Emissions reduction at the Netherlands ministry of defence: potential, possibilities and impact

Prof. Dr. Ir. R.G. van de Ketterij*

* *Netherlands Defence Academy, Faculty of Military Sciences, Den Helder, The Netherlands*
* Corresponding Author. Email: rg.vd.ketterij@mindef.nl

Synopsis

To limit the global temperature rise to 1.5°C in 2100 compared to mid nineteenth century, net post 2015 emissions should amount maximum 200 Gigaton Carbon (GTC) or 734 GT CO2 emissions [Millar, 2017]. Annual world CO2 emission rate was 36.2GT, and CO2_eq (the combined impact of all emissions on global warming, translated to the equivalent impact of CO2 emissions) emission rate was 49 GT in 2016, [Carbonatlas, 2017]. Currently only 685 GT CO2 emission quota is left, or 14 years of emitting at the current emission rate. Estimates vary widely: IPCC thinks we only have 485 GT CO2 emission quota left, while the most pessimistic estimates talk about only 200 GT CO2. With this in mind, the ambition of the Dutch Operational Energy Strategy [Schulten 2017] to reduce the dependency on fossil fuels (and hence CO2 emissions) by 20 % in 2030, is not sufficient to meet the objectives of the Treaty of Paris. We have to choose whether to keep this ambition, defining much stricter ambitions, or invest differently to keep global warming within acceptable limits. This paper discusses CO2 emissions and their distribution both over different sectors and geographical, worldwide. Next the paper discusses the options we have on short and medium term to reduce emissions, and their impact on emission reduction.

Keywords: CO2 emissions; synthetic fuels, biofuels, energy system

1. State of emissions

In 2016, worldwide CO2 emissions amounted 36183 Megaton (MT) CO2 (Carbonatlas, 2017). Other contributors to global warming are CH4, N2O, Perfluorinated Compounds (PFCs), Hydrofluorocarbons (HFCs) and Sulfur HexaFluoride (SF6), Land use, land use change and forestry (LULUCF). These other contributors added in The Netherlands 23 % and worldwide 47 % (IPCC 2014).

Table 1 (Carbonatlas, 2017) shows historic CO2 emissions of the Netherlands, China and worldwide. Emissions in the Netherlands per capita slightly declined, and in China strongly increased from 1990–2012 but stabilized since. Dutch emissions per person are very high: surpassed only by Estonia, Czech Republic, Singapore, the Russian Federation, Kazakhstan, USA, Canada, Australia and 3 Gulf States.

Table 1: CO2 emissions (MT): Netherlands, China and worldwide.

Year	Netherlands	Ton/pp	China	Ton/pp	World
1990	162	10.8	2440	2.08	22220
2000	172	10.82	3402	2.65	24640
2010	183	10.95	8769	6.45	33419
2011	170	10.18	9726	7.11	34791
2012	166	9.88	10020	7.29	35420
2013	166	9.88	10250	7.41	35779
2014	158	9.34	10284	7.40	36081
2015	165	9.76	10151	7.27	36019
2016	168	9.88	10151	7.24	36183

The natural CO2 absorption capacity of the oceans amounts around 7 GT CO2/year (IPCC, 2005). Besides Carbon capture and storage, this absorption capacity indicates maximum annual CO2 emissions.

2. Emission reduction target

Transport accounts for 14 % of all greenhouse gas emissions, or 6.86 GT CO2_eq (IPCC, 2014). These emissions will, if we do not act, consume 80% of our CO2 quota in the remainder of this century. Largest

---

Robert van de Ketterij is a professor systems engineering at the Netherlands Defence Academy, Faculty of Military Sciences. His research interests include new drive systems and new fuels enabling emission reduction a fuel consumption reduction.

http://doi.org/10.24868/issn.2515-818X.2018.065

CO2_eq emission reduction potential is expected in electricity production, industry, and buildings. Transport seems to have less potential but a strong effort is required to reduce greenhouse gas emissions.

Shipping emission estimates vary from 700 to 1046 MT CO2 (IEA transport, 2009; IMO, 2009) and are expected to rise 50 % in 2050. Seaborne trade amounted 69031 billion ton-kilometres in 2005 (Clarksons, 2017), increasing with factors 2.5 to 4 in 2050 (IEA transport, 2009). Expected CO2 emissions per ton-mile in 2050 will be 37.5 %-60 % of the 2005 level, with a worldwide emission target of 7 GT/year accounting for 14 % of the world quota. To keep shipping contribution equal, emissions should reduce to 135 MT: a reduction to 2.5 % - 5.5 % of the 2005 level.

3. NL ministry of defence energy consumption and CO2 emissions

In 2010 overall energy consumption was 10500 GJ (Rijksbegroting, 2012): Estate consumed 4200 GJ. Mobile units consumed 6300 GJ, using 135000 tons of fuel, emitting 405000 tons of CO2 (Netherlands Ministry of Defence, 2015). Target is to reduce dependency on fossil fuels and CO2 emissions with 20 % in 2020 and 70 % in 2050. This is partly based on strategic considerations, as it improves effectiveness, efficiency, and reduce vulnerability. On a world scale these reductions have limited impact but the technological solutions can be translated to civil applications.

Short term we aim for quick wins such as mixing fossil fuels with synthetic or biofuels. From behavioural point of view fuel consumption can be reduced strongly by limiting speeds above 20 knots. On the medium term, new control algorithms, control strategies and hardware could increase efficiency. On longer term, from 2030 on, completely new technology further decreases fossil fuel use and greenhouse gas emissions. In the remainder we will elaborate on these short term, medium term and long term potentials.

4. Greenhouse gas emission reduction potential

Energy consumption and greenhouse gas emission reduction potential can be split in behaviour, tank-to-wheel costs and well-to-tank costs.

4.1. Behaviour

Behavioural measures relate to speed and transportation requirements. In commercial shipping, energy to overcome the hull resistance is a major consumer. Modern ships usually have optimized hull forms and minimized resistance, minimizing power consumption (Gabrielli, 1950). Further reductions are best effectuated by ship speed reduction.

This can be established at equal logistical performance by minimising waiting and turnaround times in ports. Worldwide emissions reduction potential by port optimization is unclear but 15 % reduction at equal performance should be possible. Waiting times vary largely across the world. (Ducruet, 2014) reveals a strong reduction of turnaround times for container ships from 2.6 days in 1996 to 1.3 days in 2011. This potentially reduces power consumption 10 % on a 40 days trip from Rotterdam to Japan. For inland shipping, port times dominate the overall voyage time, and minimising waiting and turnaround times could reduce overall fuel consumption with 50 %. Aware of their influence on decreasing turnaround times, the Port of Rotterdam last year launched the app “pronto”, aiming at optimisation of the port call. In short sea shipping (Johnson, 2015) found idle times in port 40–45 % of total sailing time. Estimated port time savings potential ranges from 1 to 4 hours. With sea passage times of around 40 hours on a trip from Rotterdam to Finland, sailing speed could be reduced by 15 % at equal performance, reducing fuel consumption with 39 %. Early arrival in ports introduce waiting times at berth of around 13 hours. Obviously, proper communication between ship operator and port enables significantly reduced average speed and shorter waiting times.

4.2. Well-to-tank

Well-to-tank emissions and energy consumption associate with producing, transporting, manufacturing and distributing fuels. (Edwards, 2014) provides a comprehensive overview for a large variety of fuels. His methodology accounts for a reduction when useful co-products are formed in the process. The reduction equals the savings in energy and emissions for not producing the material the co-product replaces.

4.2.1. Fossil fuels

The production and manufacturing costs depend on facilities used and location specifics. Specific energy for crude oil production ranges from 0.019 Mega Joule energy consumption per Mega Joule produced fuel (MJ/MJ) in the Middle East to 0.073 MJ/MJ in North America. Average greenhouse gas emissions vary from 1.25 g

CO2eq/MJ in the Middle East to 6.09 g CO2eq/MJ in Asia (Edwards, 2014). Edwards (2014) reports flaring gas results in GHG emissions between 0.1 and 8.5 g CO2eq/ MJ of oil. Gas-to-liquid (GTL) refinery and GTL use could thus very well reduce greenhouse gas emissions.

Transportation of crude to the refinery is effectuated mostly by pipeline or by ship. Transportation costs and greenhouse gas emissions depend on travel speed, distance, and ship size or viscosity and temperature of the oil and amount 0.01 – 0.02 MJ/MJ and 0.6 – 1.2 g CO2eq/MJ. The refinery manufacturing stage costs between 0.06 and 0.1 MJ/MJ energy and between 3.7 and 8.6 g CO2eq/MJ (Edwards 2014, Nyboer 2002). Distribution is then realised by a combination of ships, pipelines, trucks and rail. For normal shipping, these costs are low, as ships usually bunker fuel in ports with refinery facilities nearby. Edwards (2014) reports values of 0.02 MJ/MJ and around 1 g CO2eq/MJ. For navy ships operating in remote areas, these figures are much higher.

Table 2 gives an overview of costs up to the tank. These values can amount up to 25 % of the combustion emissions, and a critical choice of production location, transportation means and distribution, can reduce overall greenhouse gas emissions with 10 %. Combustion emissions amount 72 g CO2eq/MJ.

Table 2: energy and emissions for production and transportation of crude oil based fuels

	Energy MJ/MJ		GHG emissions g CO2eq/MJ	
	min	max	min	Max
Production and manufacturing	0.019	0.073	1.25	6.09
Transportation	0.01	0.02	0.58	1.22
Flaring	-	-	0.1	8.5
Refinery	0.08	0.1	7.0	8.6
Distribution	0.02	0.02	1.0	1.0
Total	0.13	0.21	9.93	25.41

4.2.2. *Natural gas*

Energy and greenhouse gas emissions of natural gas vary strongly depending on production location, refinery and transportation and distribution costs. Edwards (2014) reports values for compressed natural gas (CNG) and Liquid natural gas (LNG) (table 3). Greenhouse gas emissions from combustion are 55 gCO2eq/MJ.

Table 3: energy costs and emissions for production and transportation of CNG and LNG from natural gas

	CNG				LNG			
	Energy MJ/MJ		GHG emissions G CO2eq/MJ		Energy MJ/MJ		GHG emissions G CO2eq/MJ	
	min	max	min	max	min	max	min	max
Production and manufacturing	0.02	0.03	3	4	0.02	0.03	3	4
Transformation at source	-	-	-	-	0.09	0.11	4	8
Transportation	0.07	0.20	5	15	0.07	0.10	5	5
Conditioning & Distribution	0.07	0.09	3	4	0.06	0.11	4	6
Total	0.16	0.32	11	23	0.24	0.35	16	23

4.2.3. *Synthetic-, and Biofuels*

Oumer (2018) reports on 1st, 2nd, and 3rd generation biofuels. First generation fuels are obtained from food crops, where 2nd generation fuels are obtained from waste products. Third generation fuels are generated from algae and other microbes, currently very limited part of the human food chain and potentially a very interesting source. We limit our overview to first and second generation fuels as sufficient data is available and these fuels currently are produced on industrial scale.

To calculate the total (well-to-wheel: WTW) CO2_eq emissions it is important to know whether a fuel is synthetic, from a biological, or from a fossil source. A synthetic fuel is obtained from a mixture of carbon monoxide and hydrogen. A biofuel is produced through biological processes, rather than through geological processes. When a fuel is produced via a biological process, CO2 emissions from combustion are set to 0. Reasoning is that the CO2 was absorbed from the atmosphere when the crop was growing the previous season and is released back during combustion, effectively giving no effect on the CO2 level.

This does not account for the loss of CO2 absorption potential resulting from land cultivation. Vegetation absorption potential vanishes by cultivation; referred to as Direct Land Use Change (DLUC) (Beck, 2013).

DLUC can dominate the emission figures: Garciá (2012) reports an impact of 57 – 324 g CO2eq/MJ for crops in former tropical rainforest to 0.37 g CO2eq/MJ for crops cultivated in former German grass land.

Removal of existing vegetation to enable cultivation releases greenhouse gas emissions, also changing CO2 absorption potential of the soil: Indirect Land Use Change (ILUC). This effect is considered 'significant' but the exact impact is subject to debate, and often not accounted for, overestimating the positive impact of biofuels on CO2 emissions.

Table 4: Energy and emission of synthetic fuels (Edwards, 2018; MKC, 2016), crude oil based products and gas.

Fuel name	Source	Energy consumption MJ/MJ		GHG emissions g CO2eq/MJ**		Combustion Emissions g CO2eq/MJ
		Min	Max	Min*	Max	
Diesel	Crude oil	0.13	0.21	10	25	72
CNG	Natural Gas	0.16	0.32	11	23	55
LNG	Natural Gas	0.24	0.34	16	23	55
Syndiesel (GTL)	Natural Gas	0.58	0.68	20	30	70
	Coal	0.9	1.15	30	140	70
	Wood (farmed)	1.1	1.3	-5	10	0
	Wood (waste)	1.5	1.7	0	2	0
Di-Methyl Ether	Natural gas	0.5	0.7	10	35	70
	Coal	0.9	1.05	110	130	60
	Farmed wood	0.9	1.2	5	5	0
	Waste wood	0.5	0.6	0	1	0
Methanol	Natural gas	0.6	0.75	20	40	80
	Coal	0.9	1.05	110	130	70
	Wood farmed)	0.95	1.2	5	5	0
	Wood (waste)	0.55	0.65	0	1	0
	Synthetic	1	1	0	0	0
Methanol***/HVO	Sunflower	1.0	1.2	45	45	0
	Soy beans	2.5	2.7	60	80	0
	Palm Oil	1.2	1.3	40	50	0
	Waste cooking oil	0.2	0.2	15	15	0
	tallow	0.45	0.45	25	25	0
Ethanol/HVO****	Rapeseeds	0.6	1.3	50	60	0
	Sugar cane	0.6	1.3	50	60	0
Methyl-Tertiary-Butyl Ether	Gasoline	0.15	0.22	12	15	75
	Natural Gas	0.35	0.38	15	17	70
Ethyl-Tertiary-Butyl Ether	Bio-ethanol	0.71	0.73	28	32	48**

* Lower values: including carbon capture and storage
** Excluding DLUC and ILUC
*** Fatty Acid Methyl Ester
****Hydrogenated Vegetable Oil
GHG emissions of sunflower, soy beans, palm oil and rapeseeds mostly result from N2O emissions.

First generation biofuels have much higher production emission costs than fossil fuels. Table 4 indicates production costs of biofuels and GTL in terms of CO2eq/MJ (Edwards, 2018; Jaramillo, 2018). Production costs of GTL are based on production from 'gaseous waste products'. Production costs are allocated to the oil produced, and only transportation and processing costs for refining the gas to liquid are allocated to GTL.

4.2.4. Synthetic fuels

Hydrogen can be produced with any primary energy source, either from decarbonisation of a hydrocarbon or organic feedstock, or by splitting water via electrolysis. Combustion does not result in CO2 emissions (Edwards, 2013). Table 5 (Edwards, 2018) lists energy consumption and CO2 emissions for a number of sources. The large variation in energy use results from the efficiency of the transformation process and the power plant used.

Ammonia can be produced with any primary energy source. Energy density is higher than Hydrogen, but part of the emissions is nitrogen and to be sustainable, this should be captured after combustion. CO2 emissions from combustion are negligible. Production costs 1.5 – 1.7 MJ/MJ (Koelker, 2011), and 88 - 99 gCO2eq/MJ (Flórez-Orrega 2017, Brohi 2014).

In Iceland, methanol is directly produced from water and carbon dioxide using a geothermal power plant. Production is very small, and energy consumption is 12.5 % higher than hydrolysis (Harp, 2015), but the process could provide a valuable future alternative.

Table 5: Energy and emissions of cryo-compressed hydrogen (Edwards, 2018)

Source		Energy consumption MJ/MJ		GHG emissions G CO2eq/MJ	
		Min	Max	Min*	Max
Natural gas		0.7	1.4	12**	140
Coal		1.7	1.8	6**	240
Farmed wood*		0.9	1.45	20	30
Waste wood		0.8	1.4	15	20
Electrolysis fed by	Natural Gas	0.8	2.5	100	200
	farmed wood	2.8	5.1	20	50
	electrical grid	3.8	4.1	220	220
	Coal	2.8	3.7	350	450
	Wind	0.80	0.95	10***	10***

*Excluding DLUC;

**Including CO2 capture and storage

*** (Wang, 2012); (Uddin, 2014) calculated 25–75 g CO2eq/MJ for small wind turbines.

4.2.5. Availability

Shipping in 2005 required between 226 and 337.5 Mtoe (Million Tonnes Oil Equivalent: 1 Mtoe equals 4.1868×10^{16} J) fuel, expected to increase to 750 - 1500 Mtoe in 2050. Any change in from fossil to biobased or synthetic fuel produced by renewable energy source, must be accommodated by growth of renewable energy or biomass production. Combustible renewables and waste supply 10.1 - 11 % (world bank, 2011; Enerdata, 2017) of the total energy demand. (Enerdata, 2017) estimates 24 % of the world energy production to be from renewable origin.

World methanol production amounts 80-90 million tonnes (Zhen, 2015; MKC, 2016): 10 % is used for gasoline blending and 4 % is consumed as bio-diesel. Current methanol production is not sufficient to supply the shipping industry, but the industrial base is strong. We should however carefully consider the impact on the methanol market in order not to provoke increased coal based methanol production, strongly increasing CO2 emissions.

Ehtanol production rapidly increased between 2000 and 2012, and then stabilised (source: https://www.statista.com/statistics/274142/global-ethanol-production-since-2000/). In 2016, 84 % of world ethanol production (98,8 Mm^3, or 78 M tons, equalling 41 Mtoe) was used for fuel production. Ethanol decreases CO2 emissions only limitedly. A significant increase in ethanol demand could introduce negative effects in the supply chain, absorbing food crops, or increasing use of vulnerable land in former tropical rainforest.

Ammonia is currently produced in large quantities: estimates vary between 150 million tonnes (source: http://www.roperld.com/science/minerals/ammonia.htm) in 2015 and 176 million tonnes in 2014 (MKC, 2016). Ammonia production provides us with 45.2 Mtoe. Most ammonia is produced for fertilizer production, but ammonia is an interesting non CO2 emitting energy carrier as it can be produced synthetically.

Hydrogen is produced in large quantities, increasing from 57 million tons (170 Mtoe) in 2004 to 68 million tons in 2014 (Badwal, 2002). Main production pathways are water electrolysis and reforming natural gas. In view of CO2 emission reduction, electrolysis is preferred. Energy production from wind or solar source is highly variable and cannot be predicted on short term. The risk of instability of the electrical grid will force energy buffering, with electrolysis as affordable solution. This increases Hydrogen availability.

4.3. Tank-to-wheel

Tank-to-wheel emissions and energy consumption relate to energy requirement of the system, energy efficiency of the powertrain and the different energy consumers, losses in the path from the powertrain to the energy consumers, chemical composition of the fuel, and possible leakage of fuel through the powertrain. Leakage of fuel will not be discussed.

The Sankey diagram in Figure 1 represents these losses for a conventional propulsion installation: 67 % of the initial energy is burned to heat: the remainder is used to overcome the hull resistance. Diesel engine efficiency is maximum 48 %; maximum propeller efficiency is 70 %. There are some transmission losses. To decrease fuel consumption and greenhouse gas emissions we can:

- Increase propulsion line overall efficiency in off-design and transient conditions
- Increase main engines' maximum efficiency
- Increase propeller efficiency
- Retrieve energy converting waste heat to mechanical energy
- Decrease energy demand

To estimate energy consumption and CO2 emissions reduction, we have to establish the potential to increase the overall efficiency of the powertrain and performance in off-design conditions and establish the operational profile.

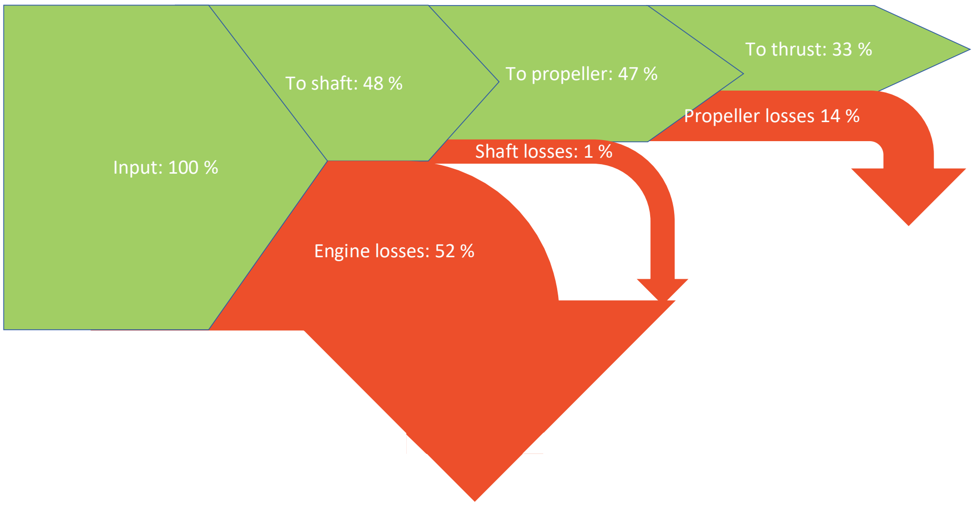

Figure 1: Sankey diagram of the propulsion line of a large ship. Only 33 % is converted to useful energy.

4.3.1. Operational profile and off design conditions

Figure 2 shows the operational profile encountered by a working class vessel and a Panamax product tanker (Baldi 2015). Load of the diesel engine is 50 % of the time between 80 % and 100 % of full load. Most of the time engine loads vary between 50 % and 75 % of full load. Also short sea ships encounter part load conditions most of the time (table 6: (Johnson, 2015)).

The propeller load of the tanker is a major power consumer, and mostly varies between 40 - 70 % of maximum load at sailing speeds between 70 and 90 % of full speed. For working class ships, load occurs at two different speed ranges: a load of 35 – 70 % at ship speeds between 70 and 90 % of full speed, and a load of around 50 % at very low speed.

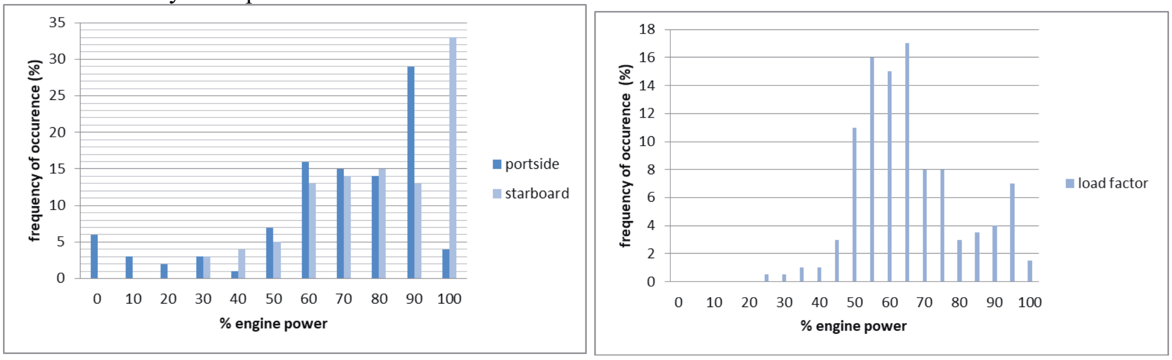

Figure 2: operational profile encountered by a working class vessel (left) and of a Panamax product tanker (right) (taken from Baldi, 2015).

Table 6: operational speed profile for short sea ships

Speed (knots)	Sailing time (%)	Impact on fuel consumption (%)
7,5 - 10	18	9,5
10-12,5	38	34,5
12,5-14,5	44	56

Table 7 (Vettehen 2008) shows the operational profile used for design of the Dutch patrol ship. Most of the time the ship sails at part load. Efficiency at part load is important as almost 50 % of the energy consumption relates to speed lower than 75 % of the design speed.

Table 7: design operational profile of the Dutch Patrol Vessel

Speed (knots)	Sailing time (%)	Impact on fuel consumption (%)
0-5	20	2,5
5-10	10	5
10-15	40	37,5
15-20	30	55

The Sankey diagram in part load condition depends on design choices. Using the parameters of the drive train of the Dutch Patrol ship (Geerstsma, 2016), we find a propeller efficiency is 68 % and a diesel efficiency of 42 % in the design condition,. Figure 3 gives the specific fuel consumption and efficiency of the main engine.

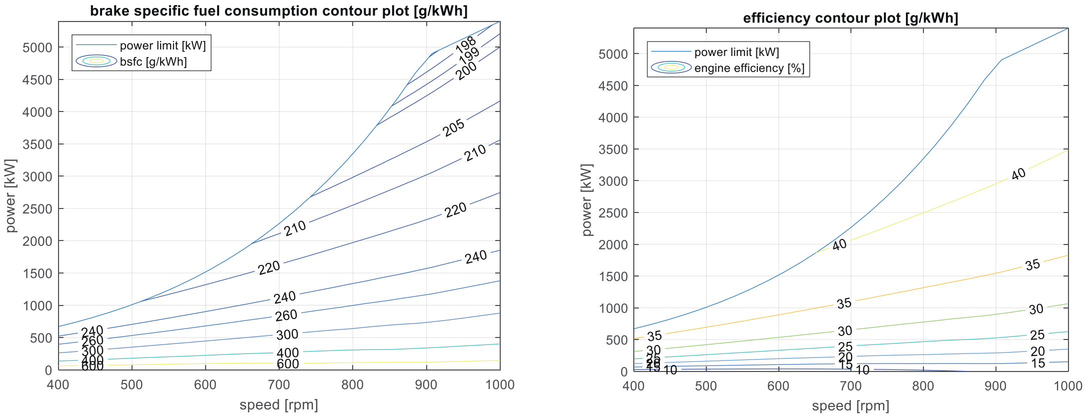

Figure 3: OPV main engines specific fuel consumption and efficiency

At 50 % of the design speed, we could change pitch, speed, or a combination. In table 8 propeller speed and engine speed are connected. Table 9 lists design choices and estimates the efficiency of main engine and propeller at 50 % of the design speed.

Pitch reduction is energetically very costly: propeller losses increase 50 %. Efficiency of the main diesel engine is very poor in any option: this could be increased to around 37 % sharing the load of both propellers by a single engine. This balances the losses of an electrical drive.

Table 8: main engine and propeller efficiency at 50 % of design speed: different design options

RPM	Pitch	Pitch	engine speed rpm	Power (kW)	η_diesel %	η_propeller %
constant	variable	0,47	1000	995	29	44
variable	constant	1.0	600	695	30	63.4
variable	variable	0,92	620	690	30	63.5

Most energy is used sailing at speeds between 80 % and 100 % but an optimised (electrical) drive at speeds below 80 % of design speed reduces overall energy consumption roughly 13,5 %. The surprisingly low load factors encountered by the Panamax product tanker hints that also for larger ships an overall energy consumption reduction of around 10 % - 15 % by propulsion line electrification is possible.

4.3.2. *Main engines efficiency*

The energy efficiency of the powertrain mainly depends on the different energy converters. We can distinguish the maximum efficiency in the best efficiency point (BEP), the efficiency reduction outside the BEP, in transient conditions, and caused by fuel chemical composition. A diesel or gas engine converts chemical to mechanical energy in most powertrains. Diesel engines efficiency has been stable over the past decades and is not expected to change.

In future power systems fuel cells with a potentially higher efficiency could become increasingly important. Efficiency ranges from 35 % for a Proton Exchange Membrane Fuel Cell (PEMFC) using a conventional fuel up to 60 % for a PEMFC using hydrogen, or a Solid Oxide Fuel Cell (SOFC) using conventional fuel. (Dicks, 2018; Biert, 2016). Improvements at the anode surface have improved the dynamic behaviour but dynamics is still restricted compared to a diesel engine. Fuel cell efficiency typically increases at part load. Disadvantage is the systems' sensitivity for pollution of the fuel. Fuel cells potentially reduce energy consumption around 5 – 10 % in full load, increasing to 15 - 20 % in part load.

The automotive industry uses batteries in hybrid or fully electric configurations at reasonably large scale. Solid state batteries are the most convenient option in a drive system (Kim, 2015). Particularly thin film cells have a relatively large energy density, limited performance deterioration over time, an efficiency around 80 % (Rahn, 2013) and leakage limited risk. Energetically, most efficient is to use excess electricity generated by wind or solar power to charge these solid state batteries directly and use those batteries for propulsion.

Metals like Cobalt and manganese, used in alloys for the anodes of current battery designs simply are not available in sufficiently large quantities on our planet. Usability of batteries on ships is also limited by the very high weight requirements: a ship sailing 10 days using 2000 kW requires a battery pack of around 2000 tons. Even though batteries could increase tank-to-wheel (TTW) efficiency and reduce CO2 emissions significantly, with current battery technology I only expect limited batteries use, e.g. to limit load fluctuations.

4.3.3. *Propulsor*

The maximum propeller efficiency is around 62 %. Throughout the years, many attempts have been made to increase propulsion efficiency, mostly aiming at limiting rotational energy loss. Many of these devices have been tested in full scale, but despite the reported efficiency increase only the ducted propeller is used at large scale (Carlton, 2012).

Perhaps the most interesting attempt is the 'whale tail', first tested in full scale by MARIN in 1999. Van Manen (2009) argued an efficiency increase of 20 % over Wageningen B series propellers. Also the whale tail is not used in practice because of mechanical difficulties encountered in construction of a full scale demonstrator.

For merchant ships on certain trades sails could generate part of the thrust. According to Gavin Allwright (IWSA) (Ship Technology, 13 March 2016) Lloyds register identified 6000 vessels (10% of the sea going ships) with potential for retrofit, and a potential energy saving between 5 % and 80 %.

4.3.4. *Waste heat recovery*

The main engine converts 50 – 70 % of power to heat. Conversion of this heat using an organic rankine cycle (ORC) has been proposed in many occasions. ORC is economically viable in geothermal and biomass applications (Colonna, 2015), and could be used with diesel engines and high temperature fuel cells. A theoretical exercise by (Hountalas 2012) revealed a waste heat energy recovery potential of 350 – 400 kW at a thermodynamic efficiency of around 20 %, recovering 2.5 % energy.

Uusipalo (2017) tested a small scale ORC using the heat from a 200 kW diesel engine. Exhaust gas temperatures were around 400 degrees C. Estimated mechanical power output was 9.8 kW at a cycle efficiency of 16.1 % recovering 5 % energy. Application of ORC could reduce overall CO2 emissions around 5 %.

5. Discussion

Behavioral changes provide a significant short term step in emissions reduction. Gains of major ports like the Port of Rotterdam indicate a possible 15 % CO2 emissions reduction without deteriorating the overall logistical chain performance.

The fuel, and its' production dominate overall energy consumption and greenhouse gas emissions in shipping. A wide range of fuels from an even wider range of sources could be used to reduce GHG emissions. The baseline value is between 82 and 98 g CO2eq/MJ for crude oil based diesel. LNG or CNG reduce overall GHG emissions between 5 % and 32 %.

Synthetic fuels based on fossil fuels are not beneficial compared to fossil fuels: use of coal as a source increases greenhouse gas emissions up to 100 %.

Synthetically produced Hydrogen, Methanol, Ethanol and Ammonia can on medium term strongly reduce greenhouse gas emissions, when created with a sustainable energy source. Synthetically produced methanol, could prove an interesting alternative with higher production costs are than hydrogen, but with higher volumetric energy, and lower additional costs for handling, compression and storage.

Biomass based fuels can reduce GHG emissions on short term, but the impact of Direct and Indirect Land Use Change must be considered as it could lead to disruption of local eco systems, increase of CO2 emissions, and worldwide food production, replacing one problem with another. Second generation biofuels based on waste products result in a strong reduction of greenhouse gases, but availability is limited to about 400 Mtoe/year (Oumer, 2018): about 4% of our energy needs. Third generation biofuels, based on sources like seaweed, could significantly reduce GHG emissions, but the market is too small to provide data for a good comparison.

Optimisation of the energy efficiency in off-design conditions with a hybrid or electric drive train saves 10 to 15 % energy. The fuel cell could replace the internal combustion engine in long term, with a potential efficiency increase of 10 % (full load) to 20 % (part load).

Waste heat recovery using a Rankine cycle can in the medium term save at least 5 % energy and emissions. On commercial ships sail assisted propulsion can reduce energy consumption 0,5 to 8 %.

6. Conclusions

- To comply with the agreement of Paris, shipping industry should reduce the greenhouse gas emissions within the next 15 years to 2,5 % - 5,5 % of the 2005 level.
- Synthetically produced fuel fed by a renewable energy source, potentially reduces emissions up to 80 %.
- Production method and source material dominate overall well-to-tank emissions of any bio- or synthetic fuel.
- Behaviour change potentially reduces emissions with around 15 %: ports play a very important role in this transition.
- Hybrid and electrical drive systems including fuel cells in medium to long term strongly reduce overall energy consumption and greenhouse gas emissions.

7. References

Alvarado M.: “The changing face of the global methanol industry”, IHC Chemical Bulletin, june 2016

Millar R.J., Fuglestvedt J.S., Friedlingstein P., Rogelj J., Grubb M.J., Matthews H.D., Skeie R.B., Forster P.M., Frame, D.J. and Allem, M.R.: “Emissions budgets and pathways consistent with limiting warming to 1.5°C”, Nature Geoscience 10, 2017

Badwal, S.P.S., Giddey S. and Munnings, C.: "Hydrogen production via solid electrolytic routes", Wiley Interdisciplinary Reviews: Energy and Environment. **2** (5): 473–487. doi:10.1002/wene.50.

Baldi, F., Larsen U. and Gabrielli C.: “Comparison of different procedures for the optimisation of a combined Diesel engine and organic Rankine cycle system based on ship operational profile”, Ocean Engineering 110 (2015), pp 85 - 93

Beck M.: “The renewable energy directive and the challenges for the Biodiesel Industry: Insights into a dynamic and opaque industry”, Anchor Academic Publishing, Hamburg, Germany, 2013, ISBN 978395489065

Biert van L., Godjevac M., Visser K. and Aravind P.V.: “A review of fuel cell systems for maritime applications”, Journal of Power Sources 327 (2016) pp 345 – 364.

Brohi E.A.: “Ammonia as fuel for internal combustion engines?” Master’s Thesis 2014:55, Chalmers University of Technology, Gothenburg, Sweden, 2014

Carbonatlas, 2017; www.globalcarbonatlas.org, visited by the author on 21 November 2017

Carlton S.: “Marine Propellers and Propulsion, third edition”, 2012 Elsevier Ltd. Oxford, United Kingdom. ISBN 978-0-08-097123-0

Clarksons Research (2017): “*Seaborne Trade Monitor. Volume 4*. No. 6. June.” Available at http://unctad.org/en/PublicationsLibrary/rmt2017_en.pdf (accessed 20 March 2017)

Colonna P, Casati E, Trapp C, Mathijssen T, Larjola J and Turunen-Saaresti T.: “Organic Rankine cycle power systems: from the concept to current technology, applications and an outlook to the future” J Eng Gas Turb Power 2015;137.

Dicks A.L. and Rand D.A.: “Fuel cell systems explained – third edition”, Wiley, 2018, Hoboken, NJ, USA, ISBN 9781118706961.

Ducruet C., Itoh H. and Merk O.: “Time efficiency at World Container Ports”Discussion paper No. 2014-08, published by the International Transport Forum.

Edwards, R., Larivé J-F., Rickeard D. and Weindorf W.: “Well-to-tank report 4.a – JRC well-to-wheels analysis” Report EUR26237 EN. Tech Report by the Joint Research Centre of the European Commission. Available at http://iet.jrc.ec.europa.eu/about-jec/downloads (accessed 23 March 2018)

Edwards R., Godwin S., Hamje H., Krasenbrink A., Lonza L., Nelson R., Reid A. and Rose K.D.: “Well-to-wheels analysis of future automotive fuels and powertrains in the European context”, Report EU26241 EN. Tech Report by the Joint Research Centre of the European Commission. Available at http://iet.jrc.ec.europa.eu/about-jec/downloads (accessed 20 May 2018)

Enerdata,”Global Energy Statistical Yearbook 2017” Available at https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html (accessed 29 april 2018)

Florentinus A., Hamelinck C., Bos A. van den, Winkel R, Cuijpers M.: “Potentials of biofuels for shipping – Final Report”, January 2012 Tech. Rep. Ecofys ordered by European Maritime Safety Organisation”

Flórez-Orrego, D. and Oliveira Jr. S. de: “On the efficiency, exergy costs and CO2 emission cost allocation for an integrated syngas and ammonia production plant”, Energy 117 (2016) pp 341 – 360.

Gabrielli, G. and Kárman von T.: “What price speed? Specific power required for propulsion of vehicles”, Mechanical Engineering, ASME, Volume 72, Number 10, (1950), pp775 - 781

Garciá Sánchez J.A., López Martínez J.M., Lumbreras Martín J.: “Comparison of Life Cycle energy consumption and GHG emissions of natural gas, biodiesel and diesel buses of the Madrid transportation system”, Energy 47 (2012) pp 174 – 198.

Geertsma R., Negenborn R.R., Visser K. and Hopman J.J.: “Torque control for diesel mechanical and hybrid propulsion on naval ships”, paper retrieved from https://www.mecss.org.uk/media/files/Sample_Layout_of_Technical_Paper_FINAL.PDF” accessed at 16/05/2018.

Geertsma R., Negenborn R.R., Visser K. and Hopman J.J.: “Design and control of hybrid power and propulsion systems for smart ships: A review of developments”, Applied Energy 194 (2017), pp 30 – 54.

Geertsma R., Vollbrandt J., Negenborn R., Visser K. and Hopman J.J.: “a quantitative comparison of hybrid diesel-electric and gas-turbine-electric propulsion for future frigates”

Geertsma R., Negenborn R.R., Visser K., Loonstijn M.A. and Hopman J.J.: “Pitch control fors hips with diesel and hybrid propulsion: Modelling, validation and Performance quantifiction”Applied Energy xxx (2018) ppxxx – xxx (in press)

Harp G., Tran K.C., Bergins C., Buddenberg T., Dach I., Koytsoumpa E.I. and Sigurbjornsson O.: “Application of Power to Methanol Technology to Integrated Steelworks for Profitability, Conversion Efficiency, and CO2 reduction”, 2nd European Steel Technology and Application Days, Düsseldorf, Germany, June 2015

IEA 2009; “Transport, Energy and CO2 – Moving toward sustainability”, IEA / OECD report, 2009

Johnson, H., and Styhre L.: “Increased energy efficiency in short sea shipping through decreased time in port”, Transport Research Part A 71 (2015) pp 167 - 178

Hountalas D.T., Katsanos C. and Mavropoulos G.C.: “Efficiency improvement of large scale 2-stroke Diesel engines through recovery of exhaust gas using a Rankine cycle”, Procedia – Social and Behavioral Sciences 48 (2012) pp 1444 - 1453

Kim J.G., Son B., Mukherjee S., Schuppert N., Bates A., Kwon O., Choi M.J., Chung H.Y. and Park S.: “A review of lithium and non-lithium based solid state batteries”, Journal of Power Sources 282 (2015) pp 299 - 322

Koelker K., Ruether J.: “Low Energy Consumption Ammonia Production: Baseline Energy Consumption, Options for Energy Optimization”, Nitrogen + Syngas Conference 2011, Düsseldorf, Germany

Manen J.D. van, and Terwisga T. van: “A new way of Simulating Whale tail propulsion”, presented on the 34th WEGEMT school, 2009. Retrieved from “http://mararchief.tudelft.nl/file/34785/” by the author on 16-05-2018.

Metz B. O., Davidson, Coninck H. de, Loos M. and Meyer L.: “Carbon Dioxide Capture and Storage” Cambridge University press, New York, USA, 2005.

Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

MKC, 2016: “Framework CO2 reduction in shipping”, Den Haag, the Netherlands, 2016: Maritiem Kennis Centrum

IMO, 2009: “Prevention of Air Pollution from Ships”, Second IMO GHG Study 2009. Update of the 2000 IMO GHG Study - Final Report Covering Phase 1 and Phase 2. International Maritime Organisation. MEPC 59/INF.10

Netherlands Ministry of defence, 2015, “Operational energy strategy” Tech. rep. Rijksoverheid

Nyboer, J. and Rivers N. (CIEEDAC): “Energy Consumption Benchmark Guide – Conventional Petroleum Refining in Canada”, tech. report Canadian Petroleum Products Institute, December 2002.

Oumer A.N., Hasan M.M., Baheta A.T., Mamat R. and Abdullah A.A.: “Bio-based liquid fuels as a source of renewable energy: a review”, Renewable and Energy Reviews 88 (2018) pp82 – 98.

Rijksbegroting 2012, annex 5. Available at http://www.rijksbegroting.nl/2012/verantwoording/jaarverslag,kst181216_28.html (accessed 20 march 2018)

Schulten P., Geertsma R. and Visser K.: “Energy as a weapon, part II”, EAAW Proceedings, 20 – 21 June 2017

Worldbank, 2018, https://data.worldbank.org/indicator/EG.USE.CRNW.ZS, visited at April, 29th , 2018.

Florentinus A., Hamelinck C., Bos A. van den, Winkel R., en Cuijpers, M.:”Potential of biofuels for shipping” ECOFYS – technical report 2012

Nationaal LNG Platform. (2014), LNG tank infra structuur. Retrieved from http://www.nationaallngplatform.nl/publicaties/ 22/05/2018

Rahn C.D., and Wang C-Y.: “Battery Systems Engineering”, 2013, published by John Wiley & Sons Ltd, West Sussex, U.K. ISBN 9781119979500.

Uddin S. and Kumar S.: “Energy, emissions and environmental impact analysis of wind turbine using life cycle assessment technique”, Journal of Cleaner Production 69 (2014) – pp 153 – 164

Uusitalo A., Honkatukia J. and Turunen-Saresti T.: “Evaluation of a small-scale waste heat recovery organic rankine cycle”, Applied Energy 192 (2017) PP146 – 158.

Verbeek R.P., Ligterink N.E., Meulenbrugge J.J., Koornneef G.P., Kroon P., Wilde H. de, Kampman B., Croezen H. and Aarnink S.: *Natural gas in transport. An assesment of different routes.* (2013) Retrieved 06 2016 from TU Delft Library: http://repository.tudelft.nl/view/tno/uuid%3Ae237aab6-b17a-44f9-a075-a24ff0ebabbd/

Vettehen M.G.M.H., and Knipping P.: “The new Dutch Patrol Ship”, Retreived from http://www.energievoorinzet.nl/_files/The%20new%20Dutch%20Patrol%20ship%20vs%20040308.pdf, accessed at 15/05/2018.

Wang Y. and Sun T.: “Life cycle assessment of CO2 emissions from wind power plants: Methodology and case studies”, Renewable energy 43 (2012) pp30 - 36

Zhen X. and Wang Y.: “An overview of methanol as an internal combustion engine fuel”, Renewable and Sustainable energy reviews 42 (2015) pp 477 – 493