by 2050 to meet the goals of the Paris agreement.

However, due to their international character the aviation and shipping sectors are not covered by the Paris agreement (IMERS, 2016). The aviation and international shipping sectors have both adopted industry-wide targets for the reduction of GHG emissions through their UN standards setting organizations, the ICAO and IMO respectively. The aviation sector aims to achieve carbon neutral growth by 2020 and halve emissions by 50% by 2050 relative to 2005 levels (IATA, 2018). As of 13 April 2018, the IMO aims to reduce GHG emissions from international shipping by at least 50% relative to 2008 levels by 2050 (IMO, 2018a).

In 2015, EU shipping emissions comprised of 12,8% of total EU transport emissions (EEA, 2017a). While several possibilities for alternative energy sources exist for stationary energy users, the challenges of large-scale energy storage at sufficient density and cost (Lloyd's, 2017) place significant constraints on the options to reduce GHG emissions in the transportation sector (Agrawal et al., 2007). As these challenges become more acute for longer transportation distances and greater cargo weights (EC, 2013a), it is expected that the heavy vehicle transport, aviation and shipping sectors will continue to exhibit a heavy reliance on energy-dense gaseous and liquid fuels for the foreseeable future (EC, 2013a). This has put forth sustainable biofuels as a promising alternative for reducing emissions in these sectors in the short- and medium-term.

A modest uptake of sustainable biofuel in the road transport sector has been present for some time, comprising 3.0% (13.4 PJ) of road sector energy consumption in the Netherlands in 2015 (excluding double counting) (CBS, 2016a; CBS, 2016b; EurObserver, 2017) and 3.7% (603 PJ) in the EU in 2015 (EurObserver, 2017; EEA, 2017b), principally as a result of blending mandates included in the Renewable Energy Directive (EC, 2017).

The aviation sector has also been actively engaged with implementing the use of sustainable aviation biofuel for a number of years (IRENA, 2017) and has since witnessed a number of important developments. These include numerous biofuel demonstration flights starting from 2006 (ETIP Bioenergy, 2018a), the decision to include aviation in the EU Emission Trading System in 2008 (EU, 2009), ICAO agreement in 2010 to strive for carbon neutral growth by 2020 and halve emissions by 2050 relative to 2005 (ICAO, 2010) and formal adoption of the CORSIA resolution to offset growth in aviation emissions past 2020 in 2016 (ICAO, 2016). This has been followed by ASTM certification of HEFA derived biofuel in 2011 (ASTM, 2011) and more recently the instigation of multi-stakeholder supply chain initiatives for the commercial provision of sustainable aviation biofuel (IRENA, 2017).

However, while the aviation sector has moved beyond strategy formulation and proof-of-concept demonstrations on to commercialization initiatives, comparable efforts in the shipping sector are considerably less developed, with a formal agreement on CO2 reduction targets having only been reached as of 13 April 2018.

Technology roadmaps can serve a useful purpose in managing and implementing technological transitions (McDowall, 2012). They do so by identifying which parties are likely to play a relevant role in the transition (McDowall, 2012), identifying specific technology and policy needs (IEA, 2014) and engaging stakeholders and forming consensus on the preferred technological pathways (IEA, 2014). This in turn allows informed and strategic decision making on the part of government and industry stakeholders (IEA, 2014) and can help to foster alignment of stakeholder actions as well as research, investment and policy goals around a strategic vision (IEA, 2014).

In order to develop an effective strategy for implementing the use of Sustainable Marine Biofuel (SMB) in the shipping sector and allow for the formulation of a roadmap to support achieving industry targets, greater insight is required into which feedstock-technology pathways offer the potential to contribute substantially to shipping GHG emission reductions and into the extent to which they are sustainable, economical and supported by the legislative environment.

The aspects of sustainability and economics of biofuels in conjunction with the nature of the legislative environment critically determine the efficacy and viability of biofuels as a component of climate change mitigation strategies and are therefore central to any actionable deployment strategy. Accurate emissions data are a prerequisite for the effective management of climate mitigation efforts and hence reliable carbon accounting mechanisms for biofuel emissions should be in place (Shishlov & Cochran, 2016). Wider sustainability concerns[1] also need to be addressed, however, for biofuels to gain social acceptance and to enable their widespread adoption (de Jong et al, 2017). Finally, economic viability has to be achieved either through regulatory requirements (mandates, prohibitions) or through cost competitiveness with fossil alternatives, potentially in conjunction with policy support measures (FAO, 2013). The legislative environment is of pivotal influence on the attainment of these preconditions. It is therefore necessary to examine the merit of biofuels for climate mitigation in light of their sustainability, economics and relation to the legislative environment.

The Netherlands is a large supplier of bunker fuel to the international shipping sector[2] and holds an important position internationally. The amount of bunker fuel sold from Dutch ports annually (533 PJ in 2016 (CBS, 2016b)) is equal to roughly 1.2 times the energy used in the Dutch road transport sector (448 PJ in 2016 (CBS, 2016b)). The Dutch international shipping sector therefore offers a large potential for GHG emission reductions and is of sufficient size to offer valuable insights into the role biofuels can play in shipping globally. In addition, in the 2016 'Energie Agenda' the Dutch government expressed that in light of industry targets and expected future legislation, carbon intensive operations associated with the provision of bunker fuels might put the Netherlands' future competitive position under pressure (GovNed, 2016). Furthermore, the Dutch chemical industry fulfils an important function in the Dutch economy and holds a competitive position internationally yet has few options to untether itself from fossil fuels. Biobased resources offer the industry a way to do so but have not yet reached the stage of technological maturity to be viable. The development of biofuel supply chains for other sectors allows part of the cost, schedule and technology risk associated with technological maturation, feedstock mobilization and capacity

[1] E.g. water use, land use, air quality, health effects, socio-economic factors, displacement effects, food security, and biodiversity

[2] The term 'international shipping sector' is used in this report to refer to the 'deep-sea' and 'short-sea' shipping sectors and excludes the 'inland' shipping sector.

deployment to be retired so that the Dutch chemical sector is in a position to transition away from fossil resources when future legislation so requires.

1.2 Research aim and research question

While the Renewable Energy Directive contains a binding target for renewable energy adoption in the transport sector as a whole, there are currently no binding legislative requirements for renewable energy adoption in the shipping sector specifically. However, any renewable energy supplied to the shipping or aviation sectors does count towards the obligation for renewable energy adoption in the transport sector as a whole. This raises the question of what level of biofuel adoption can be expected to occur in the absence of a binding shipping sector target.

As the shipping sector can make use of lower quality fuels than the road and aviation sectors, it is possible that SMB may be produced at reduced cost relative to road and aviation quality biofuel. This would increase the economic viability of SMB and lower the threshold for its adoption. The hypothesis that some level of biofuel adoption in the shipping sector will occur in the absence of a binding sector target, therefore, warrants further investigation.

In order to develop an effective strategy for achieving industry targets, insight is required into the level of renewable energy adoption current policies are likely to result in and hence the extent to which additional efforts are required. Therefore, the following research question is formulated:

What level of sustainable marine biofuel adoption can be expected in the Dutch international shipping sector by 2030 under the current legislative environment and how can sustainable marine biofuel cost-optimally enable GHG emission reductions by 2030 consistent with industry targets?

A number of scenarios are developed in support of this endeavour by making minimal assumptions with regard to future legislative conditions up to 2030 and making use of the best current knowledge on sustainable marine biofuel production methods. Based on these scenarios, a number of biofuel deployment scenarios were formulated through the use of the RESolve-Biomass model. The RESolve-Biomass model allows for the determining of the cost-optimal deployment of biofuel production pathways to achieve a given share of renewable energy through using policy information and techno-economic data on biofuel production technologies. These deployment scenarios were then analysed for their level of sustainable marine biofuel adoption, nature of technology deployment, interaction between demand sectors and other factors affecting sustainable marine biofuel adoption, in order to gain insight into what would be required to reach a certain adoption level and which adoption targets might be considered achievable. These insights may then be used to guide the development of a roadmap for the implementation of sustainable marine biofuel in the Dutch international shipping sector.

1.3 Scientific and societal relevance

A comprehensive overview of the possibilities for reducing GHG emissions through the use of SMB in the Dutch international shipping sector contributes to the knowledge base on the options for decarbonisation in shipping. This may be used as input for the formulation of a roadmap. In addition, insight into the cost-optimal mix of feedstock-technology pathways to offer sizable volumes of biofuel to the Dutch international shipping sector allows government and industry stakeholders to make informed decisions with regard to policy, investments and R&D efforts and supports the development of strategy for biofuel implementation. Decarbonising the Dutch international shipping sector also serves to secure the Dutch port of Rotterdam's competitive position from future GHG reduction obligations and maintains and contributes to the port's 'license to operate' (van den Bosch et al, 2011). Finally, shedding light on which feedstock-technology pathways have a high likelihood of being cost-optimal for the provision of biofuel yields insights that can be of value for the development biofuel supply chains in Netherlands.

1.4 Reading guide

Chapter 2 will outline the legislative context relevant to sustainable marine biofuel adoption on the international, EU and Dutch level. Chapter 3 describes pathways for the production of biofuels that can be used as marine fuels and provides a techno-economic assessment for two production pathways. Chapter 4 illustrates how the scenarios for energy demand in the EU international shipping sector were developed. Chapter 5 describes the working of the RESolve biomass model, the assumptions made in model runs and the results of the model runs for biofuel deployment. Chapter 6 presents the conclusions and recommendations of this report and provides an answer to the research question. Chapter 7 contains the annexes and chapter 8 contains the references.

2 Legislation

2.1 International

Shipping is regulated at the international level by the International Maritime Organisation (IMO), a specialised body of the United Nations. The IMO was founded in 1948 as the "Intergovernmental Maritime Consultative Organisation" and was meant as a forum for intergovernmental cooperation for the promotion of maritime safety and to facilitate international trade (UN, 1948). Its role has since evolved to include all matters related to shipping safety, environmental performance and the establishment of a level playing-field for international commerce (IMO, 2018b). The IMO considers the promotion of sustainable shipping and sustainable maritime development as one of its top priorities (IMO, 2018b). Examples of shipping aspects covered by IMO measures include ship design, construction, equipment, manning, operation and disposal (IMO, 2018b). In addition, the IMO provides a forum for stakeholders including member states, civic society and the shipping industry to work together to develop and implement global standards with regard to maritime education and training, maritime security, energy efficiency, maritime traffic management, new technology and innovation and the development of maritime infrastructure (IMO, 2018b), with the ultimate aim of providing a unified institutional framework for the global maritime transportation system (IMO, 2018b). This has led to the development of over 60 binding international treaties (IMO, 2018c). The most important of which regarding GHG emissions is the 1973 International Convention for the Prevention of Pollution from Ships, commonly known as MARPOL for maritime pollution (Hsieh & Felby, 2017). The treaty is divided into six annexes according to the type of pollutant that, through the adoption of successive amendments, have become more comprehensive over time. Annex VI deals with the prevention of air pollution from ships (IMO, 2018d). The most important policies under MARPOL Annex VI affecting GHG emissions and biofuel adoption are the Energy Efficiency and Design Index, the Ship Energy Efficiency and Management Plan and the implementation of Emission Control Areas. These are discussed below.

2.1.1 Energy Efficiency and Design Index (EEDI)

The Energy Efficiency and Design Index was adopted at the 62nd Marine Environment Protection Committee in 2011 (MEPC 62) and is intended to improve the specific fuel consumption of ships covered by the measure (Hsieh & Felby, 2017). It applies to all newly built ships from 2013 onwards. According to IMO, the EEDI is intended to "stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase." (IMO, 2011).

The EEDI sets a mandatory upper-bound on the allowable CO2 emissions per amount of transport work delivered as measured in grams of CO2 per tonne-mile of cargo transported. It prescribes a different limit for each ship type identified in the measure. The following ship types are identified: oil tankers, bulk carriers, gas carriers, general cargo, container ships, refrigerated cargo and combination carriers. For each type of ship, the reference value of the limit is equal to the average for ships of that type built between 2000 and 2010 for the period 2013-2015. The limit is to be tightened every five years from then onwards, starting with a 10% reduction with respect to the reference value for the period 2015-2020. Limits have been established until 2030, with a 20% reduction relative to the reference value for the period 2020-2025 and a 30% reduction for the period 2025-2030.

By not prescribing a particular technology for achieving the required performance and leaving the choice of how to comply with the regulation up to the industry – while at the same time tightening the standards every five years - the IMO hopes to stimulate the development of innovative and cost-effective approaches to improving energy efficiency on a continual basis (IMO, 2011).

2.1.2 Ship Energy Efficiency and Management Plan (SEEMP)

Whereas the Energy Efficiency and Design Index only applies to ships built after 2013, the Ship Energy Efficiency and Management Plan applies to all ships 400 gross tonnes and above (Hsieh & Felby, 2017). It establishes a mechanism to review industry best practices for the fuel-efficient operation of ships (IMO, 2011). It mainly focuses on operational practices like slow steaming, but also includes the review of new technologies such as waste heat recovery systems or new propeller designs (IMO, 2011). It focuses on the monitoring of ship efficiency through monitoring tools such as the Energy Efficiency Operational Indicator (EEOI) (E4tech, 2018) and to track improvements in efficiency over time. The EEOI allows ship operators to quantify the effect of any changes made to improve the energy efficiency of ships, such as more frequent propeller or hull cleaning, improved journey planning or the introduction of technical measures (IMO, 2011).

The SEEMP requires all ships of 5000 gross tones to submit fuel consumption data, along with cargo and transport work information, for each type of fuel used aboard the vessel (E4tech, 2018). This data collection is aimed to provide the basis for future GHG reduction measures as well as to track the progress and relative success of adopted measures.

2.1.3 Non-GHG Emissions and Emissions Control Areas (ECAs)

MARPOL Annex VI introduced global limits on the emission of SOx, NOx and particulate matter and established the creation of Emissions control Areas (ECA). ECAs are jurisdictions where more stringent limits on the emission of SOx (currently all ECAs) and NOx (all ECAs from January 2019 onwards) apply than is the case outside ECAs. There are currently four ECAs under MARPOL Annex VI: the Baltic Sea ECA, the North Sea ECA, the North American ECA and the United States Caribbean ECA (IMO, 2018e), as shown in Figure 1 below:

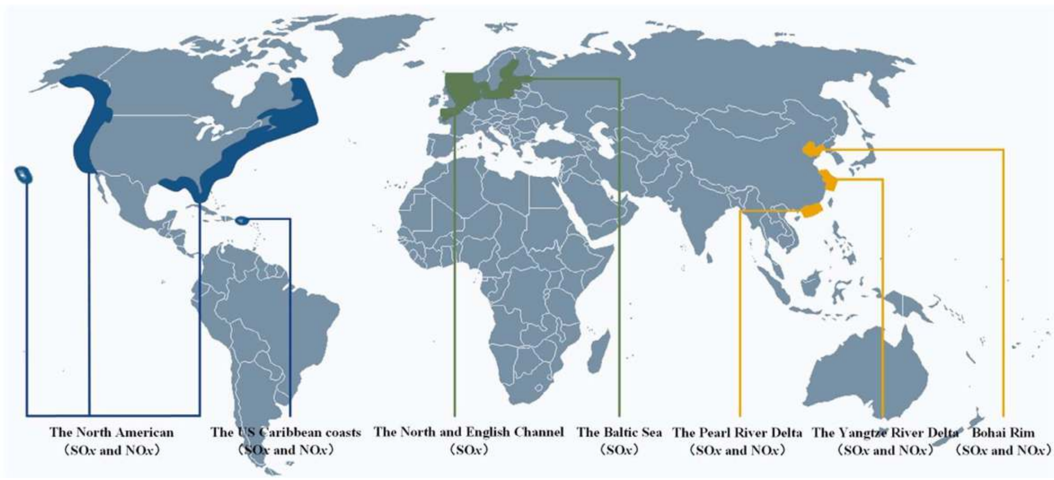

Figure 1. Map of Emissions Control Areas (ECAs) (Zhen et al., 2018)

The global limit on fuel sulphur content is currently 3,5% on a mass basis and is set to be reduced to 0,5% from January 2020 onwards (IMO, 2018e). The sulphur limit inside ECAs at present is set to 0,1%, down from its previous level of 1% since 2015 (E4tech, 2018). The stricter sulphur limit inside ECAs renders regular Heavy Fuel Oil unusable without further post-combustion treatment (E4tech, 2018). The current global limit of 3,5% does allow the use of most HFOs. This has led to ships carrying another more expensive, low-sulphur fuel for use when inside ECAs such as Marine Gas Oil (MGO), Marine Diesel Oil (MDO) or Low-Sulphur (LSHFO) or Ultra Low-Sulphur HFO (ULSHFO) (E4tech, 2018).

The regulation on NOx emissions follows a similar structure to SOx emissions, with a global limit and a lower limit inside ECAs. Currently only the North American and Caribbean ECAs have a separate NOx limit, but this is set to extent to the Baltic and North Sea ECAs from January 2019 onwards thereby harmonizing NOx regulation across ECAs. There are currently three tiers of NOx limits that are tied to the rated engine speed, as illustrated in Figure 2 below:

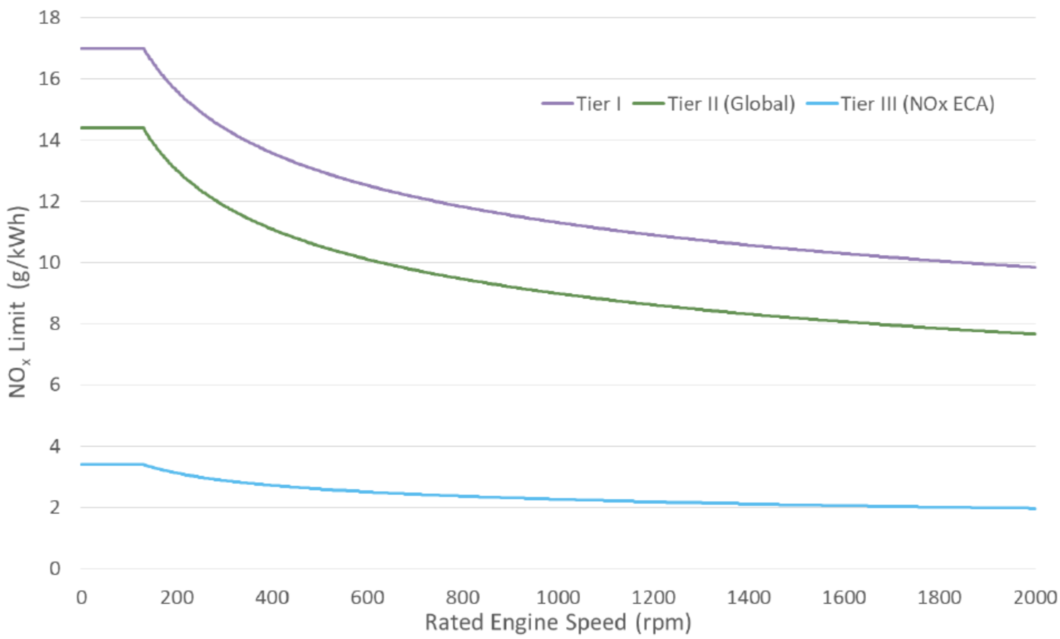

Figure 2. Tiers of NOx emission limits (E4tech, 2018)

Tier I applies to engines in ships built between 2000 and 2010. Tier II came into force in January 2011 and applies to marine diesel engines on ships built in or after 2011 (Hsieh & Felby, 2017). Both the tier I and tier II limits are global limits. Tier III came into effect in January 2016 and applies to marine diesel engines of more than 130 kW on ships built in or after 2016 when operating inside of an ECA (Hsieh & Felby, 2017).

The strengthening of the global SOx limit in 2020 will also require post-combustion treatment of HFO type fuels outside of ECAs and can be expected to affect significant fuel, fuel market and technology changes in order to ensure compliance (Hsieh & Felby, 2017). It remains to be seen whether and to what extent this will precipitate increased consumption of low-sulphur fuels, adoption of post-combustion treatment technology such as SOx scrubbers or a switch to alternative fuels such LNG or biofuels (Hsieh & Felby, 2017). The regulation is expected to lead to a decrease in HFO consumption, as the only HFO consumers will be those that have SOx scrubbers installed on board (Hsieh & Felby, 2017). This is expected to lead to a decrease in demand for HFO and resulting lower HFO prices, in turn affecting refinery operations which will have to invest in desulphization and hydrotreating facilities (Hsieh & Felby, 2017). SOx scrubbers reduce fuel economy, while the increased processing at refineries is associated with increased energy and hydrogen consumption (Hsieh & Felby, 2017). Thus, the regulation to reduce SOx emissions is likely to lead to an increase in CO2 emissions from the system perspective (Hsieh & Felby, 2017; E4tech, 2018).

At the time of writing, no reports could be found of developments to introduce further SOx or NOx regulation beyond those currently adopted. This includes further tightening of current SOx or NOx limits, development for the tier III NOx limits to apply globally, or the introduction of new ECAs.

2.2 EU

The EU is the principal supranational organisation with jurisdiction to develop and issue policy, regulation and other legislation in Europe and has significant potential influence on the successful deployment of biofuels in the EU international shipping sector (E4tech, 2018). The EU is in favour of a global approach to reducing emissions from international shipping and has therefore refrained from issuing policy in this domain (EC, 2018a). The EU supports the IMO's efforts regarding maritime GHG emissions, including MARPOL Annex VI and the IMO's reduction target (E4tech, 2018). The EU has taken initial steps to integrating maritime emissions in its GHG reduction policy through the issuance of a strategy document in 2013 (EC, 2013b) and a requirement for ships 5000 GT and above entering EU ports to monitor and report detailed information on fuel consumption, transport work and GHG emissions, starting from January 2018 (EC, 2018a). Despite a general lack of targeted measures, there are a number of EU policies that indirectly affect shipping GHG emissions in the EU. These will be set out in the remainder of this chapter.

2.2.1 Renewable Energy Directive (Directive 2009/28/EC) (RED I)

The Renewable Energy Directive (RED) was adopted in 2009 and is the overarching policy framework for the promotion of renewable energy in the EU (EC, 2009). It requires 20% of the EU's final energy consumption to be derived from renewable sources by 2020 and an amount of renewable in transport equal to 10% of each Member State's energy use in road and rail by 2020 (EC, 2009). The target for final energy consumption differs per Member State based on that country's circumstances (EC, 2009).

It is left up to each Member State to determine the specific policy instruments and general approach to meet their targets and Member States are required to submit a National Renewable Energy Action Plan that specifies their approach (EC, 2009). In addition, Member States are required issue a national renewable energy progress report every two years (EC, 2009). In 2015, Directive 2015/1513, otherwise known as the iLUC directive (E4tech, 2018), amended the RED on a number of points.

Biofuels and bioliquids are considered instrumental in meeting the 10% renewable energy in transport target (EC, 2009). The RED sets out sustainability criteria for biofuels and bioliquids produced and consumed in the EU and those not in compliance with the criteria may not receive government support or count towards renewable energy targets (EC, 2016a). Compliance is possible through national systems or so-called voluntary schemes recognized by the European Commission (EC, 2009). The main sustainability criteria include a minimum GHG saving of 50% relative to fossil fuels on a life-cycle basis (60% for new facilities) and a requirement that the raw materials for the production of biofuels or bioliquids may not be sourced from (EC, 2016a):

- Land with high biodiversity
- Land with high carbon stock
- Land that was peat land before January 2008

In addition, the RED also includes a number of reporting requirements for fuel providers, Member States and the EC on, for example, the effectiveness of the directive in limiting indirect land-use change (iLUC) GHG emission and the estimated value of ILUC emissions (PWC, 2017).

The RED also includes a cap of 7% on biofuels produced from certain feedstocks known as 'conventional' or crop-based biofuels (E4tech, 2018). Feedstocks which are not subject to this cap are listed in Annex IX-A and IX-B of the Directive 2015/1513, also known as the iLUC directive (E4tech, 2018). Member States are required to set a target of no less than 0,5% for energy from biofuels produced from Annex IXa feedstocks by

2020. The target is indicative and Member States are allowed to set a lower target if certain criteria are met. These criteria are broad enough, however, that there is no real pressure on Member States to refrain from setting a lower target or no target should they wish to do so (E4tech, 2018). However, the Netherlands have transposed the target into national law above the suggested 0,5% at 0,6% for 2018, 0,8% in 2019 and 1,0% in 2020 (E4tech, 2018). This includes double counting such that the physical amount of energy equals 0,5%.

In order to comply with the 10% target, the actual energy supplied to the transport sector may be multiplied by a certain factor for certain sources of renewable energy. These are known as multipliers and are 2 times for biofuels produced from feedstocks listed in Annex IX-A and IX-B and 5 times for electricity from renewable sources consumed by road vehicles (E4tech).

2.2.2 Fuel Quality Directive (Directive 98/70/EC)

The Fuel Quality Directive (FQD) was adopted in 1998 and subsequently amended in 2009 by Directive 2009/30/EC and again in 2015 by Directive 2015/1513 (PWC, 2017). It applies to petrol, diesel and biofuels used in road transport as well as gasoil used in non-road mobile machinery. It sets common fuel specification standards for the EU primarily for the control of substances linked to air pollutant emissions, such as sulphur (EC, 2018b). Along with the Renewable Energy Directive it also regulates the sustainability of biofuels (EC, 2018b).

The 2009 amendment introduced a requirement for suppliers to reduce the GHG intensity of fuel supplied to the EU market for use in road transport by 6% by 2020 (EC, 2018b). Emission reductions are relative to 2010 levels and are calculated on a life-cycle basis including the emissions from the extraction, processing and distribution of fuels (EC, 2018b). It is expected that these emission reductions will be primarily achieved through the use of biofuels (E4tech, 2018). In order for biofuels to count towards the GHG reduction target they must comply with the same sustainability and reporting criteria the Renewable Energy (E4tech, 2018). Fuels supplied to the marine and aviation sector are not covered by the FQD (PWC, 2017).

2.2.3 EU Sulphur Directive ((EU) 2016/802)

The EU Sulphur Directive was last updated in 2016 and follows developments at the international level under MARPOL Annex VI (EMSA, 2018). It regulates the sulphur content of gas oils and heavy fuel oils used for marine and land-based applications (E4tech, 2018). It establishes a Sulphur Emission Control Area (SECA) that coincides with the North Sea and Baltic Sea ECAs defined in MARPOL Annex VI, allowing those ECAs to be enforced under EU law (E4tech, 2018).

The sulphur content of fuels is restricted to 0,1% (by mass) for fuels used inside the SECA and 3,5% for fuels used in EU waters outside the SECA. For passenger ships, the sulphur content is limited to 1,5% outside the SECA due to their proximity to shore (E4tech, 2018). The directive also sets a 0,1% limit for fuels used by ships berthing at EU ports and it prohibits the sale of marine gas oils with a sulphur content above 0,1% (E4tech, 2018).

The directive applies to all shipping sectors, but it is of note that the inland shipping sector is already subject to much stricter limit under the FQD of 0,001% (E4tech, 2018).

2.2.4 Renewable Energy Directive for the period 2021-2030 (RED II)

On 14 June 2018 negotiators from the three EU institutions reached an informal agreement on the Renewable Energy Directive II (EU Council, 2018). At the time of writing negotiations are ongoing and the information presented here is based on what is published up to June 21, 2018.

The RED II forms the continuation of the RED I and sets EU renewable energy policy for the period 2021-2030. It establishes, among others, an overall renewable energy target of 32% by 2030. For each Member State, it sets a target for renewable energy in transport of at least 14%. This target may be lowered based on a Member State's cap on crop-based biofuels. The cap may be at most 7% of energy consumed in the road and rail sectors and may not exceed a Member State's contribution of crop-based biofuels in 2020 plus 1%. Member States may implement a cap of 2% regardless of their crop-based contribution. It sets a cap of 1,7% on feedstocks from Annex IX-B, such as used cooking oil and animal fats, that may be lifted with the consent of the European Commission. In addition, it includes a sub target of 3,5% by 2030 for biofuels produced from feedstocks listed in Annex IX-A.

As under the RED I, targets may be wholly or partially achieved by applying a multiplier to an amount of energy supplied under certain conditions. This means that the actual energy supplied is likely to be substantially lower than the targets indicate. The multipliers in effect under RED II are as follows:

- 2x for biofuels produced from feedstocks listed in Annex IX-A and IX-B
- 1,2x for biofuels supplied to the marine and aviation sector that may be applied in conjunction with the above mentioned 2x multiplier
- 4x for electricity from renewable sources used in road transport
- 1,5x for electricity from renewable sources used in rail transport

Biofuels that are believed to pose a high risk of iLUC emissions, will be capped at a Member State's level of production in 2019 unless they can be certified as 'low iLUC risk biofuels'. This cap is to be gradually reduced from 2023 onwards to 0% by 2030. The European Commission is to adopt concrete criteria and a list of feedstocks for these high iLUC biofuels by December 2020.

2.3 Netherlands

At the national level, the Dutch government has the potential to issue policy and regulations that can affect all types of shipping that take place within the Netherlands (E4tech, 2018). However, due to the international nature of shipping, particularly the deep-sea and short-sea shipping sectors, enacting legislation that is stronger than for other countries may induce adverse economic effects (E4tech, 2018). The Dutch government therefore recognises the need to seek to implement policy on the EU and international level (E4tech, 2018). This is illustrated in the 2016 'Energy Agenda', which stresses the need for international action to combat GHG emissions "in order to maintain the Dutch international competitive position in ocean shipping" (Gov't NL, 2016).

EU policies are implemented at the national level, meaning that the requirements of the EU Sulphur Directive and the Fuel Quality Directive are also part of Dutch law (E4tech, 2018). The Renewable Energy Directive leaves its specific implementation up to Member States and this is discussed later on in this chapter.

Dutch policy in relation to energy and transport policy is focussed on reducing GHG emissions (E4tech, 2018), with the Ministry of Economic Affairs and Climate and the Ministry of Infrastructure and Water management being the main bodies overseeing its development and implementation (E4tech, 2018). The most important policy documents governing Dutch energy policy are (E4tech, 2018):

- The 2013 Energy Agreement
- The 2016 Energy Report
- The 2016 Energy Agenda

The 2013 Energy Agreement was negotiated by the government and a large number of stakeholders and societal organisations in 2013 (SER, 2013). It consists of a high-level roadmap detailing Dutch energy ambitions and targets for the period 2013-2023 (SER,2013). It also includes agreement on a 60% reduction target relative to 1990 levels for CO2 emissions in transport by 2050 (SER, 2013). It focuses heavily on the power sector (E4tech, 2018) and establishes financial incentives for the promotion of energy savings and renewable electricity (SER, 2013). It sets a target of 14% and 16% renewable energy in final use by 2020 and 2023, respectively (SER, 2013).

The 2016 Energy report focuses on the period 2023-2050 and highlights transport as one of four sectors targeted for GHG reduction (Min. EA, 2016b). It mentions biofuels as the best alternative to fossil fuels for heavier and longer distance transport by road, sea and air (Min. EA, 2016b). However, it states that the supply of biomass for bioenergy production could be limited due other possible economic uses, such as food production (Min. EA, 2016b). It puts forth the Netherlands as a proponent of stricter international limits on emissions from shipping and aviation and stricter EU limits on emissions from road transport (Min. EA, 2016b).

The 2016 Energy Agenda outlines GHG reduction strategy up to 2050 and highlights international agreements as the preferred method of achieving emission reductions in international long-distance transport (Min. EA, 2016a). It expresses a commitment to LNG, biofuels, fleet renovation and improved journey planning as means of achieving CO2 reduction targets but doesn't offer specific policies or provide details on what these options would contribute (Min. EA, 2016a).

2.3.1 Implementation of the Renewable Energy Directive

The RED was transposed into Dutch law in 2011 through amendments to Environmental Management Act (Wet Milieubeheer), the Decree on Renewable Energy in Transport (Besluit Hernieuwbare Energie in Vervoer) and the Regulation on Renewable Energy in Transport (Regeling Hernieuwbare Energy in Vervoer) (CMS, 2011). This has resulted in a Renewable Energy Obligation (HEV) on parties delivering fuel to the Dutch market (NEa, 2018a). Parties delivering less 500.000 litres of diesel or gasoline a year are absolved from the obligation (NEa, 2018a).

The Dutch targets for renewable energy in transport are stricter than the RED proposes at 8,5% in 2018, 12,5% in 2019 and 16,4% in 2020 (NEa, 2018a). Fuel suppliers are required to report the total amount of fuel and the amount of renewable energy they have supplied to the Dutch market to the Netherlands Emissions Authority (NEa) by registering the amounts in the Registry Energy for Transport (REV) (Register Energie voor Vervoer) (Gov't NL, 2016; NEa, 2018b). Obligations are managed through the use of Renewable Fuel Units (HBE's), where one HBE equals 1 GJ of renewable fuel (NEa, 2018b). The multipliers (see chapter 2.1) are incorporated into the HBE system by awarding an amount of HBE's corresponding to the multiplier (e.g. 1,2 HBE's for 1 GJ of conventional biofuel supplied to the marine sector proposed in the RED II) (E4tech, 2018). There are three types of HBE': HBE-C's for conventional biofuels, HBE-G's for biofuels from Annex IXa feedstocks and HBE-O's for biofuels from Annex IXb feedstocks (NEa, 2018a). There is a trading system for HBE's, meaning that parties can acquire HBE's by supplying renewable fuel themselves or by buying HBE's from other parties that have delivered renewable fuel in excess of their required amount (E4tech, 2018). However, HBE's cannot be traded outside of the Netherlands (E4tech, 2018). Each year the NEa verifies whether fuel suppliers have fulfilled their obligation by verifying that they have correct amount of HBE's in their REV account (NEa, 2018b). Parties that have more than their required amount of HBE's at the end of the year may transfer a certain percentage to the following year. Parties that have not met their obligation are to receive a fine (Gov't NL, 2018a). HBE's are granted for renewable fuel delivered to any sector, meaning that renewable fuel bunkered in the Netherlands counts towards the obligation regardless of whether it is consumed in the deep-sea, short-sea or inland shipping sector (EU Council, 2018). However, these sectors are not included in the denominator used to calculate a Member State's renewable energy in transport obligation, which only includes energy used in road and rail transport (EU Council, 2018).

2.3.2 Shipping emission policies

There are a number of policies that affect shipping emissions, both as part of the 2017 Rutte III coalition agreement and adopted prior to its conclusion. Under the coalition agreement the 2016 Energy Agreement is to be replaced by a new' climate and energy agreement' with a target of 49% GHG emission reduction relative to 1990 levels and it highlights biofuels as one of the opportunities (Gov't NL, 2017). According to (E4tech, 2018): "The new coalition agreement means that the Netherlands will produce stricter renewable energy in transport targets than what will be included in RED II, which could be a benefit to shipping decarbonisation."

In 2016, the Ministry of Infrastructure and Environment signed the COBALD (Continuous On-Board Analysis and Diagnosis) Green deal for the measuring of energy consumption and emissions from ships in inland shipping (Port of Rotterdam, 2016). It is similar to the IMO's SEEMP and is intended to help older ships make investment decisions for efficiency improvement, as well as to ensure compliance with IMO EEDI emission reduction requirements (E4tech, 2018).

The 'Work programme Maritime strategy and Seaports 2018-2021' was signed off by the coalition in 2018 and sets an ambition for zero emissions from inland shipping by 2050 (Gov't NL, 2018b). This is aimed to be part of a new 'Green Deal' for ports and shipping to be concluded by 2018. It outlines specific actions for both inland and ocean shipping sectors along with a plan for creating an inventory of measures to help meet the IMO's targets (Gov't NL, 2018b). The Maritime Strategy is required to be enshrined into law.

Regulations for port operations and port emissions for both sea and inland ports are set by local and national bodies as well as through the transposition of EU directives (E4tech, 2018). There are close to 300 inland ports in the Netherlands that work to advance common interests through the Dutch Association for Inland ports (Nederlandse Vereniging voor Binnenhavens) (E4tech, 2018). Emissions from all activities in ports, including all ship activities and industrial are covered in the Harbour Industrial Complex footprint. The ports of Rotterdam and Amsterdam are developing policies for reducing shipping emissions through their port by laws (E4tech, 2018). Finally, the Environmental Shipping Index (ESI) and the 'Green Award' are policy instruments that are in effect for the promotion of the sustainable operation and management of ships (E4tech, 2018).

2.3.3 Summary

The Netherlands has implemented policies that look to promote GHG emission reductions, increase renewable energy contributions and affect inland shipping emissions. Many of these policies also affect the adoption of biofuels. There are no direct regulations targeting the international sectors of shipping: deep-sea and short-sea shipping.

In general, the political climate shows willingness to support ambitious GHG reduction policy for all sectors, including shipping. For ocean shipping it is preferred for action to be taken on the international level, either through the EU or the IMO, out of concern of inducing adverse economic effects on the Netherlands' expansive international shipping sector. However, the Netherlands plays an active role in advocating for shipping emission reduction policies internationally and once agreement is reached, these policies are then swiftly implemented on the national level. Examples of this include enforcement of the EEDI and SEEMP and transposition of IMO and EU sulphur regulations. Several policy initiatives in effect or are underway for reducing inland shipping emissions, both on the local and the national level. These include COBALD, the Green Deal agreement, the Maritime Strategy and the 'Green Award'. Biofuel policy is principally resultant from renewable energy in transport obligations under the RED/RED II, although the Netherlands takes concerns about possible sustainability risks seriously and at 5% has implemented a stricter cap on crop-based biofuels than required under the REDII. However, the merits of these concerns are fervently debated at this time.

3 Marine biofuel production pathways

Biofuel production pathways can be categorised in various different ways, including by type of feedstock used, level of technological maturity or by type of conversion process used. Here pathways are presented by type of conversion process used. The predominant processes for the conversion of feedstocks to biofuels are: chemical conversion, thermo-chemical conversion and biochemical conversion. With regard to biochemical pathways, only the production of biomethane was considered for this study as other biochemical pathways are currently at too early a stage of development to be competitive with more developed chemical and thermochemical pathways. Thermochemical pathways are subdivided into pathways that first produce a bio-crude which is subsequently upgraded, and pathways that break down the biomass into its basic components, which are then synthesized into hydrocarbon fuels. In the remainder of this chapter the various pathways for the production of sustainable marine biofuel are discussed.

3.1 Chemical production pathways

3.1.1 Straight Vegetable Oils (SVO)

Straight Vegetable Oils (SVOs), also known as Pure Vegetable Oil (PVO) or Pure Plant Oil (PPO), are oil extracts from plants that can be used as a substitute for HFO in some types of diesel engines (Hsieh & Felby, 2017). They do not undergo any intermediate processing steps and are used directly as a fuel (Hsieh & Felby, 2017). They can be used in low speed engines that are common in ships of all sizes used in deep-sea shipping but require engine modifications for use in four-stroke engines commonly used in short-sea and inland shipping (E4tech, 2018). Their high viscosity and high flash adversely affect engine lifetimes due to the build-up of carbon deposits inside the engine and damage to the engine lubricant. They are therefore not considered practical fuels for large-scale or long-term use (Hsieh & Felby, 2017).

3.1.2 Fatty Acid Methyl Esters (FAME)

FAME is also known as biodiesel and is produced from vegetable oils, animal fats or used cooking oils (UCO) through a process called transesterification. Triglycerides from oils and fats are reacted with methanol in the presence of a catalyst to form fatty acid methyl esters as well as glycerol and water which are later removed as waste products (ETIP Bioenergy, 2018b). FAME is a more suitable fuel for use in diesel engines than SVO due to both its lower boiling point and lower viscosity (E4tech, 2018). EN590 specifications allow blends of up to 7% FAME with diesel for use in short-sea and inland shipping E4tech, 2018). However, its high could point means that at temperatures below 32° solidified waxes form in the fuel that can clog up engine filters and reduce fuel flow properties (Hsieh & Felby, 2017). FAME is biodegradable and its higher oxygen content leads to lower oxidation stability (Hsieh & Felby, 2017). This renders it prone to degrade after a period of about two months (E4tech, 2018) to form acids, peroxides and various insoluble compounds (Hsieh & Felby, 2017). The acid degradation products of FAME are suspected of causing damage to fuel pumps, injectors and piston rings, and have led to stricter acid specifications for marine fuels (Hsieh & Felby, 2017). Long-term storage should therefore be avoided and close monitoring is required if the fuel is kept in fuel tanks for more than a number of weeks (E4tech, 2018). For these reasons the Dutch inland shipping sector has reached an agreement to no longer supply FAME in the Dutch inland shipping sector.

3.1.3 Hydrogenated Vegetable Oils (HVO)

Hydrotreatment of oils and animal fats is an alternative process to esterification to produce a diesel substitute from biomass (ETIP Bioenergy, 2018c). This product is known as Hydrotreated Vegetable Oil (HVO), renewable diesel, Hydrotreated Renewable Diesel (HRD) or Hydroprocessed Esters and Fatty Acids (HEFA) (ETIP Bioenergy, 2018c). It is free from ester compounds and does not suffer from the degradation issues that FAME does (Hsieh & Felby, 2017). HVO production is at commercial scale (E4tech, 2018) and makes use of existing hydrotreatment technology currently in use at petroleum refineries (Hsieh & Felby, 2017). It therefore has improved production costs relative to pathways that rely on less mature technologies (Hsieh & Felby, 2017). HVO is compatible with engines that run on MDO, MGO or HFO and conforms to ISO 8271 diesel specifications without the need for blending with petroleum diesel (E4tech, 2018). It is similar in characteristics to MGO (E4tech, 2018). As a result, it can be used in all existing infrastructure without requiring additional equipment modifications or blending with other fuels. However, there is limited availability of waste oils as feedstock and a lower price differential with road and aviation fuel may induce strong competition from these sector (E4tech, 2018). Thus, limited fuel availability in addition to the large volumes required for international shipping may limit its potential as GHG reduction method in the shipping sector.

3.2 Thermochemical conversion via bio-crude upgrading

3.2.1 Hydrothermal Liquefaction (HTL)

The hydrothermal liquefaction process uses high pressure (5-25 Mpa) and moderate temperature (250-500 °C), along with catalysts, to convert biomass into a crude-like bio-oil (Hsieh & Felby, 2017). The product has a high energy density (LHV of 34-37 MJ/kg) and moderate oxygen content (5-20 wt-%). The advantage of HTL over pyrolysis is that it can process wet biomass and results in a product with a high energy density (Hsieh & Felby, 2017). The process is reported to be able to use a wide range of feedstocks (Steeper Energy, 2018) including woody biomass, aquatic biomass, urban sewage and animal manures, as well as waste streams from industrial processes such as sugar refining, oil seed milling or food processing. Water present in the biomass is sub- or supercritical at these temperatures and pressures and acts as a solvent, reactant and catalyst in the liquefaction process (Hsieh & Felby, 2017). Oxygen is removed from the biomass through dehydration (loss of H2O) or decarboxylation (loss of CO2) (Hsieh & Felby, 2017). The end product is a fuel with a high H/C ratio and low viscosity that is suitable for use directly in heavy engines (Hsieh & Felby, 2017) or can be upgraded further to produce fuels like gasoline, diesel or jet fuel (Hsieh & Felby, 2017). Production is currently at pilot-scale with a plant operated by Steeper Energy in Denmark having had 4750 hours of operation since its inception in 2013 (Steeper Energy, 2017).

Pyrolysis treatment involves subjecting biomass to high temperature (~500 °C) and high pressure for a few seconds in the presence of an inert atmosphere to convert dry biomass to pyrolysis-oil (Hsieh & Felby, 2017). This process, known as Fast Pyrolysis, also produces syngas and biochar as co-products and requires the biomass to be milled and dry before entering the pyroreactor (Hsieh & Felby, 2017). Pyrolysis-oil has a lower energy density (LHV of 17-24 MJ/kg) than bio-oil produced through HTL, as well as a higher oxygen content (30-50 wt-%) (Geraedts, 2018; Lammens, 2018a). Crude pyrolysis-oil could in principle be used directly as a shipping fuel but would require significant adaptations to the engine and the fuel feeding/injection system (Hsieh & Felby, 2017). This, along with its high viscosity, low energy density and the fact that it does not auto-ignite in diesel engines, makes it quite a challenging option to replace existing fuels (E4tech, 2018). However, its characteristics and compatibility can be markedly improved by upgrading the pyrolysis-oil to reduce its oxygen content (E4tech, 2018). This can be done through either hydrotreatment in a stand-alone unit (producing Hydrogenated Pyrolysis Oil (HPO)) or through co-processing in a petroleum refinery (Hsieh & Felby, 2017. Fast pyrolysis technology for the production of bio-oil for co-firing purposes in existing heat and power applications has been commercialised by a few companies and is currently at TRL 8 (E4tech, 2018). However, the technology for upgrading is less developed at TRL 6 for refinery co-processing and TRL 5 for the standalone route (Lammens, 2018b).

Techno-economic assessment

A techno-economic assessment for sustainable marine biofuel production via standalone pyrolysis oil upgrading was conducted for this research based on interviews with market players and relevant literature. The results are summarised in the Table 1 below.

Table 1. Summary of techno-economic assessment of standalone pyrolysis oil upgrading

Technical			Economic	
Pyrolysis	**Value**	**Unit**	**Pyrolysis**	**Costs (€/GJ biofuel)**
Capacity (input)	381 000	dry t/y	Capital costs pyr. plant	2,94
Yield bio-oil production	42%		Feedstock costs	11,31
Electricity consumption	184 940	GJ/y	Electricity costs	0,84
Bio-oil production	160 020	dry t/y	Other O&M	0,58
	3 886 425	GJ/y	*Total pyrolysis*	*15,67*
Hydrotreatment			**Hydrotreatment**	
Yield hydrotreatment	64,8%		Capital costs hydroproc.	0,60
Electricity consumption	4 145	GJ/y	Hydrogen costs	4,40
Hydrogen consumption	1 211 528	GJ/y	Catalyst replacement	1,13
Biofuel production	103 711	dry t/y	Electricity + other O&M	0,14
	4 364 159	GJ/y	*Total hydrotreatment*	*6,26*
			Total	**21,93**

3.2.2 Refinery co-processing

As an alternative to standalone hydrotreatment, bio-oil, as well as other semi-processed biogenic feedstocks such as triglycerides or lignin, can be co-processed in existing petroleum refineries (ARB, 2017; Stefanidis et al., 2017; ETIP Bioenergy, 2018f). Co-processing in small amount (up to 10% by weight) has been shown to not induce significant corrosion effects or substantially affect product yields (ARB, 2017). In contrast to the typical blending of finished biofuels with petroleum-derived fuels, co-processing involves the simultaneous conversion of intermediate petroleum distillates and semi-processed biogenic products to finished fuels during the cracking or hydrogenation stage of the traditional refining process (ETIP Bioenergy, 2018f). The process results in a product virtually identical in chemical composition to fossil fuels, albeit with a portion of the carbon atoms replaced by bio-carbon (Lammens, 2018b). Four refinery processes are considered candidates for bio-oil co-processing: thermal cracking, catalytic cracking, hydrotreating and hydrocracking (ARB, 2017; ETIP Bioenergy, 2018f). By far the most researched and most mature of these routes is the co-processing of pyrolysis oil during catalytic cracking in existing Fluid Catalytic Cracking (FCC) units (ARB, 2017). Co-processing has the advantage of saving on capital costs for the establishment of standalone facilities. In addition, when co-processing in FCC units auxiliary inputs of hydrogen or energy are typically not required due to synergistic hydrogen donation reactions occurring as a result of the presence of the petroleum feed (ARB, 2017). These facilitate the conversion of oxygenates to liquid hydrocarbons at the expense of a product slightly higher in aromatics (ARB, 2017). Considering that hydrogen constitutes a large cost component of the hydrotreatment of pyrolysis oil and is associated with significant GHG emissions, refinery co-processing has been proposed as a promising approach to both reduce costs and improved GHG performance (Stefanidis et al., 2017). Co-processing is still in the development stage and commercial application is expected in the early twenty-twenties (ARB, 2017; Lammens, 2018b).

Techno-economic assessment

A techno-economic assessment for sustainable marine biofuel production via pyrolysis oil co-processing in an FCC unit was conducted for this research based on interviews with market players and relevant literature. The data for pyrolysis oil upgrading via FCC co-processing is based on interviews and correspondence with Tijs Lammens (2018a), Lammens (2018b) and SGAB (2017). The results are summarised in the Table 2below.

Table 2. Summary of techno-economic assessment of pyrolysis oil upgrading via FCC co-processing

Technical			Economic	
Pyrolysis	**Value**	**Unit**	**Pyrolysis**	**Costs (€/GJ biofuel)**
Capacity (input)	381 000	dry t/y	Capital costs pyr. plant	2,94
Yield bio-oil production	42%		Feedstock costs	11,31
Electricity consumption	184 940	GJ/y	Electricity costs	0,84
Bio-oil production	160 020	dry t/y	Other O&M	0,58
	3 886 425	GJ/y	*Total pyrolysis*	*15,67*
FCC co-processing			**FCC co-processing**	
Electricity consumption	0	GJ/y	Capital costs refinery	0,28
Hydrogen consumption	0	GJ/y	Refinery O&M	1,39
Biofuel production	3 886 425	GJ/y	*Total co-processing*	*1,67*
			Total	**17,34**

3.3 Thermochemical conversion via biomass gasification

Gasification involves the conversion of lignocellulosic biomass at high temperature (900 °C) and pressure and in the presence of some oxygen and steam into its basic components (CO, H2 and some CO2) (Hsieh & Felby, 2017). This gas mixture is known as syngas and can be used directly to produce heat and electricity or as fuel for gas turbine engines (Hsieh & Felby, 2017). Alternatively, the syngas can be cleaned and used as an intermediate product for the production of various synthetic hydrocarbon fuels. These include long-chain hydrocarbons such as synthetic diesel or kerosene through the Fischer-Tropsch process (Hsieh & Felby, 2017), (bio)methane via the Sabatier process (Hsieh & Felby, 2017), (bio)methanol via catalysis (E4tech, 2018) or (bio)dimethylether (DME) via a reaction similar to methanol catalysis. However, it is important to note that methane, methanol and DME can be produced through a number of routes and that direct conversion from syngas is not necessarily the most common (Hsieh & Felby, 2017). For example, methanol is most commonly produced from methane (of fossil origin) and

DME is more often produced via dehydration of methanol (of fossil or biological origin) than direct conversion of syngas.

3.3.1 Fischer-Tropsch (FT)

The Fischer-Tropsch process involves the use of metallic catalysts to synthesize the syngas constituents into long-chain hydrocarbon waxes (E4tech, 2018). These waxes can then be upgraded using standard hydrotreatment to produce liquid transport fuels such as diesel, kerosene and gasoline. The technology for the production of FT liquids from non-renewable sources (coal and natural gas) has been commercialised for decades and was deployed heavily by Germany during WWII to compensate for a lack of access to oil (Hsieh & Felby, 2017). However, the technology using biomass as feedstock is less developed and currently at TRL-5-6 (E4tech, 2018). As an alternative to biomass gasification, renewable FT liquids can also be produced from renewable electricity and CO2 by first producing H2 via electrolysis of water and then converting the CO2 and H2 into syngas via catalysis (E4tech, 2018). Fuels produced in this way are known as RFNBO (renewable fuels of non-biological origin) (E4tech, 2018). FT-fuels are 'drop-in' fuels and are compatible with all existing ship and port infrastructure in the deep-sea, short-sea and inland shipping sectors (E4tech, 2018).

3.3.2 Bio-methanol

Methanol is currently used as a transport fuel in Europe, albeit in low volumes (E4tech, 2018). Methanol has the advantage of being liquid at ambient temperatures and easier to handle than CNG or LNG (E4tech, 2018). At present, most of the methanol produced is derived from (fossil) natural gas. The production of biomethanol can occur via catalysis of syngas obtained from biomass gasification, by using biomethane as a substitute for fossil methane or from renewable electricity. Methanol derived from renewable electricity is known as RFNBO and involves electrolysis to obtain H2, which is then converted along with CO2 to methanol via catalysis (E4tech, 2018). Large scale demonstration production using this route is currently in operation at a site in Germany and Iceland. Apart from bunkering infrastructure, much of the infrastructure for the transportation and storage of (fossil) methanol already exists due its use in the chemical sector. This includes methanol storage terminals available in the ports of Rotterdam and Antwerp as well as other ports and deliveries of methanol by road, rail or sea occurring frequently to a wide number of locations (E4tech, 2018). Methanol can be used in spark ignition engines, dual fuel spark ignition engines and converted compression ignition engines. However, its corrosive nature and the fact that it has a reduced ability to self-ignite relative to diesel require adaptations to the ignition system and redesign of parts of the engine, injection and fuel storage system to increase fuel pressure and provide additional corrosion resistance (FCBI, 2015). Methanol engines are currently in the early stages of development (FCBI, 2015), with several being in use in ships today. These include a converted medium speed four-stroke engine on the passenger ferry Stena Germanica, and seven dual-fuel two-stroke engines methanol engines on methanol tankers with four more on order (FCBI, 2015).

3.3.3 Bio-dimethylether (Bio-DME)

Bio-dimethylether can be produced from syngas in a reaction similar to methanol catalysis or through the catalytic dehydration of biomethanol (Hsieh & Felby, 2017). BioDME has a cetane number higher than methanol and comparable to diesel, making it more suitable for use in diesel engines without the need to deal with the ignition issues that methanol has (E4tech, 2018). However, it is gaseous at ambient temperature and requires to be pressurised at around 5 bar to remain in a liquid state (E4tech, 2018). This puts additional requirements on transport, storage and bunkering infrastructure, which must be able to cope with (lightly) pressurised liquids (E4tech, 2018). Pilot projects for the production of bioDME have been conducted in Sweden using black liquor to produce syngas (ETIP Bioenergy, 2018d) and during the SPIRETH project where DME was produced aboard a ship through methanol dehydration (SSPA, 2018). BioDME's low energy density (23 MJ/kg) and the fact that it lacks the widespread infrastructure and distribution network that methanol has pose disadvantages for its use as a marine fuel (E4tech, 2018).

3.4 Bio-LNG

Bio-LNG is obtained through the liquefaction of biomethane, which can be produced in three different ways; through biomass gasification, from renewable electricity and through anaerobe digestion (AD) (ETIP Bioenergy, 2018e). Syngas obtained from biomass gasification can be reacted at elevated temperature (300-400°C) and pressure in the presence of a catalyst via the Sabatier process (Hsieh & Felby, 2017). Biomethane produced in this way is known as (bio) Synthetic Natural Gas or bioSNG and is currently at TRL 7 (E4tech, 2018). The route using renewable electricity involves electrolysis to produce a RFNBO in the same way as for biomethanol and FT liquids and is currently at TRL 5-6 (E4tech, 2018). Anaerobe digestion is by far the most prevalent route and involves the decomposition of organic matter by micro-organisms in the absence of oxygen to produce a mixture of methane, CO2 and trace gasses known as biogas (ETIP Bioenergy, 2018e). The biogas can then be cleaned to produce biomethane and subsequently liquefied (ETIP Bioenergy, 2018e). The route is at commercial scale and in widespread use in Europe for organic waste-based feedstocks such as sewage sludge, food wastes, manure and landfill material (ETIP Bioenergy, 2018e). Biogas may also be produced from lignocellulosic feedstocks after pre-treatment with steam and enzymes, although this process is currently only at pilot stage (Clemens, 2016).

There has been increased attention for bio-LNG recently as a result of increased attention for LNG. LNG is slowly gaining acceptance as an alternative fuel as a means to comply with sulphur regulations (Hsieh & Felby, 2017), although its use is mostly restricted to LNG carriers. Nevertheless, there are about 100 vessels of other types in operation that use LNG (E4tech, 2018). At present, LNG carriers comprise about 3% of the fleet by number and 5% by tonnage (Hsieh & Felby, 2017).

LNG engines can be single fuel spark ignition engines (E4tech, 2018), but are typically dual fuel LNG/diesel compression ignition engines aboard LNG carriers (Hsieh & Felby, 2017). LNG carriers commonly use dual fuel engines as the boil-off gas from the LNG storage tanks can pumped to the engine and ignited through compression by adding a small proportion of distillate fuel (E4tech, 2018). A barrier to LNG adoption is the high capital costs for system installation (Hsieh & Felby, 2017). LNG requires cryogenic storage and LNG tanks are about 4 times the size of storage tanks for regular fuel for an equivalent amount of energy (Hsieh & Felby, 2017). LNG also requires additional safety features, further inflating construction costs (Hsieh & Felby, 2017). In addition, LNG has longer fuelling times than conventional fuels, which, along with reduced cargo space due to large tank size, adversely impact the economics of operation (E4tech, 2018). To mitigate these issues, smaller storage tanks could be used, but this would increase bunkering frequency and reduce vessel range (E4tech, 2018). The cost of infrastructure changes is also a barrier to LNG adoption as conventional bunkering infrastructure and fuelling techniques cannot be used (E4tech, 2018). However, LNG may hold some potential in the short-sea and inland shipping sectors due to shorter journey distances, strict non-GHG emission regulations and the EU requirement that all inland ports along the Trans-European Transport Network (see Figure 3) have LNG bunkering facilities by 2025 (E4tech, 2018).

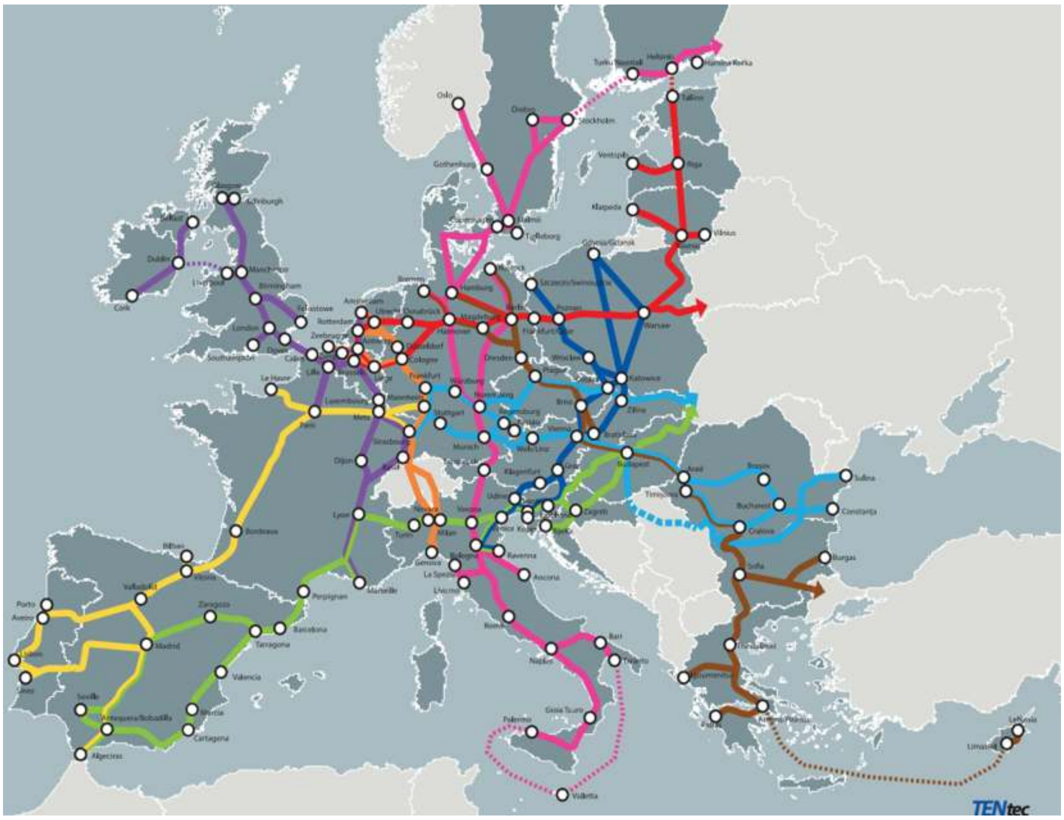

Figure 3. Trans-European Transport Network (EC, 2018c)

4 Scenarios for biofuel demand present-2030

In order to answer the research question, it is required to account for two policy scenarios[3]. One to gain insight into the level of sustainable marine biofuel adoption that can be expected to occur in the Dutch international shipping sector by 2030 under the current legislative environment. And another to gain insight into how sustainable marine biofuel can cost-optimally enable GHG reductions in the Dutch international shipping sector by 2030 that are consistent with industry targets.

Gaining insight into what level of sustainable marine biofuel adoption can be expected in the Dutch international shipping sector by 2030 under the current legislative environment requires a policy scenario consisting of the key drivers for marine biofuel adoption that are present in the current legislative environment. The principal driver for biofuel adoption under the current legislative environment is compliance with the target for renewable energy in transport under the RED I and RED II. As illustrated in section 2.2.2 and 2.2.4, renewable energy supplied to the international shipping sector counts towards the target and, in the case of the RED II, may be applied with a multiplier of 1,2. Since a multiplier for supplying renewable energy to a certain sector constitutes a financial incentive to supply renewable energy to that sector over a sector subject to a smaller multiplier or no multiplier[4], it is possible that the entry into force of the RED II will lead to a marked increase in sustainable marine biofuel adoption in the EU international shipping sector, depending on whether the financial incentive proves to be of sufficient size. A second driver of sustainable marine biofuel adoption is compliance with the stricter sulphur regulation due to come into force in January 2020 (section 2.1.3). As the stricter regulation will render the use of permissible fossil shipping fuels more expensive[5], the resulting lower cost difference between biofuels and fossil shipping fuel alternatives may prompt an increased level of adoption of sustainable marine biofuel. This is accounted for in the future fuel mix in the EU international shipping sector (see section 4.4).

Gaining insight into how sustainable marine biofuel can cost-optimally enable GHG reductions in the Dutch international shipping sector by 2030 that are consistent with industry targets requires a policy scenario involving a requirement that international shipping GHG emissions in 2030 not exceed an amount consistent with the IMO's target of a 50% reduction in GHG emissions by 2050. This places a constraint on fossil fuel consumption and the sector will have to rely on renewable energy to meet the remainder of its energy demand if it is to remain on a path to achieve its target. The level of future energy use in the EU international shipping sector is a critical factor on the level of renewable energy required in the EU international shipping sector in order to comply with the IMO's GHG reduction target. Since the GHG reduction target set by the IMO for the international shipping sector comprises a limit on the absolute amount of allowed CO2 emissions by 2050, a higher level of energy use in the international shipping sector requires a higher share of renewable energy in order to achieve the same level of GHG emissions. It is therefore necessary to account for possible differences in the level of future EU international shipping energy demand. In addition, it

[3] In this study, use was made of the RESolve Biomass (See section 5.2). The model covers the EU and requires the user to specify a level of biofuel demand for which it calculates the cost-optimal way to meet that demand.

[4] The presence of a multiplier for supplying renewable energy to a certain sector reduces the cost of compliance with the renewable energy in transport target relative to the situation absent a multiplier, by reducing the amount of renewable energy required to comply with the target by the factor of the multiplier.

[5] Compliance with the tightened sulphur limit from 3,5% at present to 0,5% from January 2020 will either require further desulphurisation of current 3,5% sulphur fuels at the refinery, installation of exhaust gas treatment equipment or a switch to another, more expensive, low sulphur fuel. See section 4.3.

is of interest to gain insight into how sustainable marine biofuel adoption is affected by different levels of shipping sector energy use.

As such, six scenarios for the demand for biofuel from present-2030 were developed based on three different scenarios for the future energy demand in the EU international shipping sector in conjunction with two policy alternatives, the renewable energy in transport obligations under the Renewable Energy Directive II and the IMO target of a 50% reduction in international shipping GHG emissions by 2050, relative to 2008 levels. These scenarios are illustrated in Table 3 below.

Table 3. Scenarios for biofuel demand resultant from RED II obligations and in order to meet the IMO GHG reduction target, under three shipping energy demand conditions

	Low EU shipping energy demand	Baseline EU shipping energy demand	High EU shipping energy demand
RED II obligations	Scenario #1	Scenario #2	Scenario #3
IMO GHG reduction target	Scenario #4	Scenario #5	Scenario #6

4.1 EU international shipping energy demand present-2030

Forecasts of EU transport energy demand typically do not include energy use for international marine bunkers (EC, 2016b) and it was not possible to discern EU international shipping energy demand information from forecasts of global marine transport and energy demand (WEC, 2011; Lloyd's, 2014; IEA,2016). It was therefore not possible to find forecasts for EU international shipping energy demand by 2030. However, the 2014 IMO Greenhouse Gas study contains a number of scenarios for future global international shipping combustion GHG emissions based on in-depth forecasts of global international shipping energy demand developed in the study (IMO, 2014). These were combined with the projected relationship between global and EU international shipping emissions from the forecast for global and EU international shipping emissions from (Schuitmaker, 2016) to develop a baseline, low and high EU international shipping energy demand scenario from present-2030.

The following considerations were taken into account in the development of the energy demand scenarios. First, the scope of this study is limited to the current legislative environment and the scenarios for future energy demand are therefore intended to reflect the range in possible future EU international shipping energy demand under measures currently adopted or planned to be adopted. Possible future measures that may affect the development of EU international shipping energy demand that are not yet adopted or planned to be adopted are not intended to be covered by the scenarios for EU international shipping energy demand. Second, uncertainty with regard to future economic growth, technology development and policy outcome creates uncertainty in future EU international shipping energy demand. It is aimed to allow for a wide range in future shipping energy demand to account for these uncertainties and in order to gain insight into the effect of shipping energy demand on sustainable marine biofuel adoption.

Accordingly, the following procedure was used to select the IMO scenario to serve as the basis for each of the three EU international shipping energy demand scenarios developed in this study. First, scenarios that involved legislation beyond legislation currently adopted or planned to be adopted were considered outside the scope of this study and were therefore not considered. Of the remaining scenarios, those corresponding to the lowest and highest global shipping energy demand were selected as the basis for the low and high EU international shipping energy demand scenario, respectively. Finally, the IMO scenario to serve as the basis for the baseline EU international shipping energy demand scenario was selected according to the IPCC definition of "baseline scenario"[6].

The IMO study contains 16 scenarios for global international shipping emissions from 2012-2050 based on two policy scenarios for the introduction of new ECAs (additional ECAs beyond those currently implemented and no additional ECAs), two efficiency trajectories (a 'low' 40% and a 'high' 60% improvement in efficiency over the 2012 fleet average by 2050), and 4 scenarios for radiative forcing, a measure of the radiative imbalance of the Earth's climate system expressed as the difference between the amount incoming solar radiation absorbed by the Earth (in Watts) and the amount of radiation emitted back into space (in Watts), per unit of the Earth's surface (in m2). The unit is Watt per square meter (W/m2). A positive radiative forcing where the amount of radiation absorbed is greater than the amount of radiation emitted will cause temperatures to rise.

The 8 scenarios for the introduction of new ECAs were not considered as they require the adoption of new legislation and there were no reports of discussions on the introduction of new ECA's at the time of writing insofar as could be determined. Of the remaining 8 scenarios, the scenarios with the lowest and highest emissions in 2050 were selected to serve as the basis for the low and high EU international shipping energy demand scenario, respectively. In line with the IPCC definition of a baseline scenario (IPCC, 2014), the IMO scenario that is based on the assumption that no additional policies or measures are implemented beyond those already adopted or planned to be adopted was selected to serve as the basis for the baseline EU international shipping energy demand scenario developed in this study. According to the IPCC the absence of additional efforts to constrains emissions leads to between 6,0 W/m2 and 8,5 W/m2 of radiative forcing by 2100 (IPCC, 2014). However, several policies for the reduction of GHG emissions have been adopted since the report's publication. Therefore, the lower end of this range more appropriately reflects the current legislative environment. In addition, according to the IMO, the 'low' (40%) efficiency scenarios assume that no policies to address air emissions or the energy efficiency of ships are adopted beyond those currently in place (IMO, 2014) and the introduction of new ECAs requires legislation that is not currently planned to be adopted. Therefore, the IMO scenario that corresponds most closely to the IPCC definition of a baseline scenario is the scenario that involves the introduction of no new ECAs, a 'low' improvement in efficiency by 2050 and a radiative forcing of 6,0 W/m2. The global levels of emissions in the IMO scenarios selected to serve as the basis for each of the three EU international shipping energy demand scenarios are shown in Table 4 below.

Table 4. Projected global international shipping CO2 emissions underlying the scenarios for EU international shipping energy demand developed in this report (mln tonnes CO2) (IMO, 2014)

Scenario	2020	2025	2030	2035	2040	2045	2050
Low energy demand	870	940	970	980	960	920	850
Baseline energy demand	890	990	1100	1300	1600	1800	2100
High energy demand	910	1100	1200	1500	1900	2400	2800

Platform Duurzame Biobrandstoffen

[6] According to the IPCC: "the term *baseline scenarios* refers to scenarios that are based on the assumption that no *mitigation* policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted." (Emphasis in original) (IPCC, 2014)

The levels of global international shipping emissions from the IMO scenarios were used to derive levels of international shipping emissions for the EU based on their historic relationship and the forecast from (Schuitmaker, 2016). The historic relationship between EU and global international shipping emissions shows a decoupling of EU and global emissions that is in line with the decoupling of EU and global GDP (PWC, 2017). This decoupling is expected to continue (PWC, 2017) and as a result EU international shipping energy use is expected to comprise a progressively smaller share of global international shipping energy use heading towards 2030 (Schuitmaker, 2016). Projected levels of EU emissions were therefore calculated as a decreasing share of global emissions based on the ratio of EU-to-global emissions from (Schuitmaker, 2016). These are shown in Table 5 below.

Table 5. Projected EU international shipping emissions (mln tonnes CO2) based on (IMO, 2014) and the projected ratio of EU to global international shipping emissions from (Schuitmaker, 2016)

Scenario	2020	2025	2030	2035	2040	2045	2050
Low energy demand	147,1	151,0	148,9	144,6	136,6	126,9	114,3
Baseline energy demand	150,5	159,0	168,9	191,9	227,7	248,2	282,4
High energy demand	153,9	176,7	184,2	221,4	270,4	330,9	376,5
Projected EU share of global intl. shipping emissions (%)	*16,9%*	*16,1%*	*15,4%*	*14,8%*	*14,2%*	*13,8%*	*13,4%*

Values for EU international shipping energy use were calculated based on levels of EU international shipping emissions. For the purpose of converting CO2 emissions to energy use, the fuel mix and emissions factors used by the IMO study to calculate global levels of emissions were assumed to correspond to the EU fuel mix and emissions factors over the same period. The results are shown in Figure 4 and Table 6. Energy demand per EU country was calculated as projected EU shipping energy demand times the country's share of EU shipping energy use in 2016 according to Eurostat.

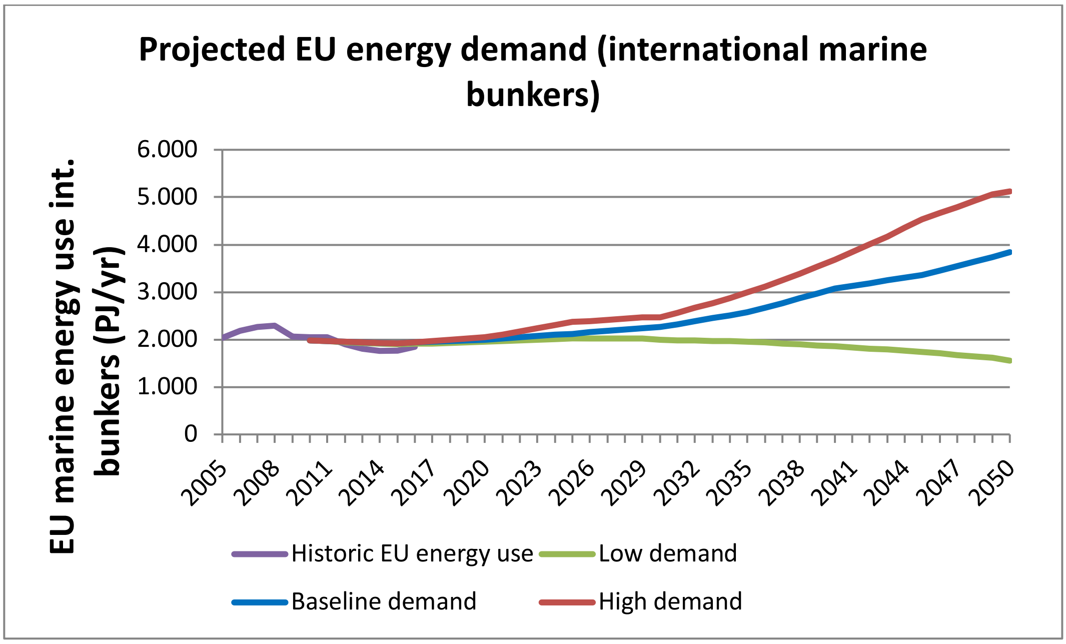

Figure 4. Scenarios for projected EU international shipping energy use 2005-2050 Source: own calculations

Table 6. Projected EU international shipping energy demand (PJ)

Scenario	2020	2025	2030	2035	2040	2045	2050
Low energy demand	1 956	2 024	1 996	1 954	1 860	1 740	1 555
Baseline energy demand	2 001	2 123	2 263	2 581	3 075	3 364	3 842
High energy demand	2 046	2 369	2 469	2 990	3 680	4 540	5 122

As can be seen in Figure 4 and can also be observed from the underlying data in Table 4 and Table 5, the scenarios show a large divergence in EU international shipping energy use by 2050. However, much of this divergence occurs after 2030. The projected energy use up to 2030 is shown in Figure 5 below.

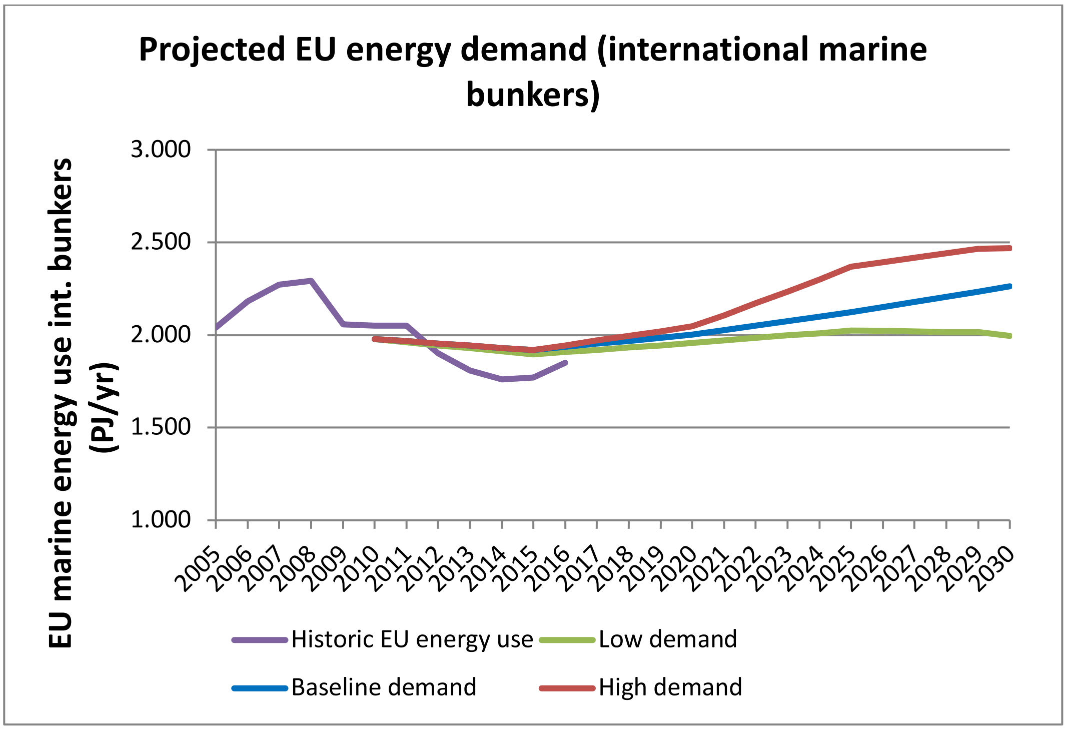

Figure 5. Scenarios for projected EU international shipping energy use 2005-2030. Source: own calculations

4.2 Biofuel requirements for meeting the IMO GHG reduction target

In order for the EU international shipping sector to achieve GHG emission reductions by 2030 consistent with the IMO's target of a 50% reduction in GHG emissions by 2050 relative to 2008, it is required that fossil energy use in 2030 not exceed a certain amount. However, as global average temperature increase is proportional to cumulative emissions (Matthews et al., 2018), the path to the 2050 target must be taken into account. In this study the allowable level of sector GHG emissions in 2030 was determined by assuming a linear reduction in emissions from the present level to the level specified by the IMO target (101mln tCO2eq). The resulting limit is 137mln tCO2eq. Based on the allowable GHG emissions, required shares of fossil fuel and biofuels were calculated, where biofuels were assumed to achieve on average a 75% reduction in CO2 emissions relative to fossil fuel in 2018. In order to account for the fact that the CO2 performance of biofuels will increase over time as the share of renewable energy in the energy system increases, their average CO2 reduction was assumed to increase linearly from 75% at present to 85% in 2050. The resulting biofuel shares in 2030 are shown in Table 7.

Table 7. Share of biofuel in EU international shipping in 2030 required to achieve the IMO GHG reduction target in 2050

	Low energy demand	Baseline energy demand	High energy demand
Biofuel share (%)	27,1%	38,9%	46,3%

4.3 Fuel mix

As a result of stricter sulphur regulation to come into in 2020, the future fuel mix for international shipping is expected to change drastically (CE delft, 2016; Hsieh & Felby, 2017; DNV GL, 2018). Whereas at present the majority of fuel (~76% by mass) used in international shipping is supplied by Heavy Fuel Oil (HFO) with an average sulphur content of 2,5% (DNV GL, 2018), the new sulphur limit of 0,5% for fuel used outside of

ECAs will render regular Heavy Fuel Oil unusable without some form of post-combustion processing (Hsieh & Felby, 2017). In practice, this means outfitting a vessel with an Exhaust Gas Cleaning System (EGCS) known as a scrubber (Hsieh & Felby, 2017). These have the disadvantages of incurring costs to install, reducing fuel efficiency and taking up valuable cargo space (Hsieh & Felby, 2017). Vessels not equipped with a scrubber will have to change to another, low-sulphur fuel in order to comply with the new 0,5% sulphur limit. The further desulphurisation of Low Sulphur Fuel Oil (~1% sulphur) is not considered economical (Marquard & Bahls, 2018) and it is expected that compliant fuels will instead consist of a blend of Heavy Fuel Oil and Marine Gas Oil (DNV GL, 2018). CE Delft (2016) estimates that once the new sulphur regulation takes effect in 2020, only 11% of global international fuel consumption will consist of regular high-sulphur HFO used by ships outfitted with a scrubber. Most of the fuel (~75%) will come from fuels with a sulphur content of 0,1%-0,5% (CE Delft, 2016).

In this study, the fuel mix for EU international shipping in 2020 is assumed to be equal to the estimated fuel mix for the Europe region in 2020, as given in CE Delft (2016). The MGO/HFO blend was calculated by assuming an MGO sulphur content of 0,1% and an HFO sulphur content of 2,5%. In accordance with the IMO study, the share of LNG was assumed to increase from its ~2% level (by mass) in 2020 to 4% by 2030 and to come at the expense of HFO usage (IMO, 2014). The fuel mix is shown in Table 8 on the next page.

The estimate for the decrease in HFO consumption may be conservative, however, as the 2016 CE Delft study is based on an estimate of four thousand vessels with scrubber installations to be in use by 2020. As of March 2018, there are only 420 vessels with scrubber installations known to be in operation or on order (DNV GL, 2018). This means that unless the use of scrubber installations increases substantially in the meantime, the consumption of HFO in 2020 may turn out to be lower than assumed here.

Table 8. Fuel mix in Europe region in 2020 based on CE Delft (2016) and fuel mix with increased LNG share in 2030

	Fuel mix in 2020				**Fuel mix in 2030**	
	Mln t fuel	Mass-%		Energy-%	Mass-%	Energy-%
MGO	9	12,4%	74,8%	76,2%	74,8%	75,7%
MGO/HFO blend [7]	54	74,8%				
HFO	8	11,1%	23,5%	21,9%	21,2%	19,6%
LNG	1,2	1,7%	1,7%	2%	4%	4,7%
Total	**72,2**	**100%**	**100%**	**100%**	**100%**	**100%**

The estimate for the decrease in HFO consumption may be conservative, however, as the 2016 CE Delft study is based on an estimate of four thousand vessels with scrubber installations to be in use by 2020. As of March 2018, there are only 420 vessels with scrubber installations known to be in operation or on order (DNV GL, 2018). This means that unless the use of scrubber installations increases substantially in the meantime, the consumption of HFO in 2020 may turn out to be lower than assumed here.

[7] The MGO/HFO blend was assumed to have a sulphur content of 0,5%, consisting of (by mass) 1/6 HFO with an average sulphur content of 2,5% and 5/6 MGO with an average sulphur content of 0,1%. These amounts of HFO and MGO are subsequently included in the respective shares of HFO and MGO in the table.

5 Biofuel deployment scenarios

5.1 Introduction

The six scenarios developed in section 4 were inserted in the RESolve-biomass model (see section 5.2)[8].

The RESolve-biomass model allows for the determination of the cost-optimal deployment[9] of biofuel production pathways to meet a user-specified demand projection for renewable energy based on technical and economic parameters of biofuel production technologies, biomass potentials, multipliers and various model constraints. The scope of the model is the EU. Model runs were conducted for each of the six scenarios and the resulting level of sustainable marine adoption and the associated portfolio of biofuel production pathways was evaluated. The country specific results for the Netherlands were used to serve as the basis for conclusions with regard to the Dutch international shipping sector.

In order to assess what level of sustainable marine adoption may be expected in the Dutch international shipping sector under the current legislative environment, model runs were conducted where demand for renewable energy in transport was set according to the obligations for renewable energy in transport under the Renewable Energy Directive I and II (see section 2.2.1 & 2.2.4) and energy demand in the EU international shipping sector was alternately set according to each of the three energy demand scenarios developed in section 4.1.

In order to assess how an amount of sustainable marine biofuel may be produced that would allow for GHG emission reductions in the Dutch international shipping sector consistent with industry targets, model runs were conducted where the demand for biofuel in the EU international shipping sector was set alternately to the shares calculated in section 4.3 and EU international shipping energy demand was set according to the associated energy demand scenario from section 4.1.

5.2 RESolve-biomass model

The RESolve-Biomass model is a cost-optimisation model for bioenergy developed as part of the Biomass Futures project by the Energy Research Centre of the Netherlands (ECN) (Uslu et al., 2012). Given a number of constraints, it determines the lowest system-cost configuration of the entire bioenergy production chain to meet a user-specified level of bioenergy demand (van Stralen et al. 2012). To this end, it uses data on, among others, fossil fuel price developments, biomass potentials, biomass demand from various sectors (electricity, heat and biofuels) and techno-economic data on biofuel production pathways (CAPEX, OPEX, conversion efficiency, product slate, auxiliary input requirements (electricity and hydrogen), introduction year, plant scale and lifetime). Key model constraints include a maximum scale-up rate for feedstock mobilisation and biofuel production capacity deployment, a cap on crop-based biofuels, biofuel specific blend walls and the pace of production capacity phase-out. The model incorporates cost-reductions through learning effects that are modelled endogenously where a higher level of deployment of a certain technology results in a greater cost-reduction for that technology. The input level of bioenergy demand may include sub-targets for certain biofuels (e.g. advanced biofuels), certain sub-sectors (e.g. the marine sector) and may be

[8] For a detailed description of the functional working of the RESolve-biomass model see van Stralen et al. (2012) and section 2.5 of Uslu et al. (2012).

[9] The model minimizes the difference between the total system costs for bioenergy generation and the costs of a reference case where the energy is instead supplied by conventional fossil fuel fuels (van Stralen et al., 2012).

met through the use of multipliers. Provided sector-specific (sub)targets are met, allocation of biofuels to particular sectors is based on the financial gap with the fossil alternatives, where biofuels are allocated to the sector where the financial gap with the fossil alternative is the smallest.

5.3 Model assumptions

Assumptions in the model are based on research performed for various projects and the research conducted in this study. Time-dependent data on the costs, supply and spatial distribution of biomass is adopted from the Biomass Policies project (Elbersen, 2012). Biomass demand for heat and electricity is established on a country level based on data from the S2Biom project (Mozaffarian et al., 2015; van Stralen et al., 2016). Energy demand from non-shipping transport sectors are based on estimates from the PRIMES model (Capros, 2013). Fossil fuel price developments are based on PRIMES estimates and the ratio between price for MGO and HFO is based Rotterdam bunker prices. The projected fossil fuel prices in 2030 are shown in Table 9 (Source: PRIMES model).

Table 9. Projected fossil fuel prices in 2030

Projected fossil fuel prices		
Fuel type	Price (€/GJ)	Sector of use
LNG	11,60	Marine
HFO	11,75	Marine
MGO	15,25	Marine
Diesel	17,82	Road
Gasoline	18,65	Road
Kerosene	21,61	Aviation

The targets for renewable energy in transport for 2030 are based on the latest (June 21) proposal for a Renewable Energy Directive II. That is to say, there is a target of 14% renewable energy by 2030 of a country's energy use in the road and rail sector, that may be lowered by the amount a country lowers its cap on crop-based biofuel from 7%. Crop-based biofuels for EU countries other than the Netherlands were capped at their 2020 level of production and their targets for renewable energy in transport set accordingly. Crop-based biofuels for the Netherlands were capped at 5% in line with current legislation and the overall target for renewable energy in transport was set at 12%. The multipliers in the model are those in effect under the RED I and II (see section 2.2.4). Energy demand for non-shipping transport sectors is shown in Table 10 below.

Table 10. EU energy demand (PJ) in transportation subsectors

Transport sub sector	2015	2020	2025	2030
Road	7 532	6 666	6 107	5 808
Rail	333	358	384	411
Aviation	2 119	2 372	2 654	2 971

The model contains technology-specific learning rates and introduction years as shown in Table 11. The techno-economic data for biofuel production via standalone pyrolysis oil upgrading and pyrolysis oil co-processing from this study were added to the model. The techno-economic data for the other conversion pathways was based on prior research.

Table 11. Technology introduction years

Conversion pathway	Year
FAME	2005
HVO	2007
ATJ	2020
BioLNG	2020
Fischer-Tropsch	2020
BioDME	2021
Pyrolysis Co-processing	2022
Pyrolysis Standalone	2023
HTL	2025

Initial model runs indicated that bioLNG for international shipping was deployed to the maximum extent possible, to the exclusion of all other biofuels. Considering that the literature indicates more or less equal costs for three production pathways (HVO, bioLNG and refinery co-processing) this was deemed unrealistic. This may have been an artefact of the way the model allocates between production pathways in cases of small price differences. When a certain production pathway is cheaper than another pathway by even a minimal amount, all production capacity is allocated to that pathway when in reality a situation more similar to an equal distribution between pathways would occur. To account for this, the bioLNG share was capped at no more than a third of marine biofuel consumption.

5.4 Results

In this section the results of the model runs for the six scenarios are presented and discussed. Biofuel adoption under RED II obligations turned out not to be substantially affected by international shipping energy demand. Results for the remaining scenarios can be found in the annexes. F&O are Fats & Oils.

5.4.1 Scenarios for biofuel deployment under RED II

The results for biofuel deployment under RED II obligations and baseline shipping energy demand on the EU level are shown in Figure 6 below. A noticeable decline in the overall level of biofuel adoption in the EU transport sector can be observed to occur following the entry into force of the RED II. This is a result of three co-occurring factors under the RED II. The presence of multipliers including the introduction of new multipliers, the increased target for double-counting biofuels (7% by 2030) and the link introduced in the RED II between a Member State's cap on crop-based biofuels and its overall target for renewable energy in transport. The latter establishes a de facto incentive for Member States to lower their cap on crop-based biofuels by allowing the overall target for renewable energy in transport to be lowered when doing so and thereby lowering the cost of compliance with the renewable energy in transport target. The effect causes a near-complete phasing out of conventional biofuels by 2030.

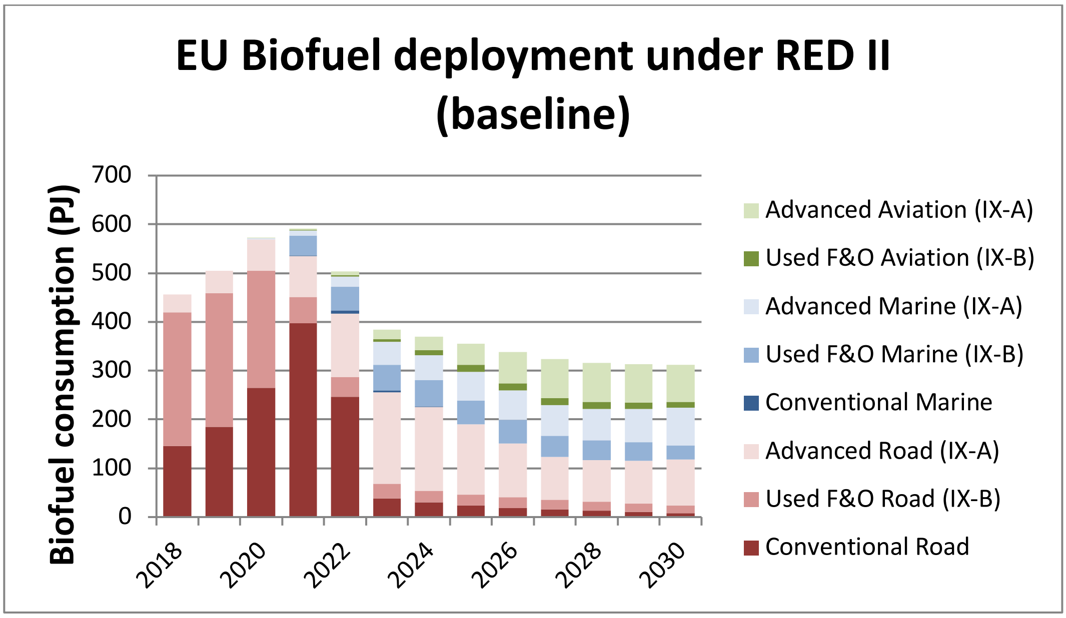

Figure 6. Biofuel deployment in the EU under baseline international shipping energy demand and RED II obligations

A substantial increase in the level of biofuel adoption in the marine and aviation sectors can be observed following the entry into force of the RED II and the associated introduction of a 1,2 multiplier for these sectors. Marine biofuel amounted to 106 PJ in 2030 or 0,9% of energy use in road and rail. However, this comes at the expense of biofuel use in the road sector and a lower overall level of biofuel adoption. This is unsurprising as compliance with the transport target is the principal driver for biofuel adoption and that target is unaffected by the supplying of biofuel to other sectors. Furthermore, the application of the 1,2 multiplier when supplying the marine and aviation sectors reduces the amount of physical energy required to meet the transport target. Overall the multipliers result in the achieving of a renewable energy share of 4,44% of energy use in the road and rail sector in the EU by 2030, of which 1,71% is supplied by renewable electricity and 2,71% by biofuels. The inclusion of multipliers increases this to an administrative share of 10,2% of energy use in the EU road and rail sector in 2030.

The year of technology introduction proved to be a factor of significant influence on the eventual composition of the technology-portfolio by 2030 (i.e. the relative contribution from different production pathways by 2030). This may be indicative of path-dependencies, where a high level of deployment of a certain technology (e.g. due to low feedstock costs) results in a reduced ability to shift reliance to another technology should circumstances change to render another technology more desirable. For example, as a result of better feedstock availability, improved CO2 performance or a product slate that better aligns with market demand.

The biofuel deployment scenario for the Netherlands under RED II obligations and baseline shipping energy demand is shown in Figure 7 below.

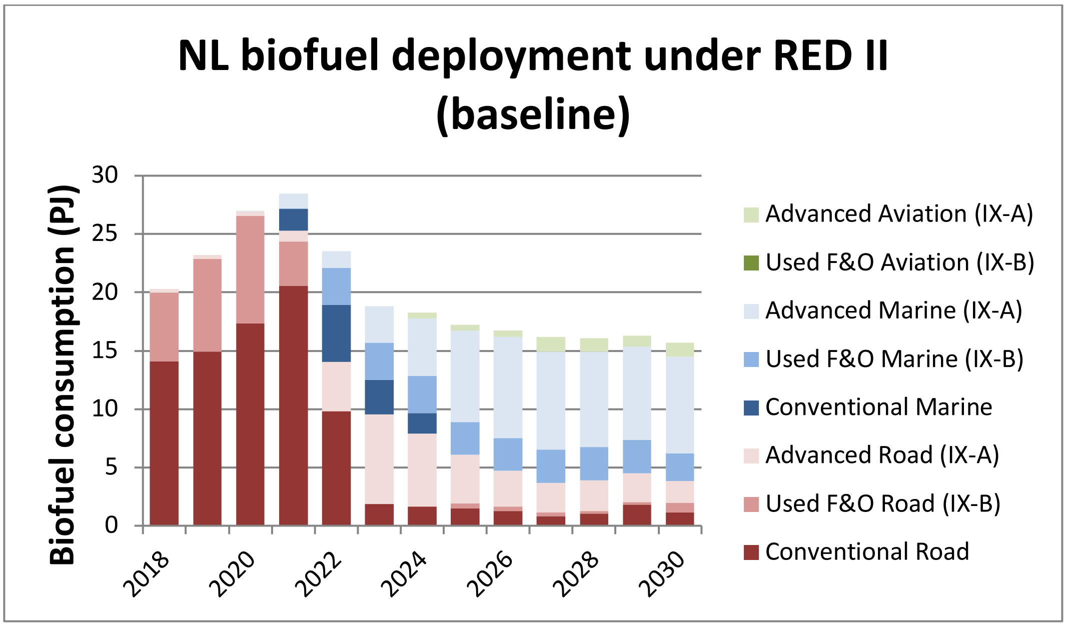

Figure 7. Biofuel deployment in the Netherlands under baseline international shipping energy demand and RED II obligations

In line with the scenario for the EU, a substantial increase in the level of marine biofuel adoption was realized in the Netherlands, amounting to 10,6 PJ in 2030 or 2,47% of energy use in the Dutch road and rail sector. The larger relative size of the Dutch international shipping sector in comparison to its road sector results in a greater relative shift to marine biofuels upon the introduction of the 1,2 multiplier for supplying the marine sector than can be observed to occur on the EU level. The overall share of renewable energy achieved by 2030 amounted to 5,05% of road and rail energy use, of which 1,40% is supplied by renewable electricity and 3,66% by biofuels. Upon the inclusion of multipliers this amounts to an administrative share of 11,9% of energy use in the Dutch road and rail sector in 2030.

As in the scenario for the EU, the coming available of a number of new technologies for the production of advanced biofuels over the period 2020-2023 that are subject to a 2x multiplier is associated with a sharp reduction in conventional biofuel in the road sector. However, it should be noted that this is contingent on the assumptions made in the model, particularly with regard to the costs of advanced biofuels relative to conventional biofuels and pricing strategies adopted by market players. Notably, the model does not take into account that players facing barriers to market entry (such as lack of access to distribution channels in the shipping sector) may opt to adopt a pricing strategy that serves to maintain conventional road biofuel's market share for longer.

The price ratio between MGO and road sector diesel proves to be a factor of critical influence on whether it is more financially attractive to supply biofuel to the road sector or the shipping sector. The effects of a multiplier for supplying biofuel to shipping on the one hand, and the larger cost difference between biofuel and fossil shipping fuel on the other, partially counteract each other. Based on the data used, the 1,2 multiplier proved to constitute a financial incentive of sufficient size to overcome the larger cost difference between biofuel and the fossil alternative in the shipping sector. However, the ratio in prices based on the fossil fuel price projections in the model was close to the tipping point where supplying biofuel to the road sector instead would be more financially attractive.

The precise relationship between prices where it is equally attractive to supply to either sector can be algebraically determined from the difference in the costs of compliance of two reference scenarios where a certain biofuel is either supplied to the shipping sector or the road sector and is given in the annexes.

5.4.2 Scenarios for biofuel deployment under IMO target

Under the constraints employed in the model and under the scenario for baseline and high international shipping energy demand, it was not possible to achieve the share of biofuel required (see Table 7) in order to limit EU international shipping sector emissions to 137mln tCO2eq on a life-cycle basis by 2030 (see section 4.2) consistent with the IMO's target of 50% CO2 reduction by 2050, relative to 2008. On the EU level, the required share was able to be achieved under the scenario for low international shipping energy demand, the results for which are shown in Figure 8 below.

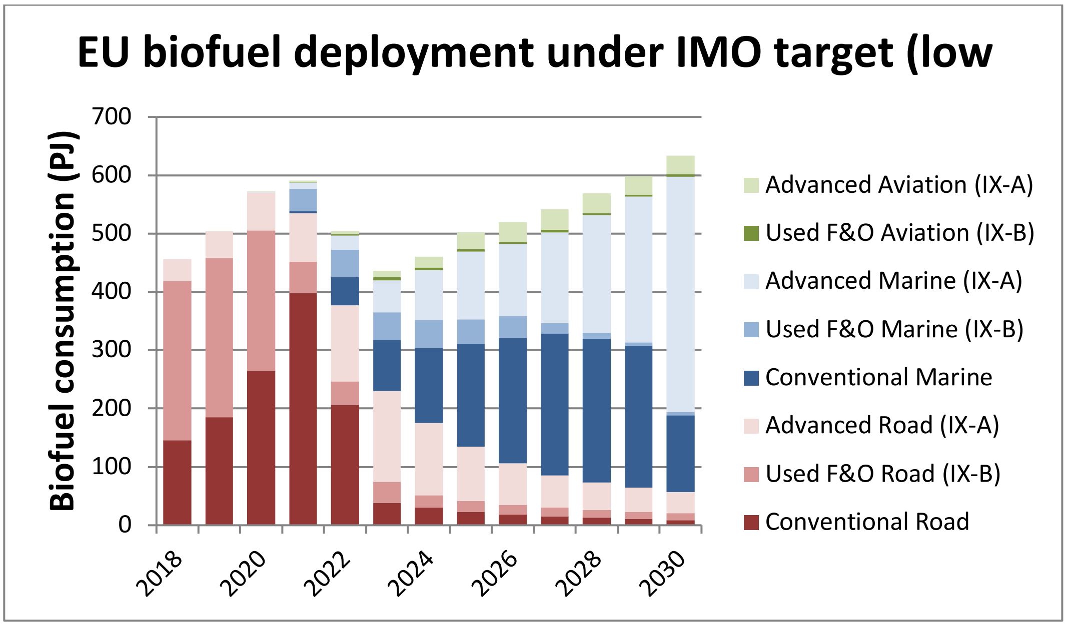

Figure 8. Biofuel deployment in the EU under low international shipping energy demand and the IMO target

Under the low International shipping energy demand scenario marine biofuel adoption amounted to 540 PJ in 2030 or 27,1% of international shipping energy demand, in accordance with the share required to remain on a path consistent with achieving the IMO's target by 2050. Total biofuel produced amounted to 633 PJ or 5,51% of EU energy use in road and rail. Total renewable energy achieved amounted to 7,22% of EU energy use in road and rail, of which 1,71% came from renewable electricity. Upon the inclusion of multipliers this amounted to an administrative renewable energy share of 15,4%.

Under the baseline and high international shipping energy demand scenarios the level of marine biofuel adoption amounted to 656 PJ and 668 PJ, respectively, or 27% of EU international shipping energy use under both scenarios. Markedly short of the ambitious shares of 38,9% and 45,3% required to remain on a path consistent with achieving the IMO's target by 2050. The results for the three International shipping energy demand scenarios on the EU level are summarized in Table 12 below.

Platform Duurzame Biobrandstoffen

Table 12. Levels of EU renewable energy adoption (PJ) under IMO target and three scenarios for EU international shipping energy demand. Value in brackets (%) indicates renewable energy adoption as a share of energy use in the EU road and rail sector.

	Low energy demand	B/L energy demand	High energy demand
Marine biofuel adoption	540	656	668
% of intl. shipping energy use	27,1%	27,0%	27,0%
Total ren. energy adoption (%)	830 (7,22%)	966 (8,40%)	956 (8,31%)
... of which biofuel (%)	633 (5,51%)	769 (6,69%)	759 (6,60%)
... of which ren. electricity (%)	197 (1,71%)	197 (1,71%)	197 (1,71%)
Administrative energy share	15,4%	18,1%	17,8%

As the model was designed to evaluate feedstock mobilisation and biofuel production capacity deployment under plausible EU policy conditions, several dynamics asserted themselves in determining what would be required to achieve a level of marine biofuel adoption consistent with the IMO target at all costs. As the amount of biofuel required in the international shipping sector to remain consistent with the IMO target far exceeded the requirements for renewable energy in transport under the RED II, the product slate associated with biofuel production pathways proved to be an important factor. As biofuel production pathways yield an assortment of products, the deployment of sufficient capacity to produce the required amounts of marine biofuel necessarily requires the production of sizable amounts of non-marine biofuels. This results in large cost inefficiencies as the non-marine biofuels are not required to comply with EU policy obligations.

Another limiting factor was the rate of additional capacity deployment for advanced biofuels required to produce amounts of marine biofuel consistent with the IMO's target. As the potential of annex IX-B feedstocks (used fats and oils) is limited and the production of crop-based biofuels is restricted under EU legislation, advanced biofuels are required to supply the lion's share of requirements under the IMO target. As only a limited amount of advanced biofuel production capacity is deployed during the period of the RED I, this required a rate of additional advanced biofuel production capacity deployment that exceeded model assumptions under the baseline and high energy demand scenarios.

On the Dutch level, the share of marine biofuel to remain consistent with the IMO's target was not achieved under the low energy demand scenario. This is due to Dutch international shipping sector's large size in relation to its road and rail sector in conjunction with the fact that the target for marine biofuel adoption applies solely to the EU as a whole rather than to each Member State individually. As such, several Member States attained levels of marine biofuel adoption in excess of their requirement under the IMO target. Notably, in order of greatest excess, Malta, Italy, France, Denmark and the United Kingdom.

The biofuel deployment scenario for the Netherlands under the IMO target and low international shipping energy demand is shown in Figure 9 on the following page.

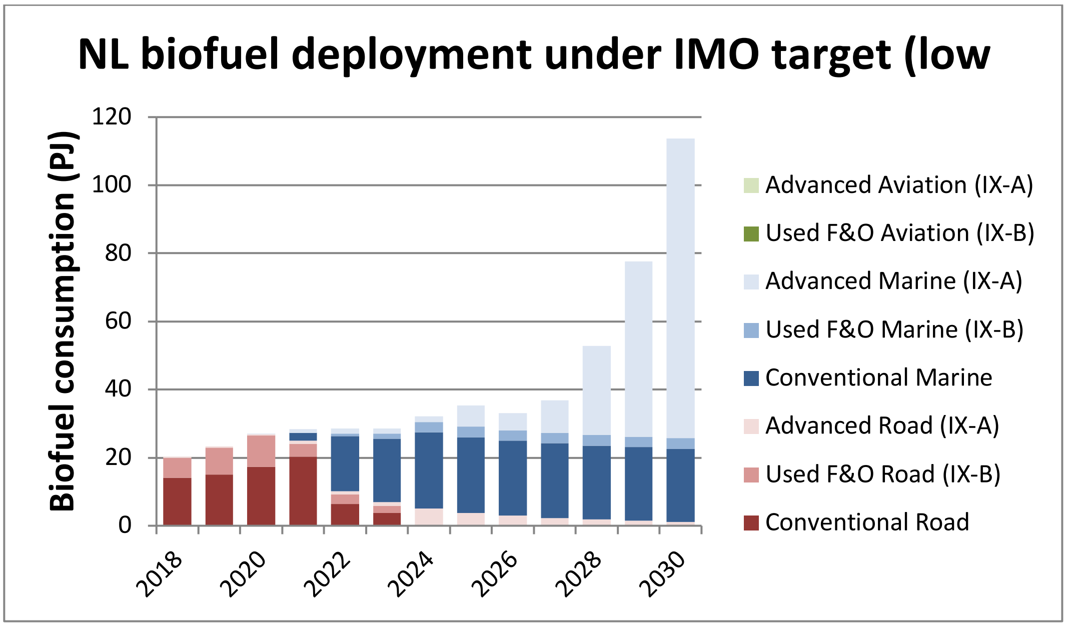

Figure 9. Biofuel deployment in the Netherlands under low international shipping energy demand and the IMO target

Marine biofuel adoption amounted to 113 PJ or 20,4% of projected Dutch international shipping sector energy demand. For perspective, energy use in the Dutch road and rail sector is projected to amount to 429 PJ by 2030. Total renewable energy supplied was 120 PJ or 27,9% of energy use in the Dutch road and rail sector, of which 114 PJ was supplied by biofuels and 6,1 PJ by renewable electricity. Energy demand in the Dutch international shipping sector exceeds that of all domestic transport sectors combined. As a result, under EU counting rules this would amount to an immense administrative share of renewable energy of 61,4% of energy use in the Dutch road and rail sector. The results for all three International shipping energy demand scenarios on the Dutch level are summarized in Table 13 below.

Table 13. Levels of NL renewable energy adoption (PJ) under IMO target and three scenarios for EU international shipping energy demand. Values in brackets (%) indicate renewable energy adoption as a share of energy use in the NL road and rail sector

	Low energy demand	B/L energy demand	High energy demand
Marine biofuel adoption	113	172	180
% of intl. shipping energy use	20,4%	28,1%	26,3%
Total ren. energy adoption (%)	120 (27,9%)	180 (41,9%)	187 (43,7%)
... of which biofuel (%)	114 (26,5%)	174 (40,4%)	181 (42,3%)
... of which ren. electricity (%)	6,1 (1,42%)	6,1 (1,42%)	6,1 (1,42%)
Administrative energy share	61,4%	93,7%	98,9%

Platform Duurzame Biobrandstoffen

6 Conclusions and recommendations

This research has attempted to gain insight into what level of sustainable marine biofuel adoption may be expected in the Dutch international shipping by 2030 under current legislation and how sustainable marine biofuel could cost-optimally enable GHG reductions in the Dutch international shipping sector consistent with the IMO's target of a 50% reduction in emissions by 2050, relative to 2008. To this end, a literature study was conducted on the current legislative environment and possible marine biofuel production pathways and a techno-economic assessment was performed for the production of marine biofuel via standalone pyrolysis oil upgrading and the co-processing of pyrolysis oil in petroleum refineries. Subsequently, six possible biofuel deployment scenarios were formulated and evaluated in terms of the factors affecting marine biofuel adoption.

The results have shown that based on financial considerations alone and within the context of the RESolve-model and its assumptions, a substantial increase in the level of sustainable marine biofuel adoption on the order of 10 PJ may be expected in the Dutch international shipping sector by 2030. This is principally as a result of the renewable energy obligations under the Renewable Energy Directive II and the introduction of a multiplier for supplying biofuel to the shipping sector. The introduction of stricter sulphur regulations in 2020 also plays a role by allowing marine biofuel to compete with the more expensive MGO rather than HFO. As the overall target for renewable energy in transport in the EU is the principal driver for biofuel adoption, biofuel adoption in the international shipping sector would come at the expense of biofuel adoption in the road sector. Important to note is that EU policy is likely to result in a reduction in transport renewable energy adoption by 2030 relative to 2020, due to the presence of multipliers and the link introduced in the RED II between a country's cap on crop-based biofuels and its renewable energy in transport target.

However, several other important considerations have to be taken into account. These include engine compatibility, the perceived risk of policy change among industry stakeholders, the role of engine manufacturers in certifying engines for biofuel use, infrastructure availability in a sufficient amount of ports in the case of specialised biofuels, and the need for a financial transfer mechanism between the road and shipping sectors.

As the international shipping sector is not subject to a renewable energy obligation, there is no incentive for ship operators to pay the additional costs for biofuel relative to the fossil alternative. Fuel suppliers will therefore likely have to offer biofuel (blends) at the price of the fossil alternative and recoup their losses in the road sector. This requires a financial transfer mechanism that allows road users to cover the cost difference between marine biofuel and its fossil alternative. It is possible that the HBE system fulfils this role.

During the course of performing the techno-economic assessments, the possibilities for producing cheaper, low-quality biofuels specifically for use in shipping were looked into. This turned out to be possible to an extent, but highly dependent on specific processes. In the case of the HTL and pyrolysis routes, upgrading was mostly focussed on reducing oxygen content and acidity, and increasing energy density as a result. Truly less upgraded biofuels via these routes would require engine modifications, which would require capital investment to perform. These may not be readily available in the shipping sector with its tight margins and would also reduce flexibility as the requisite fuelling infrastructure may not be available in most ports.

There is considerable variation in the CO2 performance of biofuels produced via various routes. The high hydrogen requirements for pyrolysis oil upgrading stood out as a poignant example. This is not covered by current legislation as it is directed at attaining a renewable energy share. It is important that the purpose of efforts to realise marked renewable energy shares not be lost from view. It is therefore recommended that future legislation be based on the realisation of CO2 reductions, where it is important that these be considered on a well-to-wheel basis.

The level of ambition of the GHG reduction target set by the IMO has become apparent from this research. The results have illustrated that in order for the international shipping sector to decarbonise sufficiently to achieve the IMO's target, incredible amounts of renewable energy are required that will require substantial efforts to achieve. As there is no natural demand for biofuel in the international shipping sector due to its greater cost relative to fossil alternatives, binding legislative requirements are essential if the IMO's target is to be achieved. As countries are unlikely to adopt these on a regional basis for fear of incurring a competitive disadvantage, it is recommended that an international approach be taken to create market demand for biofuel in international shipping on the global level, while ensuring a level playing-field. As there is significant variation in the CO2 performance of biofuels, it is important that a carbon-based rather than a renewable energy-based approach be taken. This could be done in the form of an emission trading system for the shipping sector, a requirement on shipping fuel suppliers to reduce the carbon intensity of shipping fuels or a carbon-tax on shipping fuels.

Annexes

Annex I – Biofuel deployment scenarios

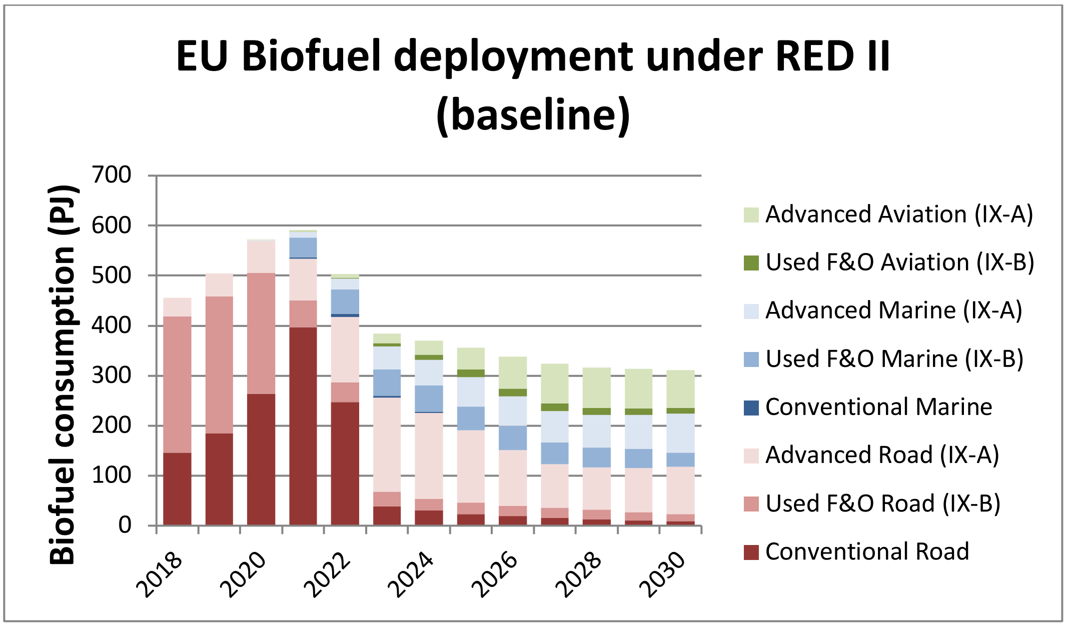

Figure Annex 1. Biofuel deployment in the EU under baseline international shipping energy demand and RED II obligations

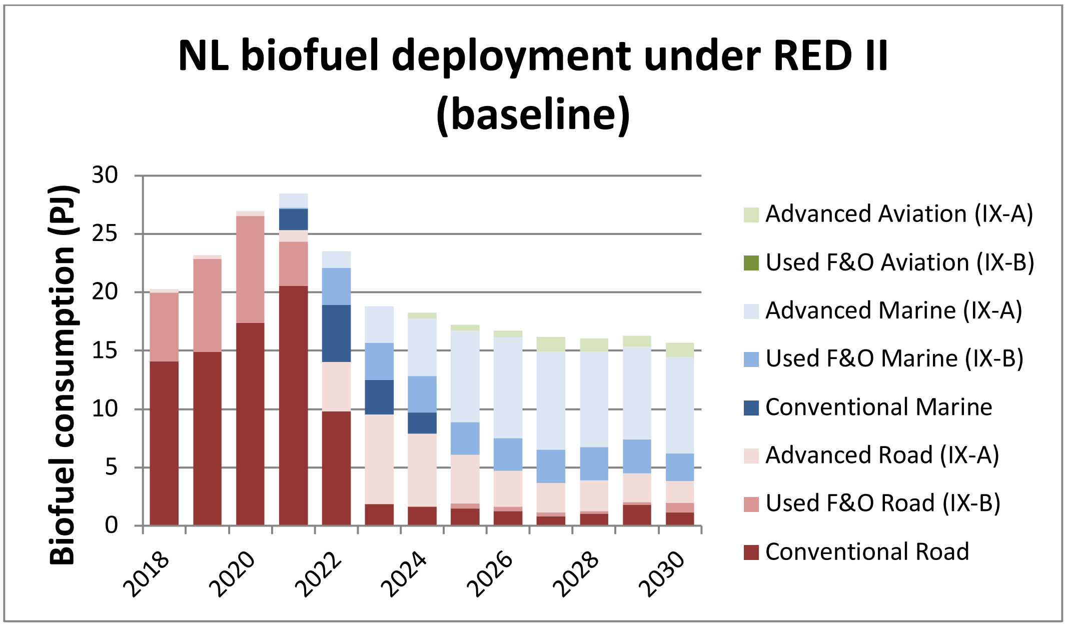

Figure Annex 2. Biofuel deployment in the Netherlands under baseline intl. shipping energy demand and RED II obligations

Platform Duurzame Biobrandstoffen

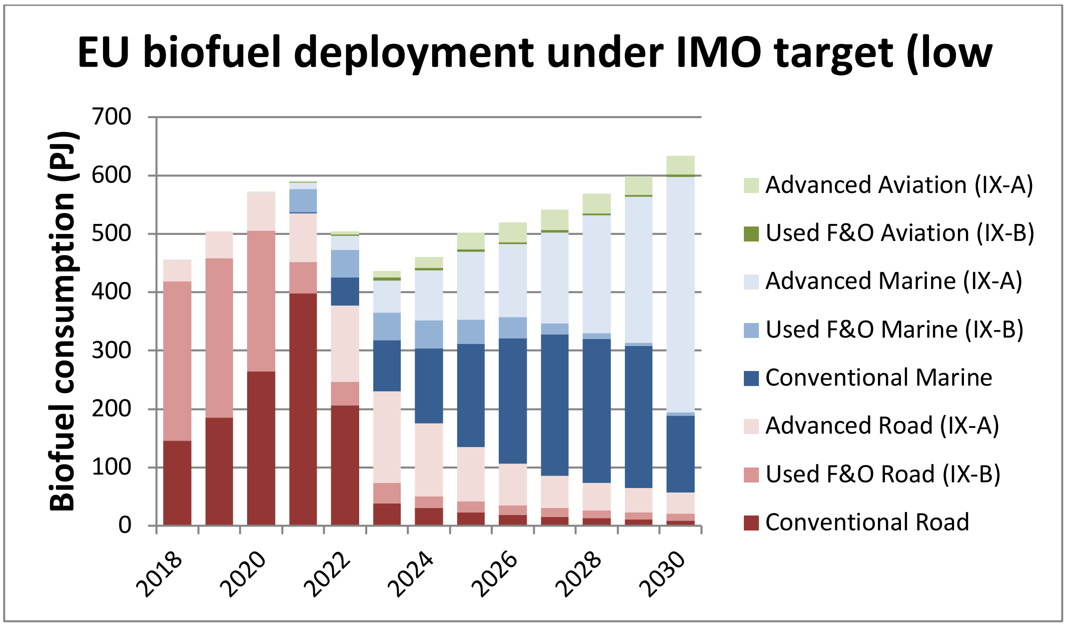

Figure Annex 3. Biofuel deployment in the EU under low international shipping energy demand and the IMO target

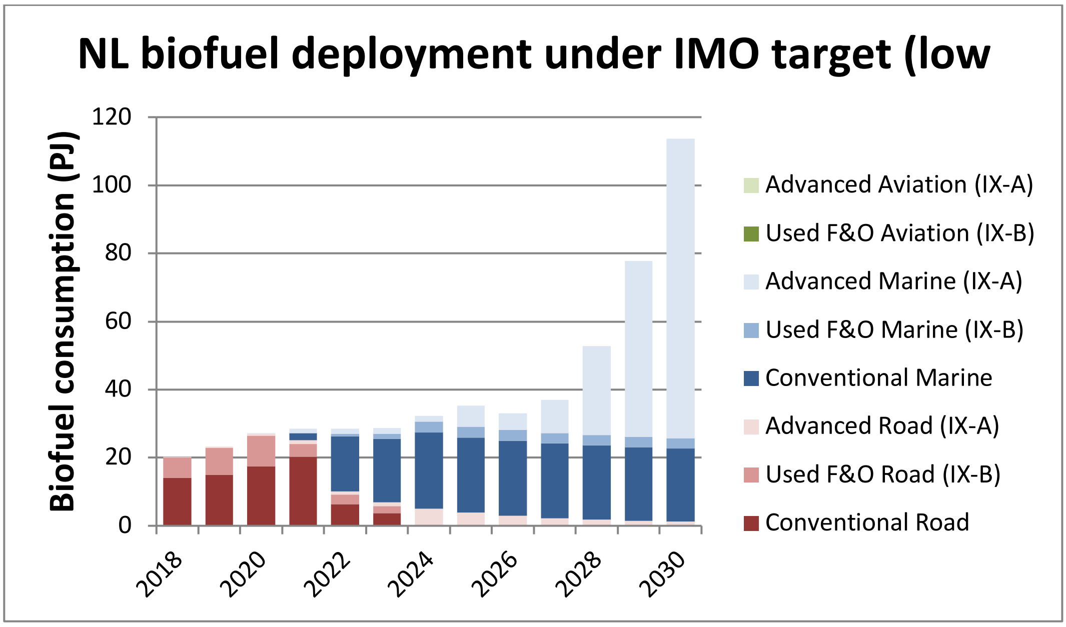

Figure Annex 4. Biofuel deployment in the Netherlands under low international shipping energy demand and the IMO target

Platform Duurzame Biobrandstoffen

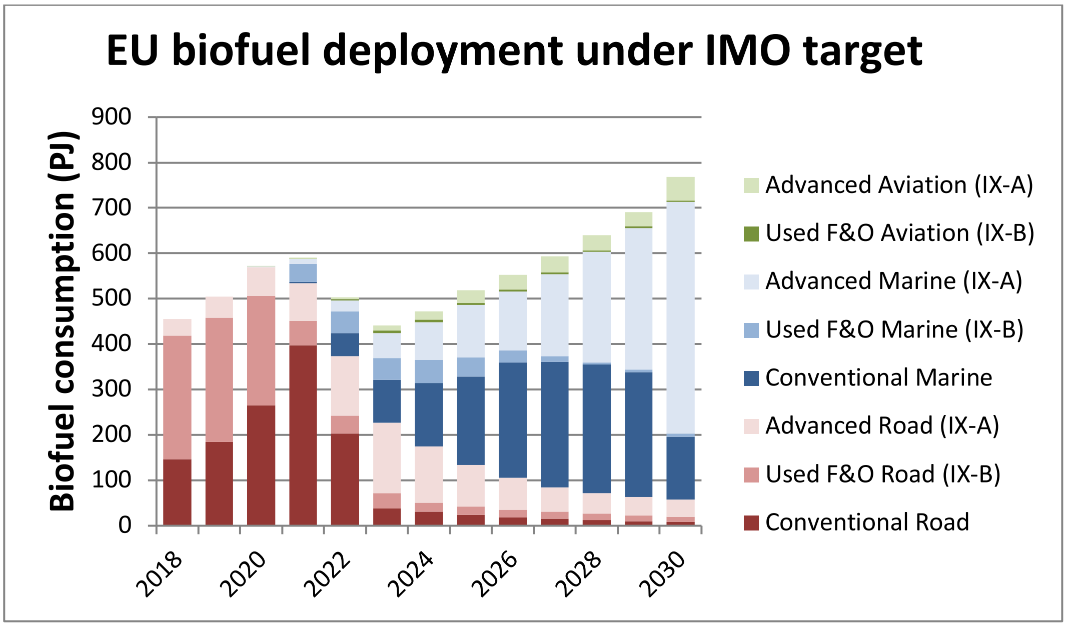

Figure Annex 5. Biofuel deployment in the EU under baseline international shipping energy demand and the IMO target

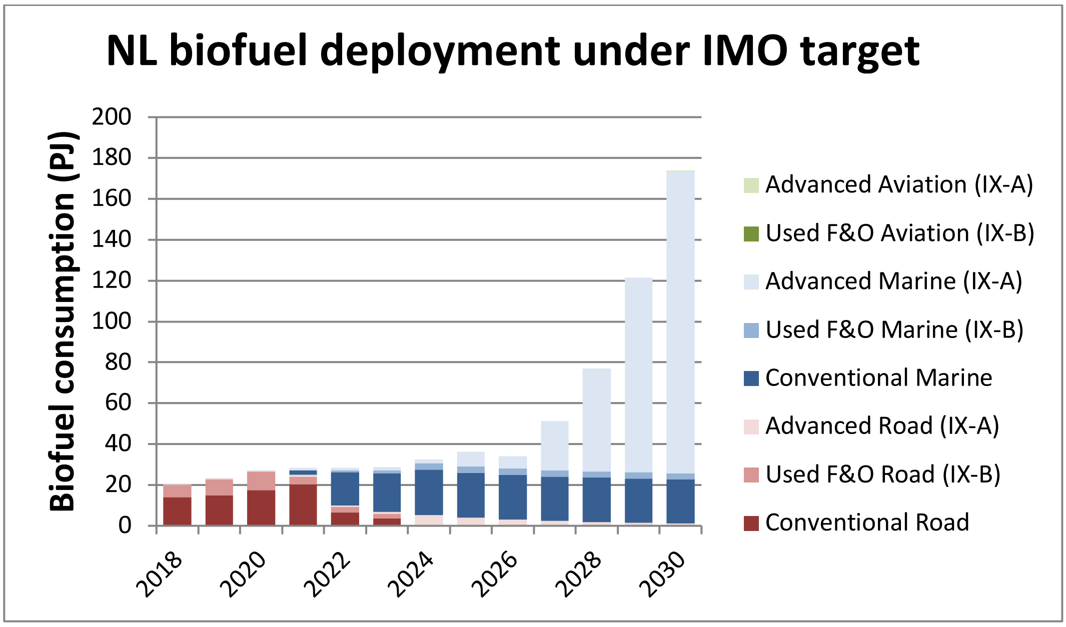

Figure Annex 6. Biofuel deployment in the Netherlands under baseline international shipping energy demand and the IMO target

Platform Duurzame Biobrandstoffen

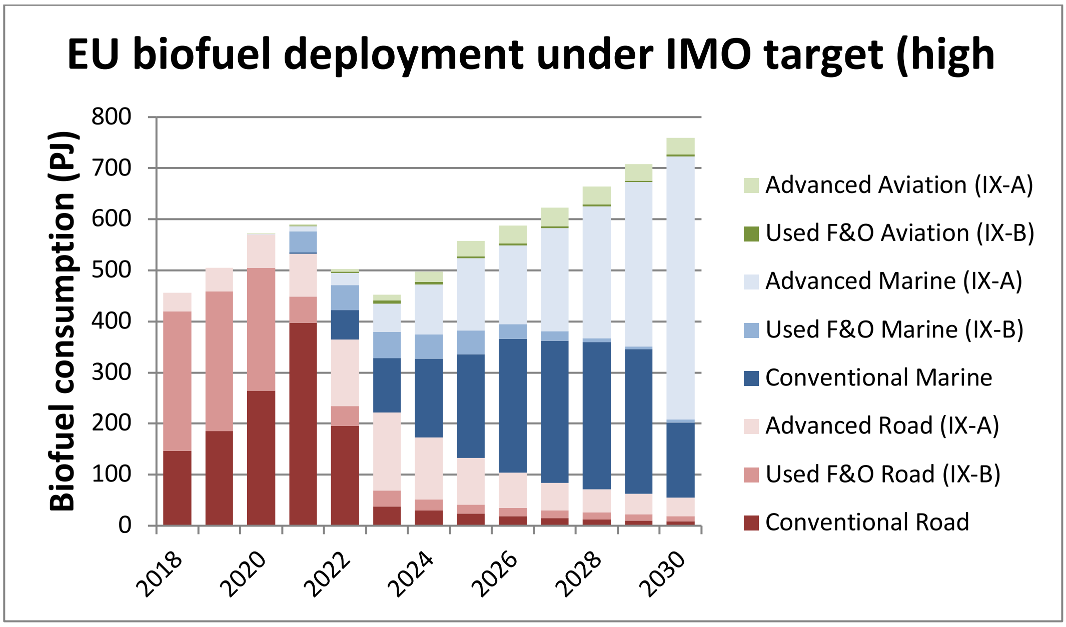

Figure Annex 7. Biofuel deployment in the EU under high international shipping energy demand and the IMO target

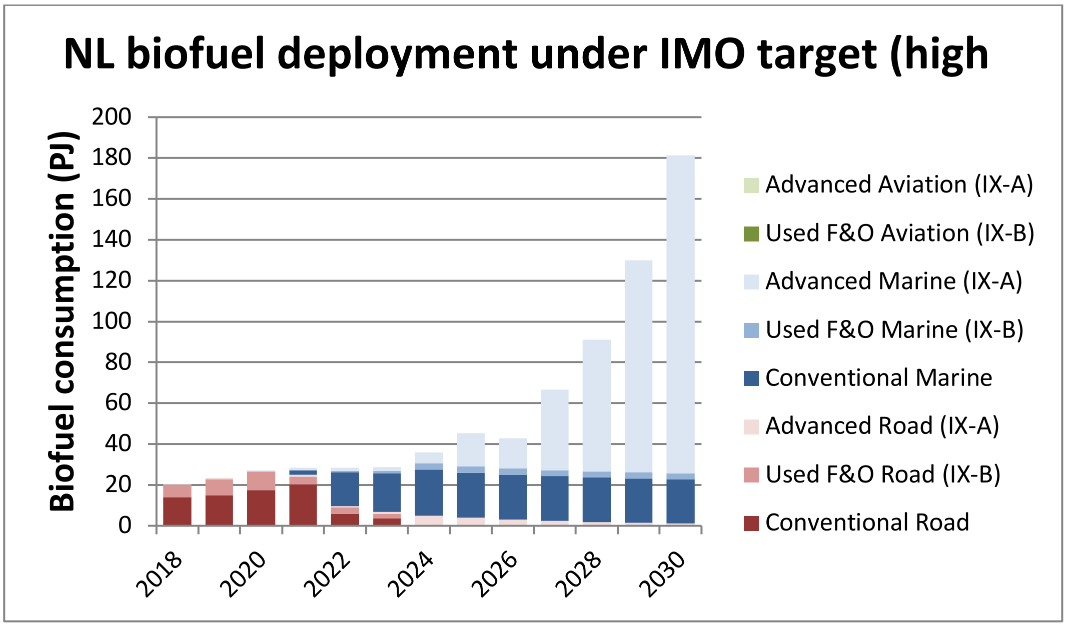

Figure Annex 8. Biofuel deployment in the Netherlands under high international shipping energy demand and the IMO target

Annex II – Parity price calculation

For a given amount of total energy supplied (fossil energy plus biofuel), the relationship in prices where it is equally attractive to supply to either sector can be algebraically determined from the difference in the costs of a reference scenario where a certain biofuel is supplied to the shipping sector and a reference scenario where the biofuel is instead supplied to the road sector. This relationship is given by the following formula:

$$C_{diesel} = \frac{M_{diesel}}{M_{MGO}} C_{MGO} + \left(1 - \frac{M_{diesel}^2}{M_{MGO} * M_{diesel}}\right) C_{biofuel}$$

Where C_{diesel} is the cost of diesel in the road sector, C_{MGO} is the cost of MGO in the shipping sector, $C_{biofuel}$ is the cost of particular biofuel, M_{diesel} is the multiplier in effect when the biofuel is used to substitute diesel and M_{MGO} is the multiplier in effect when the biofuel is used to substitute MGO.

Considering multipliers of either 1,0 and 1,2 or 2,0 and 2,4 for the road and shipping sector respectively, this formula reduces to:

$$C_{diesel} = \frac{5}{6} C_{MGO} + \frac{1}{6} C_{biofuel}$$

If the cost of road sector diesel is lower than this amount, the multipliers render it more attractive to supply the shipping sector. If the cost of road sector diesel is higher, the road sector is more attractive.

References

Agrawal, R., et al. (2007). Sustainable fuel for the transportation sector. URL: http://www.pnas.org/content/pnas/104/12/4828.full.pdf

ARB (Air Resources Board California) (2017) Co-processing of biogenic feedstocks in petroleum refineries. Draft Staff Discussion Paper. URL: https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/020717_staffdiscussionpaper.pdf

ASTM (2011). ASTM Aviation Fuel Standard Now Specifies Bioderived Components. URL: https://www.astm.org/newsroom/astm-aviation-fuel-standard-now-specifies-bioderived-components

BioGrace (2012) About the BioGrace project. URL: http://www.biograce.net/content/abouthebiograceproject/about_the_biograce_project

Van den Bosch, F.A.J., Hollen, R.,Volberda, H.W., Baaij, M.G. (2011) The strategic value of the Port of Rotterdam for the international competitiveness of the Netherlands: A FIRST EXPLORATION. URL: https://www.erim.eur.nl/fileadmin/default/content/erim/research/centres/smart_port/admin/c_book_releases/havenrapport%20engelse%20versie_0.pdf

Capros, P. et al. (2013) EU Energy, Transport and Emissions. Trends to 2050. Reference scenario 2013.

CBS (2016a) Vloeibare biotransportbrandstoffen; aanbod, verbruik en bijmenging. URL: http://statline.cbs.nl/Statweb/publication/?VW=T&DM=SLNL&PA=71456NED&D1=a&D2=a&D3=11-13&HD=171120-1410&HDR=G1,G2&STB=T

CBS (2016b) Motorbrandstoffen; afzet in petajoule, gewicht en volume. URL: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=83406ned&D1=a&D2=0&D3=117,134-135,145,147-149,151-152&HDR=G1,G2&STB=T&VW=T

Clemens, J. (2016) Straw fermentation technology sharing. Presentation at SINO-EU 2016 BNG Summit on 5 November 2016. URL: http://www.bngsummit.com/wp-content/uploads/2016/11/11.straw_clemens.pdf

CMS (2011) Dutch Implementation of the Renewable Energy Directive for Biofuels. URL: https://cms.law/en/NLD/Publication/Dutch-implementation-of-the-Renewable-Energy-Directive-for-biofuels

Commercial Aviation Alternative Fuels Initiative (2010) Fuel Readiness Level (FRL). URL: http://www.caafi.org/information/pdf/frl_caafi_jan_2010_v16.pdf

E4tech (2018) Master plan for CO2 reduction in the Dutch shipping sector – Biofuels for shipping

EC (2009) Renewable Energy Directive. URL: https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

EC (2013a) Clean Power for Transport: A European alternative fuels strategy. URL: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0017:FIN:EN:PDF

EC (2013b) Integrating maritime transport emissions in the EU's greenhouse gas reduction policies. URL: https://ec.europa.eu/clima/sites/clima/files/transport/shipping/docs/com_2013_479_en.pdf

EC (2016a) Sustainability Criteria. URL: https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria

EC (2016b) EU Reference Scenario 2016 – Energy, transport and GHG emissions - Trends to 2050. URL: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

EC (2017) Renewable Energy Progress Report. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0057&qid=1488449105433&from=EN

EC (2018a) Reducing emissions from the shipping sector. URL: https://ec.europa.eu/clima/policies/transport/shipping_en

EC (2018b) Fuel Quality. URL: https://ec.europa.eu/clima/policies/transport/fuel_en

EC (2018c) Infrastructure - TEN-T – Connecting Europe. URL: https://ec.europa.eu/transport/themes/infrastructure_en

EEA (2017a) CO2 Emissions from Transport by Mode, Including international bunkers: EU-28. URL: https://ec.europa.eu/transport/sites/transport/files/pb2017-part3.xls

EEA (2017b) Final energy consumption by mode of transport. URL: https://www.eea.europa.eu/data-and-maps/indicators/transport-final-energy-consumption-by-mode/assessment-8

Elbehri, A., Segerstedt, A. & Liu, P. (FAO) (2013). Biofuels and the sustainability challenge – A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. p.7 URL: http://www.fao.org/docrep/017/i3126e/i3126e.pdf

Elbersen, B., Staritsky, I., Hengeveld, G., Jeurissen, L. & Lesschen, J-P. (2012) Outlook of spatial biomass value chains in EU28. D2.3 Biomass Policies project.

EMSA (European Maritime Safety Agency) (2018) Sulphur Directive. URL: http://www.emsa.europa.eu/main/air-pollution/sulphur-directive.html

ETIP Bioenergy (2018a) Biofuels for Air Transport. URL: http://www.etipbioenergy.eu/?option=com_content&view=article&id=293

ETIP Bioenergy (2018b) Transesterification to biodiesel. URL: http://www.etipbioenergy.eu/value-chains/conversion-technologies/conventional-technologies/transesterification-to-biodiesel

ETIP Bioenergy (2018c) Hydrotreatment to HVO. URL: http://www.etipbioenergy.eu/value-chains/conversion-technologies/conventional-technologies/hydrotreatment-to-hvo

ETIP Bioenergy (2018d) Demonstration of BioDME – Dimethylether as an advanced biofuel at industrial scale. URL: http://www.etipbioenergy.eu/?option=com_content&view=article&id=279

ETIP Bioenergy (2018e) Biogas/biomethane for use as a transport fuel. URL: http://www.etipbioenergy.eu/value-chains/products-end-use/products/biogas?highlight=WyJsYW5kZmlsbCJd

ETIP Bioenergy (2018f) Co-processing in refineries. URL: http://www.etipbioenergy.eu/value-chains/conversion-technologies/advanced-technologies/co-processing-in-refineries

EU (2009). Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003 87 EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community (OJL 8, 13.01.2009, pp. 3–21). URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:008:0003:0021:en:PDF

Platform Duurzame Biobrandstoffen

EU Council (Council of the European Union) (2018) Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. URL: https://www.eumonitor.nl/9353000/1/j9vvik7m1c3gyxp/vkpf7e0ionyq

EurObserver (2017) Biofuels Barometer 2017. URL: https://www.eurobserv-er.org/pdf/biofuels-barometer-en/

FCBI (2015) Methanol as a marine fuel report. URL: https://www.g2xenergy.com/images/downloads/0815_MethanolMarineFuel_Report-EN-lowres.pdf

Geraedts, S (2018) Interview conducted on May 2, 2018.

Gov't NL (Government of the Netherlands) (2016) Energie Agenda. URL: https://www.government.nl/binaries/government/documents/reports/2017/03/01/energy-agenda-towards-a-low-carbon-energy-supply/Energy+agenda.pdf

Gov't NL (Government of the Netherlands) (2017) Confidence in the future: 2017-2021 Coalition Agreement. pp. 41-47 URL: https://www.kabinetsformatie2017.nl/binaries/kabinetsformatie/documenten/verslagen/2017/10/10/coalition-agreement-confidence-in-the-future/coalition-agreement-2017-confidence-in-the-future.pdf

Gov't NL (Government of the Netherlands) (2018a) Biobrandstoffen. URL: https://www.rijksoverheid.nl/onderwerpen/milieuvriendelijke-brandstoffen-voor-vervoer/biobrandstoffen

Gov't NL (Government of the Netherlands) (2018b) Werkprogramma Maritieme Strategie en Zeehavens 2018–2021. URL: https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2018/02/22/rapport-werkprogramma-maritieme-strategieen-zeehavens/rapport-werkprogramma-maritieme-strategie-en-zeehavens.pdf

Florentinus, A., et al. (Ecofys) (2011). Potential of biofuels for shipping. URL: www.ecofys.com/files/files/ecofys_2012_potential_of_biofuels_in_shipping_02.pdf

Hsieh, C.C. & Felby, C. (2017) Biofuels for the marine shipping sector. URL: http://task39.sites.olt.ubc.ca/files/2013/05/Marine-biofuel-report-final-Oct-2017.pdf

IATA (2018) Fact Sheet Climate Change. URL: https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-climate-change.pdf

ICAO (2010). Resolutions Adopted by the Assembly, A37-19 Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change (November 2010). URL: http://www.icao.int/Meetings/AMC/Assembly37/Documents/ProvisionalEdition/a37_res_prov_en.pdf

ICAO (2016). Historic agreement reached to mitigate international aviation emissions. URL: https://www.icao.int/Newsroom/Pages/Historic-agreement-reached-to-mitigate-international-aviation-emissions.aspx

IEA (2014) Energy Technology Roadmaps: a guide to development and implementation. URL: http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapAguidetodevelopmentandimplementation.pdf

IMO (2011) EEDI & SEEMP explained- Website of MARPOL Annex VI. URL: https://www.marpol-annex-vi.com/eedi-seemp/

IMERS (2018) Aviation, Shipping and the Paris Agreement. URL: http://imers.org/aviation-shipping-and-paris

IMO (2014) Third IMO Greenhouse Gas Study. URL: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

IMO (2018a) UN body adopts climate change strategy for shipping. URL: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

IMO (2018b) Introduction to IMO. URL: http://www.imo.org/en/About/Pages/Default.aspx

IMO (2018c) Status of treaties. URL: http://www.imo.org/en/About/Conventions/StatusOfConventions/Documents/StatusOfTreaties.pdf

IMO (2018d) International Convention for the Prevention of Pollution from Ships (MARPOL). URL: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

IMO (2018e) Low carbon shipping and air pollution control. URL: http://www.imo.org/en/MediaCentre/hottopics/ghg/pages/default.aspx

IRENA (2017) Biofuels for aviation – Technology brief. URL:http://www.irena.org/documentdownloads/publications/irena_biofuels_for_aviation_2017.pdf

de Jong, S., Hoefnagels, R., van Stralen, J., Londo, M., Slade, R., Faaij, A., Junginger, M. (2017). Renewable Jet Fuel in the European Union – Scenarios and Preconditions for Renewable Jet Fuel Deployment towards 2030.

Lammens, T (2018a) Interview conducted on June 25, 2018.

Lammens, T. (2018b) Advanced Biofuels from Fast Pyrolysis Bio-Oil. Presentation at: ETIP Bioenergy Workshop Emerging Technologies on 4 June 2018, Brussels. URL: http://www.etipbioenergy.eu/images/WS_Emerging_Technologies_Presentations/04%20Advanced%20Biofuels%20from%20Fast%20Pyrolysis%20Bio-Oil%20-%20Lammens.pdf

Lloyd’s Register & UMAS (Lloyd’s) (2017) Zero-Emission Vessels 2030. How do we get there?

Lloyd’s Register (2014) Global Marine Fuel Trends 2030. URL: http://discovery.ucl.ac.uk/1472843/1/Global_Marine_Fuel_Trends_2030.pdf

Marquard & Bahls (2018) Heavy Fuel Oil (HFO). URL: https://www.marquard-bahls.com/en/news-info/glossary/detail/term/heavy-fuel-oil-hfo.html

Matthews, H.D. et al. (2018) Focus on cumulative emissions, global carbon budgets and the implications for climate mitigation targets. URL: http://iopscience.iop.org/article/10.1088/1748-9326/aa98c9

McDowall, W. (2012) Technology roadmaps for transition management: The case of hydrogen energy. Technological Forecasting and Social Change 79(3) p. 530-542

Min. EA (Netherlands Ministry of Economic Affairs) (2016a) Energy Agenda – Towards a low carbon energy supply. URL: https://www.government.nl/binaries/government/documents/reports/2017/03/01/energy-agenda-towards-a-low-carbon-energy-supply/Energy+agenda.pdf

Platform Duurzame Biobrandstoffen

Min. EA (Netherlands Ministry of Economic Affairs) (2016b) Energy Report – Transition to sustainable energy. URL: https://www.government.nl/binaries/government/documents/reports/2016/04/28/energy-report-transition-tot-sustainable-energy/energy-report-transition-to-sustainable-energy.pdf

Mozaffarian, H., Londo, M., Pantaleo, M. & Kraan, C. (2015) Market analysis for lignocellulosic biomass as feedstock for bioenergy, biobased chemicals & materials in Europe: A quantitative estimate of biomass demand in 2020 and 2030. Deliverable 7.2 S2Biom project.

NEa (Nederlandse Emissie Authoriteit) (2018a) Jaarverplichting EV. URL: https://www.emissieautoriteit.nl/onderwerpen/verplichtingen-ev/jaarverplichting-ev

NEa (Nederlandse Emissie Authoriteit) (2018b) Inboeken hernieuwbare energie. URL: https://www.emissieautoriteit.nl/onderwerpen/inboeken-ev/inboeken-hernieuwbare-energie

Port of Rotterdam (2016) Inland vessels to participate in trial measuring their emission levels. URL: https://www.portofrotterdam.com/en/news-and-press-releases/inland-vessels-to-participate-in-trial-measuring-their-emission-levels

Schuitmaker, R.A. (2016) Evolution of Global Maritime Freight Energy demand and CO2 emissions: A BAU and 2DS Scenario. Msc. Thesis

SER (Social Economic Council) (2013) Energieakkoord voor duurzame groei. URL: https://www.ser.nl/~/media/files/internet/publicaties/overige/2010_2019/2013/energieakkoord-duurzame-groei/energieakkoord-duurzame-groei.ashx

SGAB (Sub Group on Advanced Biofuels) (2017) Building up the future – Cost of Biofuel. URL: http://www.gastechnology.org/tcbiomass/tcbiomass2017/SGAB-Cost-of-Biofuels-Report.pdf

Shishlov, I & Cochran, I. (2016) Six lessons for carbon accounting under article 6 of the Paris agreement. Climate Brief 14. URL: http://www.ieta.org/resources/International_WG/Article6/Portal/I4CE%20-%20Six%20MRV%20lessons%20for%20Article%206.pdf

SSPA (2018) SPIRETH – Methanol as marine fuel. URL: https://www.sspa.se/alternative-fuels/spireth-methanol-marine-fuel

Steeper Energy (2017) Hydrofaction pilot plant surpasses 4750 hours of operation. URL: https://steeperenergy.com/2017/11/30/steeper-energys-pilot-plant-surpasses-4750-hours-of-hot-operation/

Steeper Energy (2018) Hydrofaction (TM).URL: https://steeperenergy.com/hydrofaction/

Stefanidis, S.D. et al. (2017) Co-processing bio-oil in the refinery for drop-in biofuels via fluid catalytic cracking. WIREs Energy and Environment Volume 7, Issue 3, May/June 2018. URL: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wene.281

van Stralen, J., Dalla Longa, F., Beurskens, L., Uslu, A. (2012) Functional description of the REsolve model kit and the biomass allocation. URL: https://www.ecn.nl/publications/PdfFetch.aspx?nr=ECN-E--12-019

van Stralen, J., Kraan, C., Uslu, A., Londo, M. & Mozaffarian, H. (2016) Integrated assessment of biomass supply chains and conversion routes under different scenarios. D7.3 S2Biom project.

Suarez, F. & Lanzola, G. (2005). The half-truth of first mover advantage. Harvard Business Review: April 2005. URL: https://hbr.org/2005/04/the-half-truth-of-first-mover-advantage

United Nations (UN) (1948) Convention on the Intergovernmental Maritime Consultative Organisation. URL: https://treaties.un.org/doc/Treaties/1958/03/19580317%2005-05%20PM/Ch_XII_1p.pdf

United Nation Framework Conference on Climate Change (UNFCCC) (2015). Paris Agreement. URL: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Uslu, A., van Stralen, J., Beurskens, L., Dalla Longa, F. (2012) Use of sustainable biomass to produce electricity, heat and transport fuels in EU27 – A model-based analysis of biomass use for 2020 and 2030. URL: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_use_of_biomass_electricity_heat_transport_fuel_en.pdf

WEC (World Energy Council) (2011) Global transport scenarios 2050. URL: https://www.worldenergy.org/wp-content/uploads/2012/09/wec_transport_scenarios_2050.pdf

Zhen et al. (2018) The effects of emission control area regulations on cruise shipping. Transport Research part D: Transport and Environment (62), pp. 47-63.