Future Fuels in Shipping – Opportunities and Costs

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1 Summary

For a long time the question what will be the future fuel in shipping has been answered most time with: "heavy fuel oil and may be some gas oil". Within recent years it became obvious that this answer is outdated. Emission reduction in general and especially the world wide aim to reduce greenhouse gases have reached shipping. A number of proposals are heavily discussed. Will the new fuel be hydrogen, methane, ammonia or something completely different?

The technical background about fuel options and an overview of the likely fuel and technology solutions has been done e.g. in the white paper "Assessment of Selected Alternative Fuels and Technologies" which has recently been published in an updated version /DNVGLwhitepaper2019/ and now also includes some explanations about power to x fuels including ammonia. This article uses such available technical information as e.g. given by the DNV GL whitepaper to go beyond these data. The focus is on information to enable answers of the three questions:

1. Is there a need to change the complete infrastructure and propulsion technology in shipping?
2. What is the relevance of the "fuel question" for current investment decisions in shipping?
3. How much the "future fuels" will cost and how far away is the "future"?

A lot of experts are providing answers to these key questions and most of time they have a special view and interest driving the answers. This article is not aiming to give "the ultimate answers". The aim is to highlight basic relations and facts by bringing some light into the "pros and cons" of different fuels currently discussed including the costs which have to be expected. At the end of the publication an outlook for the future scope of application of the different fuel alternative is given.

The material used for the figures which are presented are publicly available studies on the subject which include cost studies on the production of "Power to X" (PtX) fuels. The information from these sources is used to conclude on the main cost drivers and to calculate the likely cost boundaries for the different options. The focus is on the main contributors to the production costs for the fuels. Some related infrastructure challenges are named but not evaluated in detail.

2 Energy carrier costs development

The long term energy carrier prices relevant for the today prices for ship fuels are given in **Fig. 2.1.** Note that natural gas prices are hub prices for gas and not LNG prices.

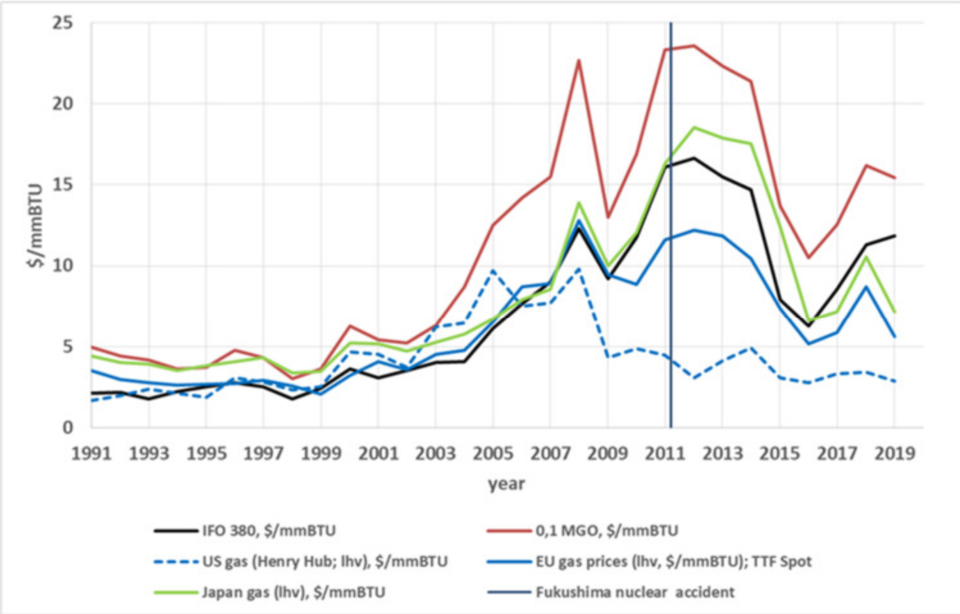


Fig. 2.1 Yearly average energy carrier prices

A major information from this figure may be that fuel becomes more and more costly and that MGO was always "too expensive". It can also be seen that gas in the US has climbed up until the shale gas boom started and fallen down to a very low level where it stays since 10 years. It has the same absolute cost level as 20 years ago and is now much cheaper than crude oil.

Looking to the relations between energy carrier prices disclose some more long term trends and relations. **Fig. 2.2** shows the relation between the prices for natural gas, HFO, MOG and crude oil (Brent).

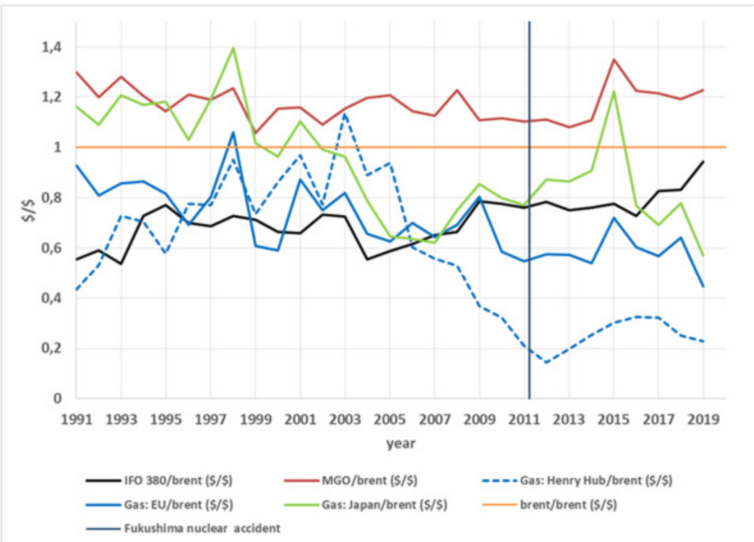


Fig 2.2 Yearly average energy carrier prices related to crude oil Brent price.

Crude oil Brent therefore has always the value of 1,0 $/$.

First of all MGO has always been more expensive than crude oil Brent at a relative constant level of 15 to 20% above crude oil Brent. This seems logical because no one can sell his product below the costs of the raw material for ever. As the figure shows this seems even true for refineries. Another long term trend is that HFO gets more and more expensive since at least 10 years. Coming from a level of 60% of crude Brent it is now close to it. The reason may be that the pressure for refineries to dump HFO into the market is decreasing with improving refinery technology.

For the gas markets in Asia and Europe the trend of closely related markets with the lowest prices in Europe becomes clear. It can be seen that gas in Japan and Europe come closer together after Japan has overcome the gas import boom related to the nuclear accident in Fukushima. Note that natural gas prices in Japan are always LNG prices because there is no gas pipeline to Japan.

A reason for a wider spread between oil and gas prices is the possibility to import LNG from the spot market which has opened after 2005. In addition US is now a LNG exporter (since 2017) with equal distances to Europe and Asia (using the new Panama Channel). These equal distances to the Asian and European market is also true for the largest exporter of LNG which still is Qatar.

With regard to LPG, Methanol and Ammonia which are not included here it can be assumed that they have a price behaviour above or lowest close to the level of their raw materials. As MGO they are commercial products produced from Oil, Natural Gas (LPG) and from Natural Gas (Methanol, Ammonia). In other words they are the products the producers earn money with.

The latest absolute value for crude oil Brent in **Fig 2.1** is equal to approx. 450 US $/t and for MGO approx. 625 US $/t. Diesel price at a German fuel station currently is approx. 1800 US $/t (1,39 €/l with approx. 0,7 €/l taxation). Please keep these figures in mind for your judgement when looking to the costs of PtX evaluated in the following.

3 Some basic assumptions

This article focus on possible alternative future ship fuels and the price limitations for these fuels. It is not a review of the technical, political, financial and time possibilities to introduce these fuels.

The only emissions discussed here are Carbon Dioxide (CO2) emissions. NOx, SOx, PM emissions are not included. For the effect of methane slip reference is made to /thinkstepstudy/. From /thinkstepstudy/ it is obvious that the use of methane (CH4) has a positive effect on CO2 equivalence emissions even if the current available ship propulsion technology is used. It seems not very likely that engineers will not be able to reduce methane slip further towards 2040 and beyond. The discussion of CH4 slip is a publication on its' own and goes beyond the scope of this article. Anyhow methane slip is of minor relevance when compared to the avoidance of 100 % of the Tank To propeller (TTP) emissions (comp. below).

A short time ago (I even assume some months ago) the production of carbon or nitrogen containing fuels from renewable electricity and carbon was not known in public. These fuels are called Power to X fuels (PtX) and they are now everywhere in the media and it is hardly not possible not to know that they come from hydrogen but can be diesel, methane, petroleum gas, methanol, ammonia, etc.. For this reason the how and why of PtX production is not discussed here further. A good reference is the DNV GL white paper on alternative fuels which I know well because I had the pleasure to contribute to it as editor, project coordinator and main author /DNVGLwhitepaper2019/.

To even think about fuel alternatives in shipping has some basics which need to be fulfilled to start to introduce fuel alternatives in shipping. These basics are namely:

- The world takes their CO_2 reduction targets serious (Paris agreement, IMO targets). Please note that this means, that all countries take action to reduce their CO_2 footprint. It does not mean that countries act in an extreme manner as some countries do in one or the other direction.
- The OECD countries manage to keep a relevant industrial base and economic welfare.
  - There is a need for large scale import of renewable energy to these countries.
  - Beyond 2040 the import of renewable energy will largely be based on PtX.
- Overall the people on earth get a better life than they have today and the population grows further (from 7,6 billion to 9,8 billion in 2050 which is an increase of 71 mil/a!).
  - The need for energy and resources is not shrinking.
  - The need for transport is not shrinking.
- It is not possible to meet the IMO CO_2 targets for shipping by newbuilding alone.
  - The fleet in service must cover a part of the CO_2 reduction.
- Shipping and aircraft are forced to take a share in CO_2 reduction even if their contribution stays marginal towards 2040.
  - A switch in fuel towards PtX is unavoidable.
  - Shipping comes soon on the worlds agenda as a consumer of PtX.
- It is not possible to meet the 2°C target
  - fossil fuels are relevant beyond 2050.

For this article please note that the names of the chemicals/fuels and their sum formula of the molecules are used as synonyms. For the different names comp. **Table 3.1**.

Name	Molecule
Hydrogen	H_2
Methane	CH_4
MGO, HFO	$C_{10}H_{22}$
Methanol	CH_3OH
Ammonia	NH_3

Table: 3.1: Names and sum formula for the molecules

For MGO and HFO the $C_{10}H_{22}$ (n-decan) is used as model molecule.

This article focusses on general solutions for worldwide deep sea shipping. Fuels from biomass are not a special subject of this article. They are included in the section about production costs as a reference. Overall biomass has limitations in the amount which can be produced and a lot of industry attention outside the use of fuel. This will most likely limit their application to some special sectors in shipping. E.g. Scandinavian ferry traffic when there is cheap access to biomass fuel.

4 Some basics about CO_2 emissions from fuel

As it is the basic to understand the following the two parts of CO_2 emissions from ship fuel are in brief addressed in the following.

The first part of CO2 emissions is related to the production and transport of the fuel and named "Well To Tank" emissions (WTT). These are all emissions occurring until the fuel is in the fuel tank of the ship.

The second and for fossil fuels much larger part is related to the combustion of the fuel and named "Tank To Propeller" emissions (TTP). TTP includes all CO2 emissions from the fuel tank of the ship to the propeller.

The two parts are illustrated by **Fig.4.1**. By the way, the Solar Gas Turbine shown in **Fig.4.1** may not be a typical prime mover of ships today but as has been described by the PERFECt ship project /PERFECtShip01/ it is well suited to drive high power ships in the near future.

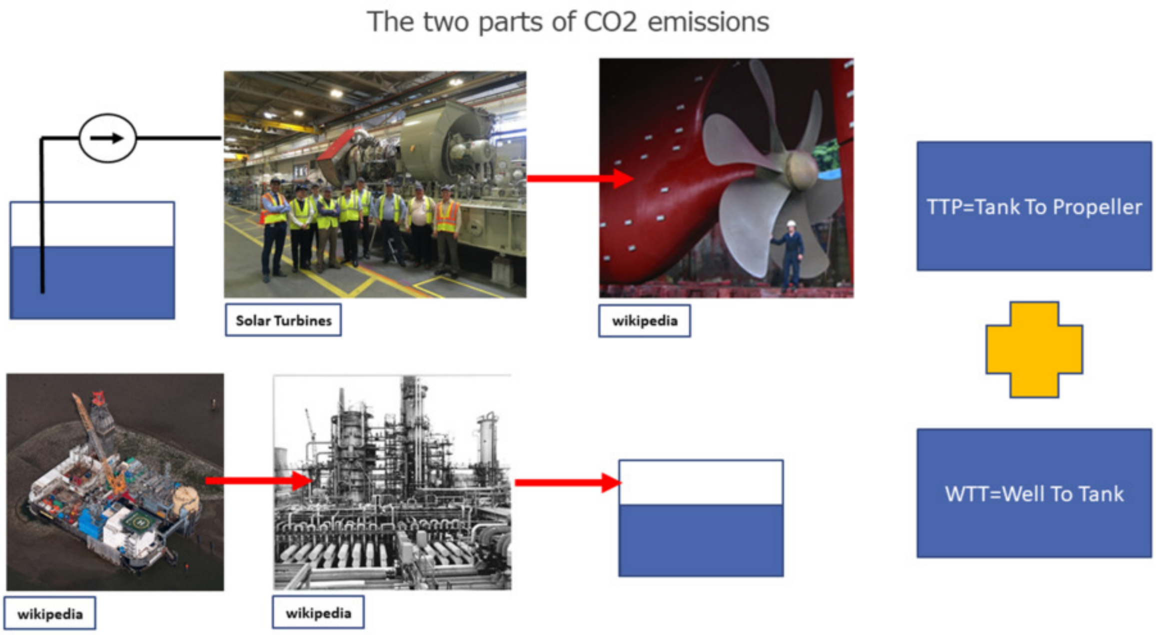


Fig. 4.1: Illustration of WTT and TTP emissions

Fig. 4.2 shows the WTT and TTP emissions of some potential ship fuels. The data for this figure are based on own calculations/literature research and especially on /DNVGLwhitepaper2019/. The high influence of the TTP emissions is obvious.

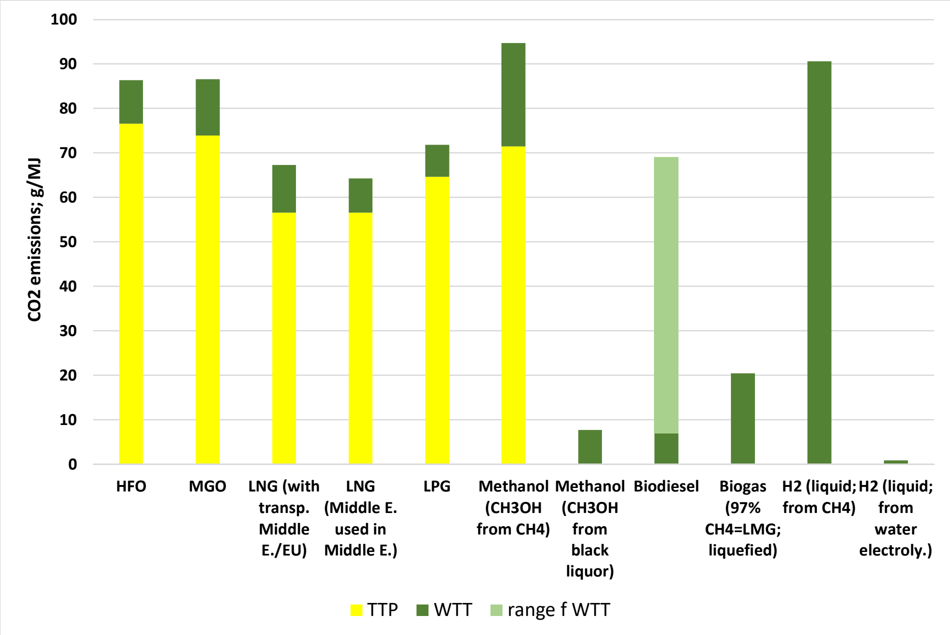


Fig 4.2: WTT and TTP CO2 emissions of some potential ship fuels.

By definition fuels produced in a closed loop CO2 cycle are defined as fuels with zero TTP emissions. E.g. those fuels are bio fuels or fuels using hydrogen from electricity and carbon from biomass, air or nitrogen from air. From **Fig. 4.2** it is obvious that most fossil fuels have a similar WTT value which is much smaller than their TTP value. The WTT of alternative fuels has the same absolute range as the WTT from fossil fuels. Exception is biodiesel where the WTT varies a lot because today's biofuels of first generation have a high WTT while second and third generation WTT have significant lower WTT. Hydrogen produced from CH4 as it is done today has a high WTT but no TTP because the result of the combustion is water which does not contain carbon. At least when it is not mineral water. With the high WTT of hydrogen from CH4 it is obvious that it is not a fuel alternative. This is different for hydrogen from electrolysis. Please note the very low WTT of hydrogen from electrolyses.

As a general rule of thumb it can be assumed that the alternative fuels discussed here have no higher WTT than the relevant fossil ship fuels. For this reason in a first approach the aim to reduce CO2 can be reduced to the reduction of TTP.

The most time and cost efficient way to reduce emissions from shipping is to reduce the TTP emissions of fuels used today by mixing fossil fuels with their PtX counterparts. It is obvious that it is possible to reduce TTP by mixing with fuel with zero TTP if the WTT emissions stay comparable or even become better. On the other hand these "drop in fuels" can easily be used by existing ships without large technical conversions. In the end there will be no fossil fuels used any more. Assuming that the WTT emissions of PtX is not higher than the WTT of their fossil counterparts gives a reduction potential of at least 90 % as can be seen from **Fig. 4.3.** In fact the WTT of PtX can be assumed to be below the WTT of fossil fuels therefore the reduction potential may be higher.

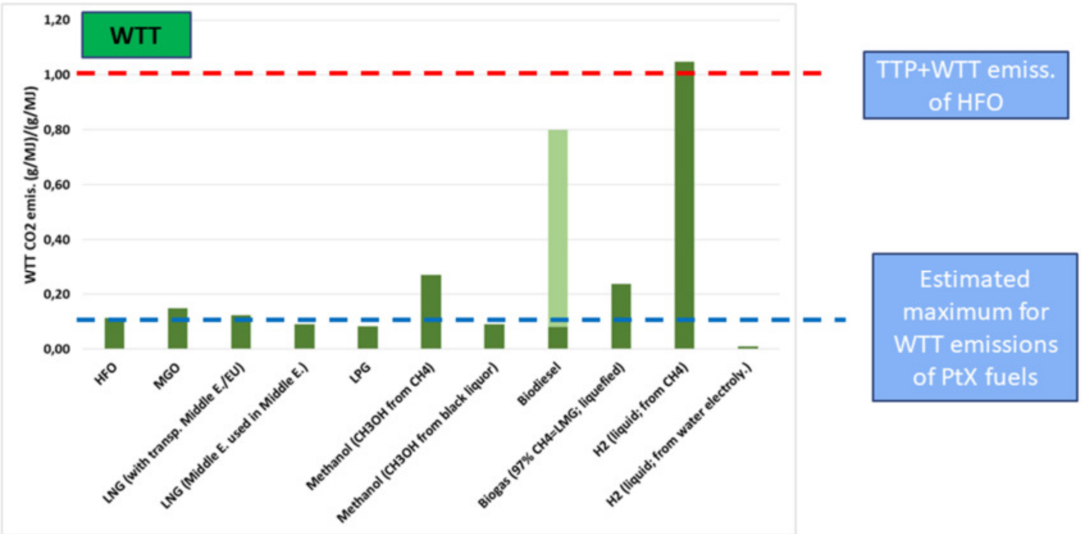


Fig 4.3: CO2 emission reduction potential of PtX (1,0=HFO)

The questions remaining are:

1. What are these "drop in fuels"?
2. How much will they cost?
3. Are there other fuels with so much benefit that it is useful to go for newbuildings only to reach the CO2 targets in shipping?

And at the end: Should I care about this problem or is this something my successors should struggle with?

The answer to the later one is given right now and you may judge at the end of the article if it is correct. If you are close to pension and your company does not plan newbuildings in the next 5 years, you do not need to care about PtX. If this is not the case you should care about. If you belong to the first group you may be interested to give some answers to your grandchildren. If yes, please continue to read.

The other questions above are highlighted to some extend in the following.

5 How to produce PtX

The production principles of PtX is illustrated in **Fig. 5.1**. Similar figures can be found very easily e.g. in /DNVGLwhitepaper2019/. In the end it is easy. You only need electricity from CO2 free sources to produce hydrogen by electrolysis. Then you need a carbon source which can be CO2 or a nitrogen source when you like to produce ammonia. Some key words are "Sabatier Process" (CH4), "Fischer Tropsch Process" (gasoline, diesel), "Haber Bosch Cycle" (NH3), etc. When you look into Wikipedia to those keyword you find that these technology are everything but not new and not for the laboratory only.

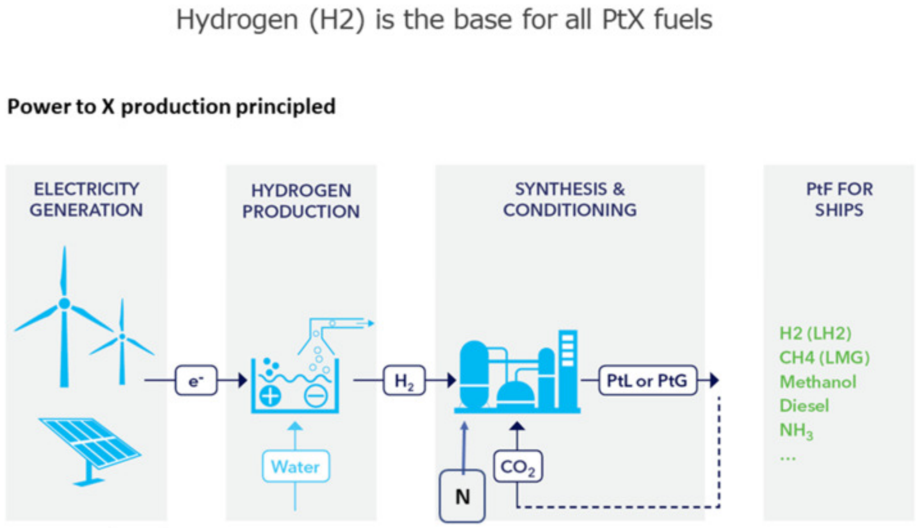


Fig. 5.1: Production principle to produce PtX (figure derived from / DNVGLwhitepaper2019/).

In fact a large number of studies on PtX have already been performed to give the cost base for different scenarios for decarbonisation of world energy supply. Basic information on plant costs, synthesis efficiencies, etc. used for the own calculations presented here are from /DENALeitstudie2018/, /Brynol2017a2018/, /Beerbuehl2014/.

6 World production of relevant ship fuel alternatives

According to IMO the energy used in shipping in 2020 will be approx. 330 Mio t/a oil equivalent /IMO MEPC 70/5/3/, /IMO MEPC 70.INF6/. This is approx. 3300 t/(a ship). Using this value as 100% **Fig. 6.1** shows the energy content for the current world production of the mainly discussed potential alternative fuels for shipping related to the energy needed by shipping. Please note that all these potential alternative ship fuels are used today in other sectors and none of those fuel alternatives is used in shipping.

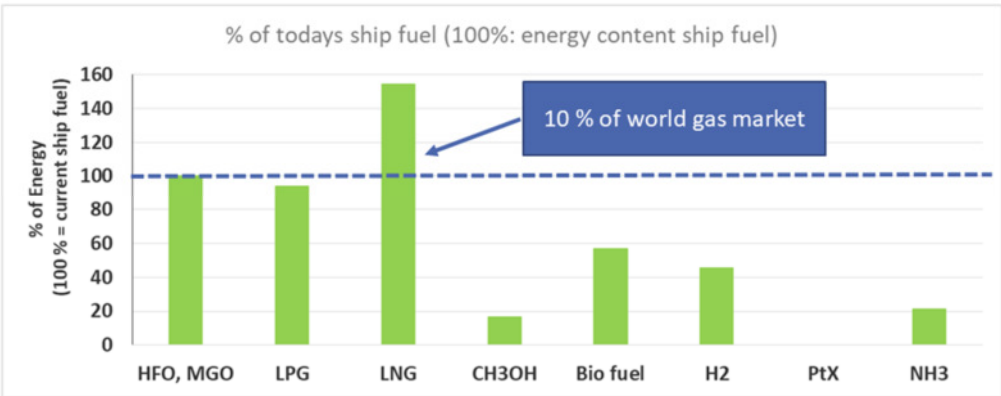


Fig. 6.1: Relation between energy content of the current worldwide production of potential ship fuel alternatives to the energy needed by shipping.

It is obvious that for all alternatives except LNG an enormous amount of additional production capacities is needed if shipping is using the alternatives in a way relevant to reach the IMO targets for CO2 reduction. In fact with the exception of Bio-Fuel all alternatives are currently produced nearly completely from fossil resources. To contribute to CO2 targets they have to be produced as PtX fuels. A PtX production with relevant quantities is not existing today. Even if a massive PtX production is launched today there is no chance for relevant volumes before 2030 and a small chance for 2040.

The switch to LNG will be easy for shipping. LNG only contributes 10% to the world's natural gas market. These 10 % are more than the complete energy need by shipping. The gas market is not dominated by LNG and therefore shipping will be able to get LNG as fuel for a price related to natural gas plus a premium to make it attractive for suppliers to sell to shipping.

If shipping goes for new fuels the number of fuels will be limited. Not all fuels from **Fig. 6.1** will be used.

Hydrogen as ship fuel receives a lot of promotion today. Often this is related to the introduction of fuel cell systems into shipping and the misunderstanding that the use of fuel cells need hydrogen fuel storage on board. Without any doubt hydrogen can be used as bunker in a large number of ships. On the other hand these ships will have only a very limited contribution to the overall energy need in shipping. For deep sea shipping hydrogen will not be the bunker fuel, simply because it needs nearly 5 times the volume of oil fuel even if it would be stored as liquefied hydrogen (LH2). If LH2 will be competitive regarding the price you may judge on the information given below.

7 The price for PtX fuels

In the following the price range for the most relevant PtX fuels for shipping is evaluated. The aim of this evaluation is to give a view to the most relevant cost drivers and the related cost boundaries. If not named differently the figures given in the following are related to the energy content of oil based fuel. The used conversion value is the LHV (Lower Heating Value) of 11,67 kWh/kg which is equal to 42,0 MJ/kg.

7.1 Carbon Costs

Very often the costs for the carbon in PtX is highlighted as a most relevant cost driver. For three cases these costs are illustrated in **Fig 7.1** for methane (CH4), PtX oil (C10H22) and methanol (CH3OH). The cases are:

1. Carbon Capture and Use (CCU) with carbon capture from power plants in Germany and production of PtX in northern Africa. For transport cost evaluation the charter rates for a round trip of a CO2 carrier to Casablanca have been assumed. This gives quite high transport costs because of the long distance to Casablanca.
2. CCU with carbon capture from power plants in Germany and PtX production in Northern Australia. For transport cost evaluation the charter rates for a round trip of a CO2 carrier to Darwin has been assumed.
3. Carbon capture from air according costs levels given by DENA for 2030 /DENALeitstudie2018/.

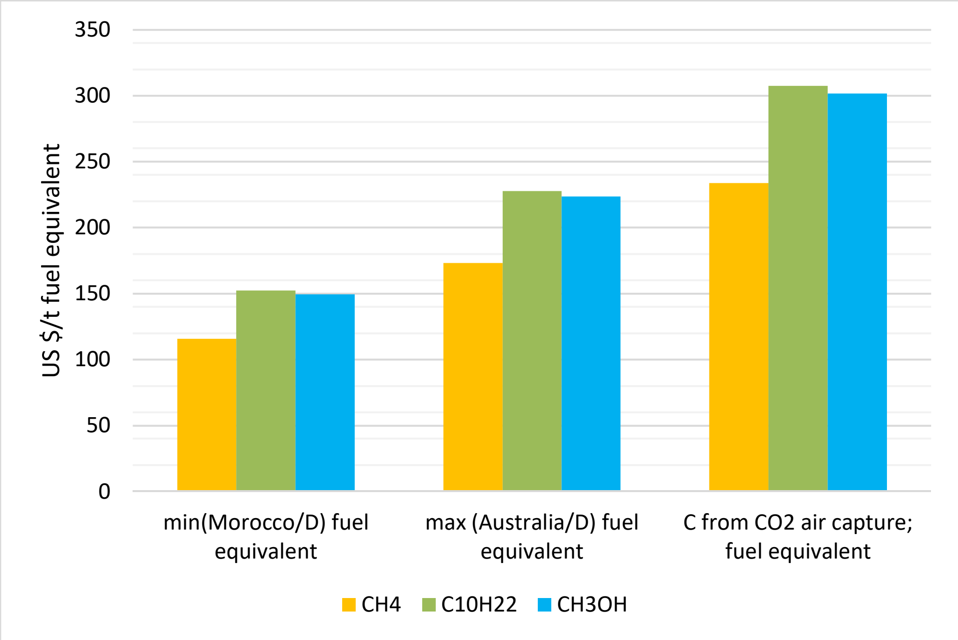


Fig 7.1: Costs for the carbon in PtX fuels.

As can be seen from **Fig 7.1** even CCU and transport of carbon as CO2 to Darwin is much cheaper than the capture from air. May be it is the more clever way to use CCU instead of capture from air if the same amount of CO2 is otherwise released to atmosphere. CCU will be a good method to reduce carbon costs for a long period of time. E.g. the last coal power plant is intended to be closed down in Germany in 2038. At that time still gas fuelled power plants and a lot of industry applications may be operated in Germany.

May be it is also clever that northern Africa provides PtX to Europe and Australia to Asia. The idea that the industrialised countries will be self-sustainable with regard to energy supply is something which will not happen as long as there is a relevant industry in these countries. For this reason it should be noted that shipping may take a part of the PtX production but that the main part still will be used on shore for the sustainable energy supply not covered by inland resources.

From **Fig 7.1** the cost range for carbon supply is approx. between 100 to 300 US $/t fuel oil equivalent. As an outlook to the following please note that the lowest cost limit for PtX is 1058 US $/t fuel equivalent. For this figure electrical electricity costs are assumed to be zero! From this it is obvious that carbon costs are relevant but do not dominate the PtX production. It is also obvious that CO2 carriers may be a very good business in future.

7.2 Electricity costs as the most relevant cost driver

Producing electricity is always related to technical installations which are not for free. If someone assumes this different he only assumes that someone else is paying the bill. As PtX production will be a big business for countries with a lot of wind power, solar radiation and may be even nuclear power zero electricity costs will not happen. **Fig. 7.3** illustrates the electricity costs per ton fuel oil equivalent. A realistic range for very low electricity costs (including transfer grid etc.) seems to be 3 to 7 US $ct/kWh which gives an average calculation base of 5 US $ct/kWh.

For the PtX fuels given in **Fig 7.3** it need to be noted that the carbon content of the fuels contribute to the heating value and that the term "fuel oil equivalent" defines the amount of fuel which has an equivalent heating value of a given mass of oil fuel. The mass content of 1 t fuel oil equivalent with a heating value of 11,67 MWh/t is illustrated in **Fig. 7.2**. E.g. 350 kg of hydrogen (H2) have the same energy content as 1000 kg of oil fuel. On the other end more than 2000 kg of methanol (CH3OH) or Ammonia (NH3) is needed to get the same energy as 1000 kg of oil fuel has. From **Fig 7.2** it is obvious that the mass content of hydrogen in the fuel oil equivalent is below 350 kg for methane, oil and methanol fuel and above 350 kg for ammonia. As a result, less hydrogen than for hydrogen as fuel has to be produced for the same oil fuel equivalent energy content for methane, oil fuel and methanol and more hydrogen for ammonia. For this reason **Fig 7.3** shows that oil like PtX has the lowest electricity costs and ammonia the highest.

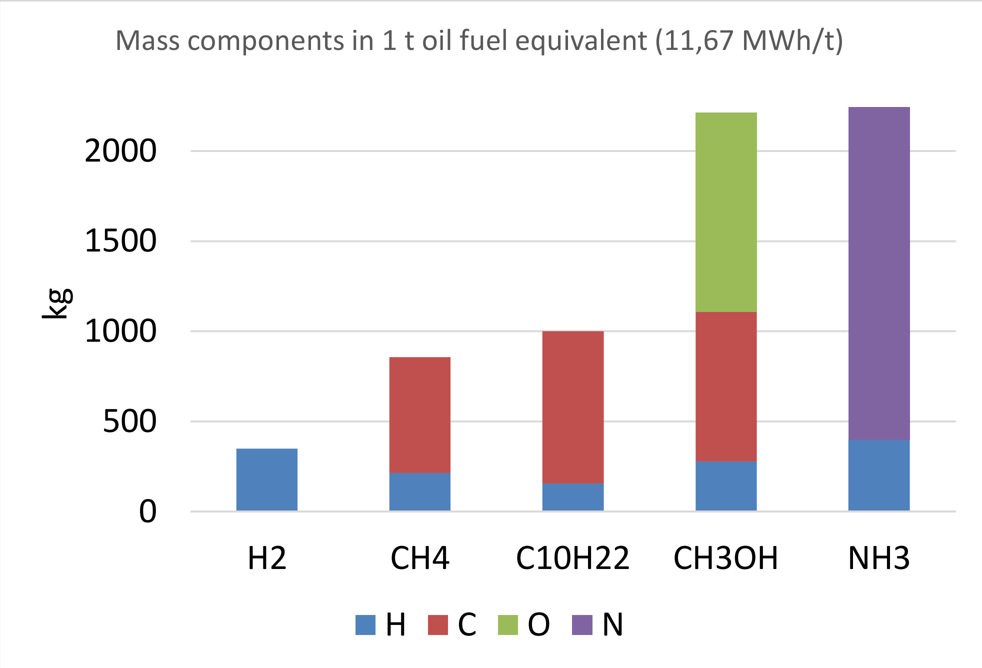


Fig 7.2: Mass composition for the energy equivalent of 1 t oil fuel (11,67 MWh/t)

Hydrogen gas is not the cheapest fuel with regard to electricity costs. E.g. for PtX oil like fuel the hydrogen costs are only 45 % of those for the energy equivalent amount of hydrogen itself. The electricity costs of ammonia are the highest costs for the fuel equivalence. The other fuels are in between.

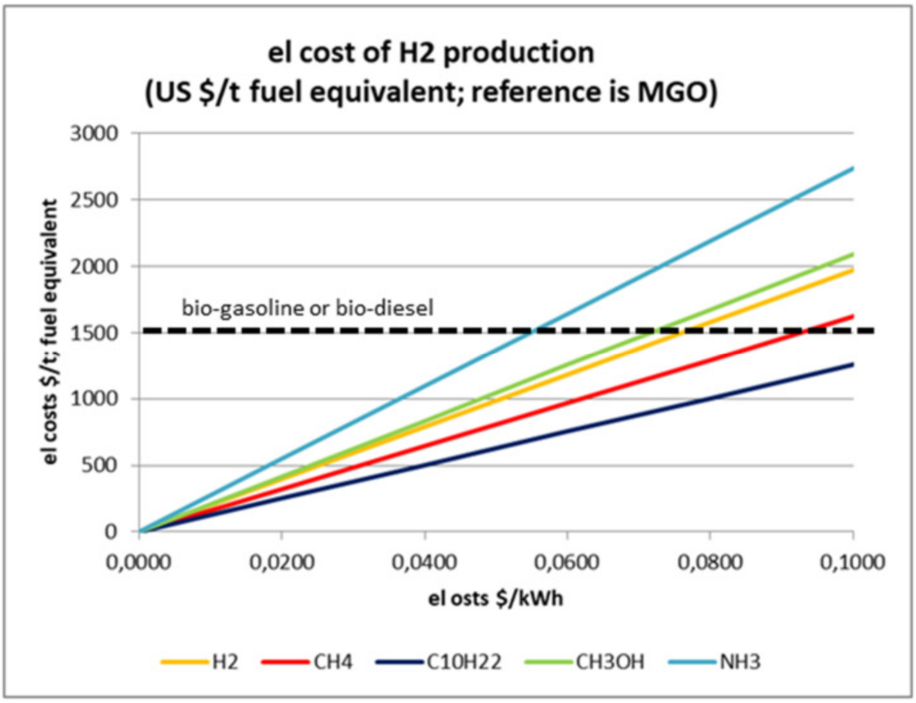


Fig 7.3: Electricity costs for the hydrogen production for 1 ton of oil fuel equivalent PtX

7.3 Total production cost of PtX fuels for shipping

To end up with the total production costs the following cost contributors have been considered.

1. Process costs for electrolysers and synthesis process including CAPEX, OPEX and energy consumption.
2. Liquefaction costs for Liquefied Methane Gas (LMG) and Liquefied Hydrogen (LH2).
3. Carbon costs assumed as average between capture from air and CCU (North Africa case).

Nitrogen costs for ammonia production have been set to zero! Water costs for hydrogen production have been set to zero because they are not relevant for this boundary limit cost assessment.

For the 5 US $ct/kWh electricity cost case the results are given in **Fig 7.4**.

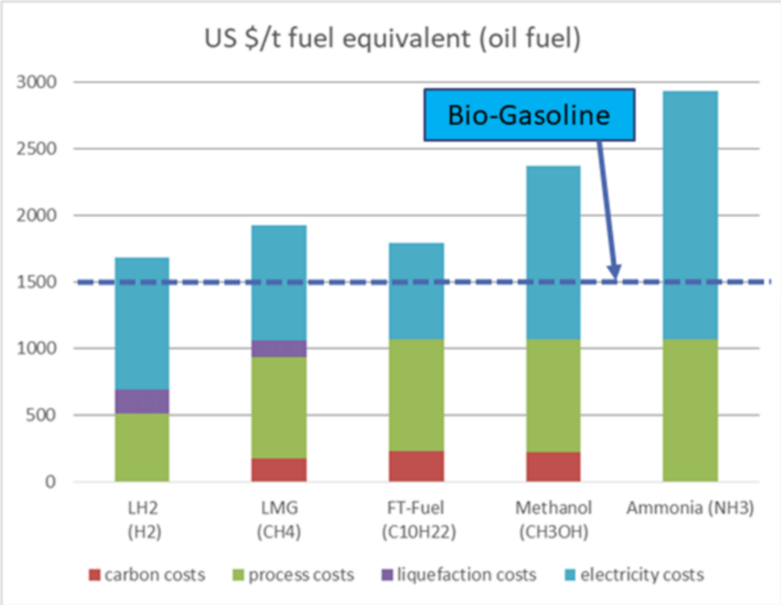


Fig 7.4: Cost boundaries for PtX fules at 5 US$ ct/kWh electricity costs.

Obviously the costs for bio-gasoline or bio-diesel may be the most competitive ones. On the other hand the request for bio mass, the competition between food and bio mass production, the need to keep natural resources even in a sustainable energy world may change this picture. Considering all the uncertainties **Fig 7.4** illustrates that the cost race between PtX diesel, liquefied methane and liquefied hydrogen is open. Cost wise methanol and ammonia might have to struggle to become ship fuels of the future for deep sea shipping.

Having in mind that today's MGO price is closer to 500 US $/t fuel equivalent than to 1500 US $/t fuel equivalent makes clear that the fuel costs of the future will be much higher than today but they will not be unaffordable.

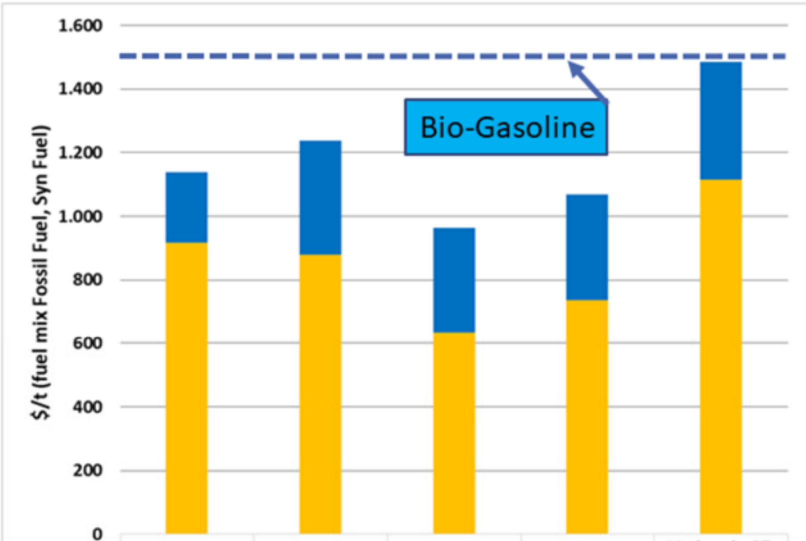
Is this the end of the story or is there something to consider in addition?

8 The relevance of PtX costs for today's investment decisions

After all the most interesting evaluations above the question "what does this mean for me today?" need to be answered. Also a ranking of options over time may be a useful help in discussion with investors and banks.

PtX will play a role after 2030 and towards 2050. So another decade of business as usual? How to sell this to investors and banks? At the end a newbuilding ordered 2020 will be less than 10 years old in 2030 and scraped around 2045. Taking the IMO targets serious, leads to the fact that decision makers need to consider the fuel future today. At least the younger ones (around 50) in prosperous shipping companies should do this (comp. above).

An indication for the answer to these question is given in **Fig 8.1**.



	HFO + FT-Fuel	MGO + FL fuel	LNG +LMG	LPG + Pt-LPG	Methanol + PT-Methanol
fossil	223	357	328	330	371
PtX	916	880	635	737	1114

Fig 8.1: What does it mean to fulfil IMO 2050 target by drop in fuel only?

For **Fig 8.1** it is assumed that the 50% CO2 reduction target is fulfilled by using a mixture of fossil based fuel and PtX fuel. The TTF of PtX fuel is assumed to be zero. The WTT has not been considered because it is assumed to be approx. the same for all fuels and small compared to TTF emissions. For the fossil fuels today's market prices are assumed. For the PtX fuels the prices explained before are used.

It is obvious that biofuels lose their leading position if they are compared with PtX. This might be unfair because a blend of biofuels with HFO or MGO is possible and will bring the leading biofuel position back if only 2nd and 3rd generation biofuel is assumed. Please note that 3rd generation biofuel is in the research state and 2nd generation not on the market in relevant quantities (comp. /DNVGLwhitepaper2019/). But this is true for PtX also.

For the PtX/fossil mixtures it becomes obvious that the mixture between Liquefied Natural Gas (LNG) and Liquefied Methane Gas (LMG) is most competitive. The reason is that LNG needs a low amount of LNG to fulfil the 50% requirement because the carbon content of CH4 is much lower than for HFO, MGO and also lower than for LPG. Methanol is suffering from the high costs and the low heating value.

Considering the information given in **Fig 8.1** and the information given above it can be concluded that a decision for an LNG ("**L**iquefied **N**atural **G**as") newbuilding is future proofed. Looking beyond 2050 it can be assumed that natural gas will be the last fossil fuel which will be replaced. At the same time LMG ("**L**iquefied **M**ethane **G**as") is a very competitive PtX fuel with practically the same physical properties as LNG has. LMG will replace an increasing amount of LNG over time. Finally all LNG will be replaced by LMG. For these reason and considering all other emission benefits regarding NOx, PM, SOx LNG is the fuel of choice today.

9 What will happen in future?

At this point of the article and presentation you have reached the point where a former division manager of mine always opened his eyes again after having closed them from the beginning of the presentation for "better concentration".

At the end of this article I like to give a ranking what might happen with ship fuel in the future (**Fig 9.2** and **Fig 9.3**). The ranking criteria are given in **Fig 9.1**.

Fig. 9.1: Ranking criteria for future fuels in shipping.

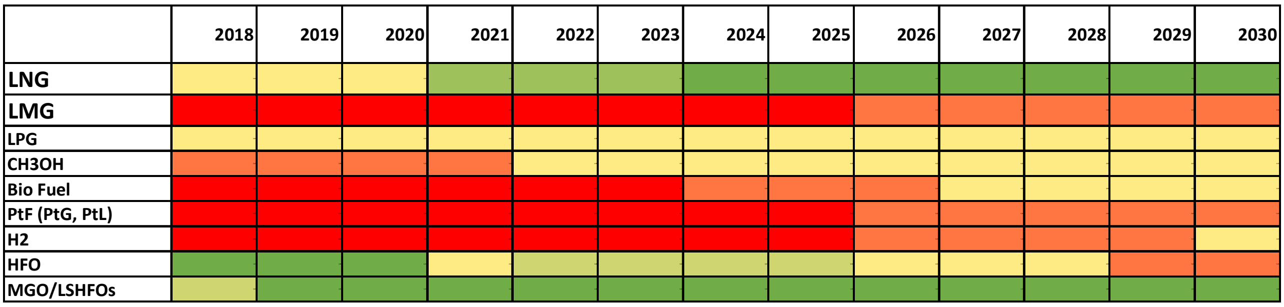


Fig 9.2: Outlook for the possible fuels within the next decade.

With the basic assumptions given above there will be a development towards PtX in the next decade but with limited influence on the day to day shipping business. The benefits of LNG (for NOx, SOx, PM and CO2) are so obvious that a stronger trend towards LNG is expected. At the same time it will be common sense that LNG is the transition to LMG without any change in ship technology. The use of HFO will decrease and MGO/LSHFOs will be the main fuels for shipping.

The outlook beyond 2040 in **Fig 9.3** is clearly speculative but may be useful to judge trends which are developing now and become relevant for investment decisions.

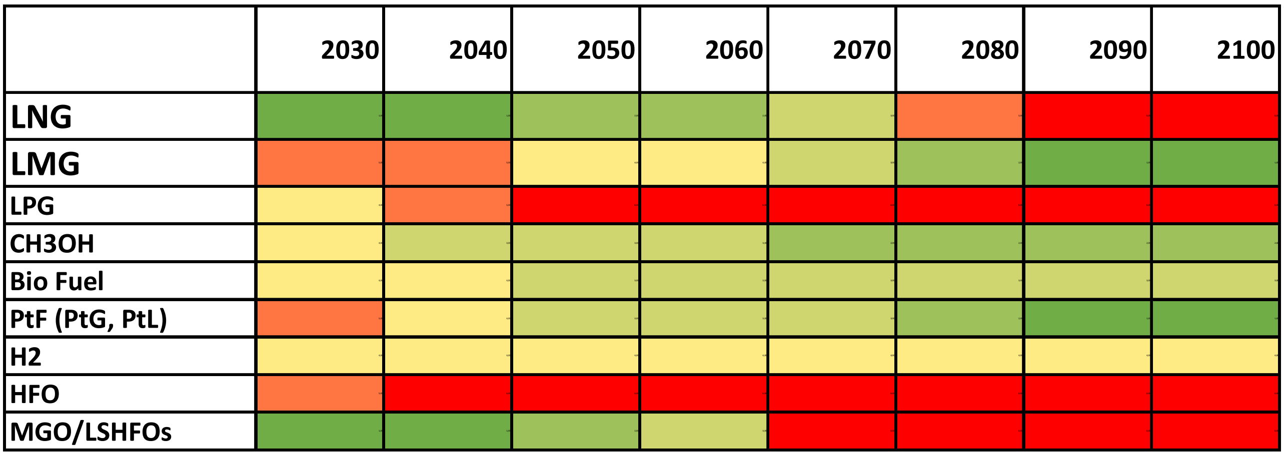


Fig. 9.3: Outlook for possible fuels in 2040 and beyond

As a summary:

1. HFO will be phased out over time.
2. MGO and may be LSHFO survive the next decades.
3. LNG will be increasingly used, LPG may be used also.
4. Hydrogen plays no role in deep sea shipping and a minor role beyond 2030.

5. PtX starts to be market relevant at the end of the decade 2020 to 2030.
6. Methanol and Biofuel may play a role also.

Please note that the ranking for a given case, may look quite different from this general one. At the end a more detailed individual evaluation is needed to come up with a useful decision matrix for management decisions.

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10 Literature

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