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Green and efficient Danube fleet

"Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness"

Report on applicable most promising greening technologies & efficient fleet management solutions

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3 Abbreviations

Abbreviation	Explanation
AC	Alternating Current
BTL	Biomass-to-Liquid
CCNR	Central Commission for the Navigation of the Rhine
CESNI	Comité Européen pour l’Élaboration de Standards dans le Domaine de Navigation Intérieure
CTL	Coal-to-Liquid
DC	Direct Current
DNV GL	Det Norske Veritas
DOC	Diesel Oxidation Catalyst
DoD	Depth of Discharge
DPF	Diesel Particle Filter
EGR	Exhaust Gas Recirculation
ES-TRIN	European Standard on Technical Requirements for Inland Navigation vessels
FAME	Fatty Acid Methyl Ester (Biodiesel)
FC	Fuel Cell
GTL	Gas-to-Liquid
HT	High Temperature
HVO	Hydrotreated Vegetable Oil
IWA	Inland Waterway vessels Auxiliaries
IWP	Inland Waterway vessels Propulsion
IWT	Inland Waterway Transport
LNG	Liquefied Natural Gas
LT	Low Temperature

NRE	Non-Road Engines
NRMM	Non-Road Mobile Machinery
OEM	Original Equipment Manufacturer
PBU	Pressure-build-up system
PEM FC	Proton Exchange Membrane Fuel Cell
PM	Particulate Matters
ROI	Return on Investment
RPM	Revolutions per Minute
SCR	Selective Catalytic Reduction
SWOT	Technique to analyse the Strengths, Weaknesses, Opportunities and Threats
TRL	Technological Readiness Level
UNECE	United Nations Economic Commission for Europe
XTL	X-to-Liquid

4 Introduction

Against the background of the expected climate change and the requirements of society as regards a clean and green transport, also for Inland Waterway Transport (IWT) a Greening of the fleet, i.e. the reduction of greenhouse gases and air pollutants is desired. Collective & coordinated efforts at national & European level are needed to support the Danube IWT sector in adapting the fleet to environmental & market challenges. The main objective of this report is to summarize up-to-date knowledge on the new regulations (NRMM regulation (EU) 2016/1628 and ES-TRIN) including their consequences for inland shipping and greening technologies to Danube fleet operators and other IWT stakeholders. An update is given considering the Danube specifics with regards to the technical feasibility and economic viability. This is based on outcomes of previous projects including MoVe It! (FP7), PROMINENT (H2020) and GREEN DANUBE (DTP).

The project MoVe It! funded by the EC within the 7th framework program yielded that the most extensive greening of the fleet for given budget is achieved with inexpensive measures for as many vessels as possible. Few flagship projects with advanced measures maximize the effect per ship but have only a small influence on the (environmental) performance of the sector. The age structure of the existing fleet and the low commissioning activities need to be considered as well. Consequently, the suitability for retrofitting is an important evaluation criterion.

Another focus lies on viable solutions for efficient fleet management including their financial, operational & environmental impact when being deployed. An overview is given of alternative fuels and their use - both deployable at short time (drop in fuels/bio-fuels) and those needing more extensive preparation (LNG, hybrid, fuel cell and hydrogen). Also, air pollutant emission reduction is covered including exhaust gas after-treatment systems for existing diesel engines, new engine concepts and alternative optimisation solutions like on-board emission and fuel consumption monitoring. This aspect includes the reduction of energy consumption by energy efficient navigation and energy efficient ship design as well as hybrid and electric propulsion.

4.1 What is Greening?

Greening consists of mainly three aspects:

- increasing the vessel's efficiency
- reducing the amount of emitted CO_2 per ton kilometre
- reducing the emitted air pollutants

These aspects are also shown in Figure 1. Additionally, the vessel operator benefits from the increased vessel's efficiency by lower fuel costs.

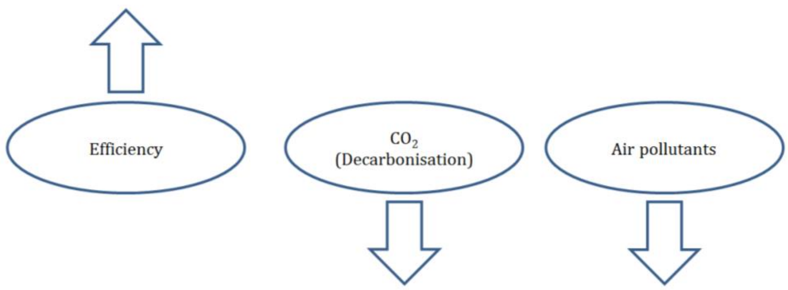


Figure 1: Aspects of Greening

4.2 Where are Greening opportunities?

For the IWT there are numerous opportunities where to start Greening, as seen in Figure 2.

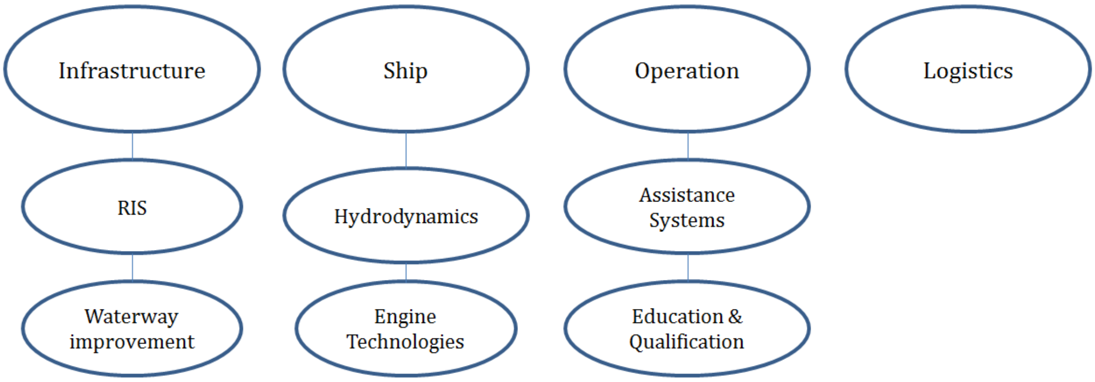


Figure 2: Greening Opportunities in IWT

The main points for intervention are the waterway infrastructure, the vessel itself, the operation of the vessel and the logistics planning. The improvement of the infrastructure allows the vessels to sail faster with lower energy demand and increases the transport capacity. Developments of the ship hydrodynamics and the engine technologies increase the efficiency and reduce emissions. At the same time smart ship operation helps to make the best possible use of the available waterway resources and the current state of the vessel. Therefore, the logistic companies must supply the ship operator with detailed scheduled cargo and times of available port services.

4.3 Challenges and boundary conditions

To assess the suitability of greening options for the Danube region the specific characteristics of the Danube waterway and its fleet have to be considered. Another important point is the individuality of inland vessels. Almost every ship is unique and therefore requires an individual combination of suitable measures. If these two prerequisites are met, an overall improvement can be achieved.

4.3.1 The Danube waterway

With an average water flow of around 6,855 m^3/s and a total length of 2,857 kilometres, the Danube is the second largest and second longest river in Europe after the Volga. The river drains large parts of Central and South-Eastern Europe. It flows through or touches ten countries (Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, the Republic of Moldova and the Ukraine) - more than any other river on earth. The Danube is one of the oldest and most important European trade routes and connects different cultures. Since the fall of the Iron Curtain, the Danube has regained its economic importance. The river connects many species-rich and unspoilt natural areas and is an important location for hydroelectric power stations.

For the transport of three layers of containers a bridge height of at least 7.30 m to 7.80 m is recommended by the CCNR. As some bridges are not meeting this requirement, an obstruction to container transports cannot be prevented, as not the full number of containers can be transported. The bottlenecks can be seen in Figure 3.

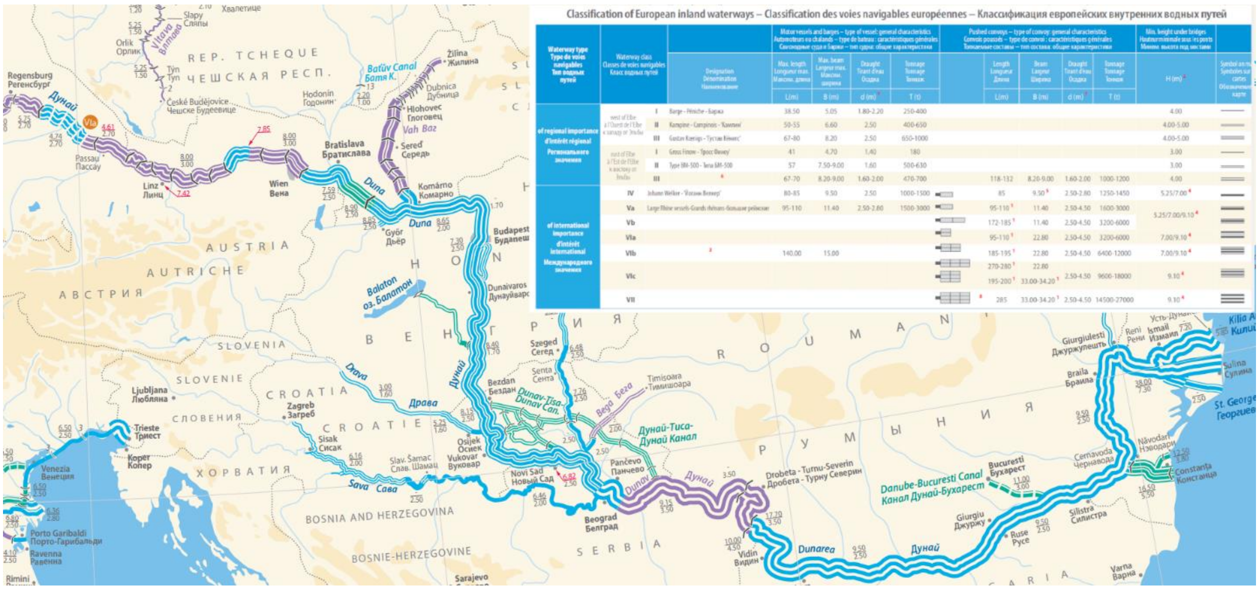


Figure 3: Bridge heights at the Danube - Bridges with lower heights are marked in red; Source: www.unece.org

Besides the low bridge heights there are a few very shallow spots that do lead to a significant reduction of the vessel's cargo capacity especially for bulk transports. This obstacle is a threat to the competitiveness of inland waterway vessels over other modes of transport, since they can no longer take full advantage of the large transport capacity. Another bottleneck surveyed during the PROMINENT project can be seen in Figure 4.

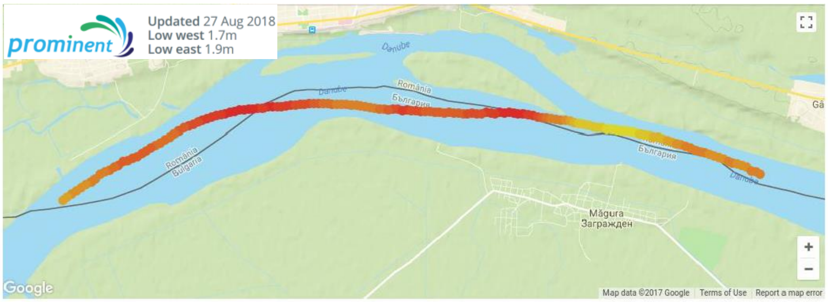


Figure 4: On-board water depth measurements from NAVROM pusher; Source: www.iwtnavigator.eu/depths, Danube water levels tool (Corabia)

These two examples illustrate that measures to improve the waterway are of utmost importance for the desired cargo shift. However, the GRENDEL project focuses on the fleet modernization. Therefore, the infrastructure measures are not considered further in the following.

4.3.2 The Danube fleet

The Danube fleet comprises about 3,000 units of various ship types. The following tables and illustrations give a more detailed insight.

Table 1 gives a detailed overview of the number of vessels, engine power and payload for the Danube fleet and the change from 2015 to 2016. It can be seen that the number of vessels decreased more than the amount of engine power and payload. This suggests that in particular small ships have been scrapped. An overview of the current fleet by countries and main types of vessels in the years 2015 and 2016 is given in Table 2.

Table 1: General overview of the number of vessels on the Danube, incl. engine power and payload of the fleet

Year	Number of vessels	Engine power [kW]	Payload [t]
2015	3,586	684,706	3,236,472
2016	3,165	643,317	2,975,545

Table 2: The Danube fleet and its composition by countries and by main types of vessels 2015-2016; Source: www.danubecommission.org

	Year	UA	MD	RO	BG (2015)	RS	HR	HU	SK	AT	DE	Total	Share in total composition of Danube fleet (in %)
Motorized vessels													
Number of units	**2016**	**29**	*	**157**	**57**	**74**	**23**	**68**	**10**	*	*	**418**	***13,2***
	2015	**31**	*	**154**	**57**	**97**	**19**	**70**	**23**	*	*	**451**	***12,6***
	%	93,5	*	101,9	100,0	76,3	121,1	97,1	43,5	*	*	92,7	
Total power of motorized vessels (kW)	**2016**	**48 259**	*	**77 933**	**40 956**	**47 808**	**15 439**	*	**4 822**	*	*	**235 217**	***36,6***
	2015	**48 864**	*	**76 720**	**40 956**	**37 929**	**12 384**	*	**7 797**	*	*	**224 650**	***32,8***
	%	98,8	*	101,6	100,0	126,0	124,7	*	61,8	*	*	104,7	
Total carrying capacity of motorized vessels (t)	**2016**	**65 078**	*	**141 775**	**69 637**	**82 612**	**27 663**	*	**10 365**	*	*	**397 130**	***13,3***
	2015	**70 762**	*	**139 672**	**69 637**	**88 066**	**20 621**	*	**12 775**	*	*	**401 533**	***12,4***
	%	92,0	*	101,5	100,0	93,8	134,1	*	81,1	*	*	98,9	
Tugs										*	*		
Number of units	**2016**	**3**	*	**141**	**14**	**13**	**27**	**43**	**4**	*	*	**245**	***7,7***
	2015	**5**	*	**134**	**14**	**94**	**30**	**43**	**2**	*	*	**322**	***9,0***
	%	60,0	*	105,2	100,0	13,8	90,0	100,0	200,0	*	*	76,1	
Total power of tugs (kW)	**2016**	**2 316**	*	**28 704**	**4 955**	**3 475**	**7 640**	*	**1 022**	*	*	**48 112**	***7,5***
	2015	**3 640**	*	**27 723**	**4 955**	**24 768**	**8 748**	*	**915**	*	*	**70 749**	***10,3***
	%	63,6	*	103,5	100,0	14,0	87,3	*	111,7	*	*	68,0	
										*	*		
Pusher vessels													
Number of units	**2016**	**53**	*	**153**	**39**	**33**	**9**	**15**	**29**	*	*	**331**	***10,5***
	2015	**61**	*	**152**	**39**	**65**	**10**	**15**	**30**	*	*	**372**	***10,4***
	%	86,9	*	100,7	100,0	50,8	90,0	100,0	96,7	*	*	89,0	
Total power of pusher vessels (kW)	**2016**	**88 669**	*	**167 856**	**41 943**	**30 855**	**4 356**	*	**26 363**	*	*	**360 042**	***56,0***
	2015	**94 735**	*	**164 524**	**41 943**	**55 388**	**5 294**	*	**27 423**	*	*	**389 307**	***56,9***
	%	93,6	*	102,0	100,0	55,7	82,3	*	96,1	*	*	92,5	
Towed barges													
	2016	**18**	*	**356**	**46**	**18**	**58**	**5**	**2**	*	*	**503**	***15,9***
Number of units	**2015**	**18**	*	**370**	**46**	**228**	**66**	**6**	2	*	*	**736**	***20,5***
	%	100,0	*	96,2	100,0	7,9	87,9	83,3	100,0	*	*	68,3	
Total carrying capacity of towed barges (t)	**2016**	**28 912**	*	**213 578**	**63 893**	**7 805**	**32 529**	*	**1**	*	*	**346 718**	***11,7***
	2015	**28 912**	*	**225 943**	**63 893**	**294 001**	**38 981**	*	1	*	*	**651 731**	***20,1***
	%	100,0	*	94,5	100,0	2,7	83,4	*	100,0	*	*	53,2	
Pushed barges													
Number of units	**2016**	**249**	*	**789**	**111**	**119**	**56**	**245**	**99**	*	*	**1 668**	***52,7***
	2015	**257**	*	**764**	**111**	**180**	**45**	**246**	**102**	*	*	**1 705**	***47,5***
	%	96,9	*	103,3	100,0	66,1	124,4	99,6	97,1	*	*	97,8	
Total carrying capacity of pushed barges (t)	**2016**	**365 553**	*	**1 279 514**	**177 381**	**184 613**	**59 748**	*	**164 888**	*	*	**2 231 697**	***75,0***
	2015	**379 008**	*	**1 242 361**	**177 381**	**169 101**	**43 657**	*	**171 700**	*	*	**2 183 208**	***67,5***
	%	96,4	*	103,0	100,0	109,2	136,9	*	96,0	*	*	102,2	
TOTAL – Total number of vessels	**2016**	**352**	*	**1 596**	**267**	**257**	**173**	**376**	**144**	*	*	**3 165**	***100***
	2015	**372**	*	**1 574**	**267**	**664**	**170**	**380**	**159**	*	*	**3 586**	***100***
	%	94,6	*	101,4	100,0	38,7	101,8	98,9	90,6	*	*	88,3	
TOTAL – Total power of fleet (kW)	**2016**	**139 244**	*	**274 493**	**87 854**	**82 138**	**27 435**	*	**32 207**	*	*	**643 371**	***100,0***
	2015	**147 239**	*	**268 967**	**87 854**	**118 085**	**26 426**	*	**36 135**	*	*	**684 706**	***100,0***
	%	94,6	*	102,1	100,0	69,6	103,8	*	89,1	*	*	94,0	
TOTAL – Total carrying capacity of fleet (t)	**2016**	**459 543**	*	**1 634 867**	**310 911**	**275 030**	**119 940**	*	**175 254**	*	*	**2 975 545**	***100***
	2015	**478 682**	*	**1 607 976**	**310 911**	**551 168**	**103 259**	*	**184 476**	*	*	**3 236 472**	***100***
	%	96,0	*	101,7	100,0	49,9	116,2	*	95,0	*	*	91,9	

* Hereinafter, data are not available or magnitude "0".

Figure 5 is illustrating, that the majority of vessels still have an engine without emission standard. This means, the engines market introduction has been before 2003. Those engines do not meet any of the CCNR 1 or CCNR 2 standards. Not only that the engines are deprecated, but also the age of the vessels is rather high too, which can be seen in Figure 6.

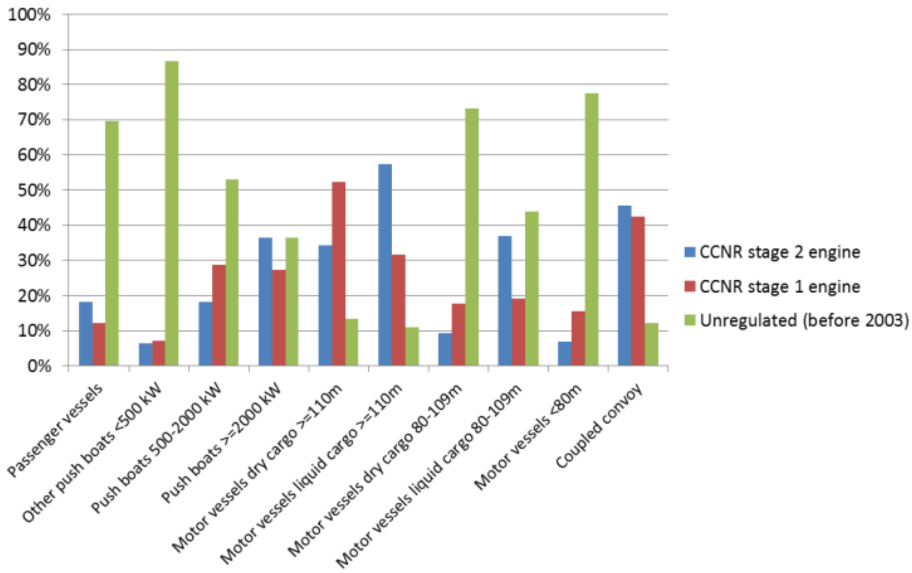


Figure 5: Engine type per main fleet family in the European fleet; Source: PROMINENT D1.1 List of operational profiles and fleet families

		Before 1941	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	After 2010	Unknown	TOTAL*
TOTAL 2016	Number of vessels (unit)	52	277	545	707	1 271	277	65	0	3	3 197
	%	1,6	8,7	17,0	22,1	39,8	8,7	2,0	0	0,1	100

* Ukraine, Republic of Moldova (2008), Romania, Bulgaria (2015), Serbia, Croatia, Hungary, Slovakia (see section 3).

		Before 1941	1941-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	After 2010	Unknown	TOTAL [1]	TOTAL*
TOTAL 2016	Number of vessels (unit)	52	218	442	595	1 171	275	65	0	3	2 821	3 197
	%	1,8	7,7	15,7	21,1	41,5	9,7	2,3	0	0,1	100	
	Power (kW)	3 103	25 244	108 153	106 029	146 591	46 679	2 907	0	129	438 835	656 791
	%	0,7	5,8	24,6	24,2	33,4	10,6	0,7	0	0,0	100	
	Carrying capacity (t)	59 069	120 266	293 417	597 083	1 436 279	445 367	67 803	0	2 326	3 021 610	3 021 610
	%	2,0	4,0	9,7	19,8	47,5	14,7	2,2	0	0,1	100	

* Ukraine, Republic of Moldova (2008), Romania, Bulgaria (2015), Serbia, Croatia, Hungary, Slovakia.

[1] Disregarding number of vessels from Hungary, as Hungary does not provide data on power and carrying capacity of vessels; disregarding data on power of motorized vessels with a breakdown by periods, excluding Croatia and Slovakia.

Figure 6: Summary data on the Danube fleet by years of construction (as of 31st December 2016); Source: Danube Commission

5 Criteria for the evaluation of greening measures

In the long term an energy transition towards zero-emission inland navigation is desired. The approach selected is highly dependent on the focal point. With a focus put on air pollutants modern engines like Stage V or Euro VI truck engines and NRE or equivalent retrofitted aftertreatment systems already contribute to a reduction to a large extent. A fleet fully equipped with Stage V engines would emit 79 % less NO_x and 97 % less particles. But with the focus on CO_2 alternative non-fossil fuels or zero-emission technologies like fuel cell systems and batteries have to be considered. However, up to now this is only feasible to be financed in niche applications.

As a general approach the experience of the PLATINA, PLATINA II, Move It! and PROMINENT projects is used. There are some criteria that need to be considered for the measures to be taken on the Danube when choosing greening technologies for a certain ship to gain the best solution. The results are heavily depending on the individual ship and its operational scenario. This means that an expert analysis is indispensable. Greater benefits can be achieved by a proper combination of different measures. But the selection of the most useful measure(s) is a complex task.

5.1 General criteria from PLATINA II and PROMINENT

The criteria from the PLATINA II and PROMINENT projects are:

1. Effects on energy consumption and emissions
   - Impact shall be more than 5 % reduction of one emission type
2. Feasibility
   - Economic feasibility for the ship owner
   - Technical feasibility
3. Availability for mass implementation
   - Technological maturity
   - Non-technical maturity and other hindrances

5.2 Special criteria for the Danube

The GRENDEL criteria consider the special characteristics of the fleet on the Danube. The average age of the ships' engines is more than 20 years; therefore, the payback period for the recommended measures shall be reasonable. In general, the technologies shall be affordable while having a certain level of technological readiness or contribute greatly to the improvement of the ship's emission standard. Due to the fleet's age and the few newbuilding activities, the proposed actions shall be available for retrofit and newbuilding. In addition, the profit of the greening measure should be maximised compared to the investment.

Most ships only have limited space in the engine room, e.g. for pushers it is nearly impossible to convert to LNG due to the lack of space in the engine room, but also due to spatial limits for the equipment needed in addition and the greater volume of the tank. These conditions shall also be taken into account. Before any measure is chosen for a certain ship, the specific characteristics must be known.

With regard to the above-mentioned criteria the measures were chosen. This means e.g. that measures that have a high greening potential, but also require a very large investment, were excluded. On the other hand, easy measures, that only have a small greening effect, but an investment close to zero (e.g. reduction of deadweight by sorting out unnecessary spare parts) were included.

6 Greening long-list and short-listed measures for the Danube region

The greening long-list is composed by points out of the CCNR strategy as well as the PROMINENT project. The following categories were taken into account:

- Ship-related technical measures
  - Fleet structure
  - Fuels
  - Propulsion system (engine and propeller)
  - Hydrodynamics
  - Ship structure and weight
- Ship operational aspects
  - Sailing behaviour
  - Maintenance
- Education and Qualification

The measures for each category were evaluated under the aspects of emission reduction potential (CO_2, PM, NO_x, SO_x) compared to the current fleet, applicability to a share of the Danube fleet, the economic potential, payback period and the technological readiness level (TRL). Each aspect was given four levels which can be seen in Table 3.

Other than seagoing vessels, the diesel used for inland waterway transport on the Danube complies mostly with the EN 590 standard. This standard is the same as for road transport diesel, meaning that the sulphur content is no higher than 10 ppm. This means the main focus does not have to be on SO_x reduction, as emissions are generally already low.

Table 3: Levels of assessment criteria

Level	Emission reduction potential (CO_2, PM, NO_x) compared to current fleet [%]	Applicability on shares of the Danube fleet [%]	Economic potential payback period (ROI) [Years]	Technological Readiness Level (TRL) / Technological Maturity
1	≤ 25	≤ 25	> 20	1 to 3
2	> 25 to ≤ 50	> 25 to ≤ 50	10 to 20	4 to 5
3	> 50 to ≤ 75	> 50 to ≤ 75	5 to 10	6 to 7
4	> 75	> 75	≤ 5	8 to 9

Table 4 to **Fehler! Verweisquelle konnte nicht gefunden werden.** show the GRENDEL long-list of greening measures. This list consists of measures proposed by the CCNR, the PROMINENT project and the DNV GL. Not every measure is suitable for every ship even if it lies within the targeted group of the measure. The individual case must always be considered here. Table 7 shows the greening short-list. The chosen measures are rated to best meet the situation of the Danube.

Table 4: Greening long-list I

Type	Area	Measure	Emission reduction potential CO_2	Emission reduction potential NO_x	Emission reduction potential PM	Applicability on share of the Danube fleet (fleet applicability)	Economic potential payback period (ROI)	Technological maturity (TRL)	Non-technical maturity & other hindrances	Short listed
Infrastr.	Ports & Berthing locations	Shore side power	1	1	1	2	3	3		X
Ship-related technical measures	Fleet structure	Larger vessel units	4	4	4	3	2	4		
		More coupled convoys	1	1	1	3	3	4		
		Lengthening (+25 %; Europe type vessel)	1	1	1	3	4	4		
		Lengthening (+10 %; < Europe type vessel)	1	1	1	3	1	4		
	Fuels, standardised solutions	LNG (Liquefied Natural Gas)	2	4	4	1	1	3	financial support	X
		Drop-In fuels GTL/HVO/PTL	0	2	2	2	4	4	no bunker stations	X
		CNG	2	4	4	1	1	3	reg. & fin. support	X
		Emulsified fuels	1	2	2	2	4	4	financial support	X
		Fuel cells	4	4	4	1	1	1		X

Table 5: Greening long-list II

Type	Area	Measure	Emission reduction potential CO_2	Emission reduction potential NO_x	Emission reduction potential PM	Applicability on share of the Danube fleet (fleet applicability)	Economic potential payback period (ROI)	Technological maturity (TRL)	Non-technical maturity & other hindrances	Included in Danube Strategy
Ship-related technical measures	Propulsion system, engine solutions	Right sizing	1			2	2	4		
		SCR (selective catalytic NO_x red.)	0	4	0	2	2	4	financial support	x
		Diesel particulate filters (PM red.)	0	0	4	2	2	4	financial support	x
		Combined SCR and DPF (NO_x + PM red.)	0	4	4	2	2	4	financial support	x
		Stage V diesel engine	0	4	4	2	2	4	financial support	x
		Overhaul of existing engines	1	1	1	3	3	4		x
		Diesel-electric propulsion	1	1	1	2	2	4	financial support	x
	Propulsion system, propeller	Multiple propeller propulsion	1	1	1	2	n.a.	4		
		More efficient propulsors	1	1	1	2	n.a.	4		
		Adjustable tunnel apron	1	1	3	1	4	4		
	Hydro-Dynamics	Coupling point optimisation	1	1	1	2	5	4		
		Optimised hull dimension and form	1	1	1	3	n.a.	4		
		Duct strut removal	1	1	1	3	2	4		
		Remove flanking rudders	1	1	1	3	4	4		
		Alternative rudder concepts	3	3	3	2	1	4		
		Optimised trim and heel	1	1	1	1	n.a.	4		
		Optimised anchors, anchor pockets	1	1	1	3	n.a.	4		
		Optimised bow pump jet inlet	1	1	1	3	n.a.	4		
		Ducted propellers								x
	Ship structure & weight	Reduced dwt	1	1	1	1	n.a.	4		x

Table 6: Greening long-list III

Type	Area	Measure	Emission reduction potential CO_2	Emission reduction potential NO_x	Emission reduction potential PM	Applicability on share of the Danube fleet (fleet applicability)	Economic potential payback period (ROI)	Technological maturity (TRL)	Non-technical maturity & other hindrances	Included in Danube Strategy
Ship operational	Sailing Behaviour	Smart and energy-efficient navigation (speed adaption)	1	1	1	4	4	4		
		Automation	1	1	1	4	4	4		
		Smart and energy-efficient navigation (optimised track choice)	1	1	1	4	4	2	ECDIS charts essential	
		Smart steaming, just in time lock approach	2	2	2	4	4	4		
		Speed optimisation using decision support systems	1	1	1	4	4	2		x
		Journey planning optimisation	1	1	1	4	4	4		x
		Automatic channel guidance optimisation	1	1	1	4	4	2		
	Maintenance	Clean underwater bodies / hull / ballast/ bilges	1	1	1	4	3	4		
		Undamaged propellers	1	1	1	4	4	4		
		24/7 engine service contract	1	1	1	4	n.a.	4		
Education & Qualification		Awareness for energy-eff. Nav.	1	1	1	4	4	4		x
		Vocational training incl. E-learning	1	1	1	4	4	4		x

Table 7: Greening short-list on measures best meeting the Danube situation

Type	Area	Measure	Emission reduction potential CO_2	Emission reduction potential NO_x	Emission reduction potential PM	Applicability on share of the Danube fleet (fleet applicability)	Economic potential payback period (ROI)	Technological maturity (TRL)	Non-technical maturity & other hindrances
Ship-related technical measures	Fuels, standardised solutions	LNG (Liquefied Natural Gas)	1	4	4	1	1	3	financial support
		GTL/HVO fuel	1	2	2	2	4	4	no bunker stations
		CNG	1	4	4	1	2	2	reg. & fin. support
		Emulsified fuels	1	2	2	2	4	4	financial support
		Fuel cells	4	4	4	1	1	1	
	Propulsion system, engine Solutions	Selective catalytic reduction (SCR)	0	4	0	2	1	4	financial support
		Diesel particulate filters (DPF)	0	0	4	2	1	4	financial support
		Combined SCR and DPF	0	4	4	2	1	4	financial support
		Exchange of main diesel engine stage V	1	4	4	2	1	4	financial support
		Overhaul of existing engines	1	1	1	3	2	4	
		Diesel-electric propulsion	1	1	1	2	1	4	financial support
	Hydrodynamics	Ducted Propeller	1	1	1	3	1	4	
	Ship structure & weight	Reduced dwt	1	1	1	4	4	4	
Ship operational		Speed optimisation using decision support systems	1	1	1	4	4	2	
		Journey planning optimisation	1	1	1	4	4	4	
Education & qualification		Awareness for energy-efficient navigation	1	1	1	4	4	4	
		Vocational training incl. E-learning	1	1	1	4	4	4	

As the infrastructure is a whole new topic besides the vessels themselves and since the Danube region is primarily characterized by less developed regions and findings of GRENDEL have shown that there are currently no financial incentives available at the national level, topics of the Interreg-Danube database on innovative technologies like shore power are put aside here. Also, technologies that are nice to have but not directly related to emission reduction and air pollutants like ambient water transmission as well as a side by side propeller are due to the tight budget not looked at in more detail. Besides there are quiet some technologies not yet having an adequate readiness level like dual fuel hydrogen diesel combustion engines and hydrogen in combustion engines in general as well as innovative energy storage solutions. They are considered too costly while at the same time not yet having proven operational reliability to be used for the Danube region as of now.

Compared to the long list most maintenance topics are spared as maintenance contracts are costly and require additional personal not on-board the vessel. Also sailing behaviour related topics requiring a lot of additional electronical equipment are expected to be not suitable for the Danube fleet having a low investment capacity. Most measures related to hydrodynamics, fleet structure as well as the change of the overall propulsion system are not taken into account due to the low newbuilding activity in the Danube region.

7 Applicable most promising greening technologies

The core objective of the GRENDEL project is to give a lasting impulse to the modernisation process of the Danube fleet. With the Danube being considered as the economic backbone of a region that comprises 10 different European countries, adapting its severely outdated inland fleet to the needs and requirements of a future oriented transport system is an endeavour that must go beyond borders.

Even though IWT is considered as one of the most environmental-friendly modes of transport, it is by far not exploited at its full potential. The reasons for this are manifold. As mentioned before the Danube Region is primarily characterized by less developed regions, vessel operators in this particular case usually lack the necessary financial capacities to properly invest in their fleet. Moreover, there are currently no financial incentives available at the national level that would encourage the greening of the Danube fleet. The IWT sector is furthermore characterized by the relatively slow incorporation of innovative technologies as compared to other modes of transport.

On the short term this puts especially technologies in favour that require little change to existing systems. Therefore, **drop-in fuels** are very interesting as they do not require significant adaptation of the engine or the fuel system. The second generation biofuels like HVO are compatible with petroleum diesel and can be produced from many different sources and processes. **After-treatment** is also an innovative approach to reduce harmful effects on the environment that in addition provides the opportunity to be retrofitted to existing systems. As every engine produces harmful emissions, there are proven exhaust after-treatment technologies available today to very effectively reduce soot, NO_x, HC & CO. The noise level produced by the diesel engine is reduced by the muffler while PM are reduced by a filter (DPF), the gaseous pollutants like carbon monoxide (CO) and hydrocarbons (HC) need an oxidation catalyst and nitrogen oxides (NO/NO_2) require a SCR-system to be installed in order to keep the emissions low. The proper functioning is also dependent on the maintenance of the system as well as the fuels and lube oils quality. Another technology particularly suitable for retrofitting is **diesel-electric propulsion**. This provides the possibility to quickly change over to zero-emission technologies in a later stage and points with its low noise level and a lower impact on the environment as compared to conventional propulsion systems. Also **gas and gas-electric propulsion** have a lower environmental impact than conventional fuels. Besides this, there are efficient zero-emission technologies like **hydrogen fuel cell systems,** which are a sustainable solution for the transport and energy generation sector. Various energy sources can be used as fuel for fuel cells. Also **battery-electric propulsion** is at least locally free of emissions. Up to now it is particularly suitable for short distances. As a sustainable and reliable technology, it has the potential to be based on renewable energy with low to no environmental footprint.

Other technologies are **shore power for IWT** or so-called cold ironing, which has the advantage of neither noise pollution nor vibrations with at the same time low emissions. This is especially favourable in urban areas with high population density in the immediate neighbourhood. Another new sector is **autonomous shipping**, where adapted technological solutions meet new market requirements. Beside this there are topics like **ambient water transmission,** which is a new technology to lubricate gears with water instead of oil and therewith the potential to considerably reduce noxious elements. This goes along with another innovative project of a **side-by-side propeller,** that has the ability to operate at lower water levels (draught). **Dual fuel hydrogen diesel combustion engines** have a low emission rate and could contribute to pave the way towards a green revolution on the water. **Hydrogen in combustion engines** increases the efficiency and lead to a considerable reduction of harmful emissions. Moreover, **innovative energy storage solutions** are extremely useful for long distances. Especially technologies based on methanol require less storage space coupled with low maintenance costs. If the methanol is produced by renewable energy sources, no environmental footprint is left. As these innovative technologies, except for the shore power connection, which therefore requires a considerable amount of onshore infrastructure, are still in the development phase the focus is put to the topics mentioned in the paragraph above.

7.1 Gas and gas-electric propulsion

LNG as a fuel is a technologically proven and available solution. LNG offers advantages, especially for ships with a high energy demand and load factor which benefit from the lower energy costs. Conventional oil-based fuels will remain the main fuel option for most vessels in the near future, and, at the same time, the commercial opportunities of LNG are interesting for many projects. While different technologies can be used to comply with air emission limits, LNG technology is a smart way to meet existing and upcoming requirements for the main types of emissions (SO_x, NO_x, PM, CO_2). This section offers insight into gas and gas-electric propulsion, ranging from relevant regulations, technical concepts, information on economics and environmental sustainability as well as references to deployed examples.

REGULATIONS

Requirements governing the use of liquefied natural gas as a fuel for inland waterway vessels are set in the **European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN)** which is constantly updated.

Regulation (EU) 2016/1628 (NRMM) sets, so called, **Stage V emission limits** for new (main and auxiliary) engines placed on the market and installed in inland waterway vessels *(entering into force as of 1 Jan 2019 for engines with a reference power of less than 300 kW and as of 1 Jan 2020 for engines with a reference power including and above 300 kW)*. The Stage V calls for limit values for emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) for internal combustion engines installed in inland waterway vessels. The certification of engines to comply with Stage V limits is on-going and first certified engines are expected later in 2020[1].

The **classification societies** developed a set of safety criteria for gas as vessel fuel which are included in their rules and focus at minimising risks associated with building gas-fuelled vessels (dealing with propulsion, power generation and auxiliary systems, equipment and design features or development and operation of LNG bunkering facilities, etc.).

LNG FACTS

Liquefied Natural Gas (LNG) is natural gas (predominantly methane, CH_4) produced by cooling down the natural gas to minus 162°C, thus converting it to liquid form for ease of storage and transport.

Physical properties

Structure	More than 90 % methane (CH_4) with the rest mostly ethane, propane, butane, nitrogen. LNG shall not to be mistaken for LPG – Liquefied Petroleum Gas (mainly propane and butane).	Attributes	Odourless, colourless, non-toxic, non-corrosive
Temperature	-162 °C (-260 °F)	Flammability range	5-15 % of fuel-air mixture
Volume	1/600 of the volume of natural gas in gaseous form and 3.5 times more compact than compressed natural gas (CNG)	Behaviour if spilled	Evaporates, forming visible “clouds”. Portions of cloud could be flammable or explosive under certain conditions. A fuel-air mixture of about 10 % methane in air (about the middle of the 5–15 % flammability limit) and atmospheric pressure might be ignited if it does encounter an ignition source (a flame or spark or a source of heat of 1000 °F (540 °C) or greater).
Density	Between 430 kg/m³ and 470 kg/m³ (compared to water it is less than half		

[1] Status as per April 2020.

	as dense, which means that LNG will float on water if spilled)		Otherwise the vapour will generally dissipate into the atmosphere, and no fire will take place.
Conversion	1 ton LNG = 2.2 m³ LNG;		
	1 ton LNG = 15.2 MWh (GHV);	Energy density	21 MJ/l (diesel 36)
	1 MWh = 3.4121 MMBTu		

Environmental drivers

LNG contributes to significant reduction of sulphur oxides emissions (SO_x), nitrogen oxides emissions (NO_x), Particulate Matters (PM) and carbon dioxide emissions (CO_2) from engine exhaust emissions in comparison to traditional fuels.

In comparison to diesel:

- CO_2 reduced up to 25 % (for near zero methane slip)
- PM reduced nearly to 100 %
- NO_x reduced up to 90 %
- SO_x emissions up to 95 %

In comparison to LPG:

- Greenhouse gas emissions reduced by 15 %
- PM reduced by up to 10 %
- NO_x reduced by up to 50 %

The use of liquefied bio-methane further increases CO_2 performance of LNG at short term perspective. Currently ongoing exploration of next generation renewable gas production technologies such as the Austrian "Underground Sun Conversion" project will further diversify gas (fuel) market by offering synthetic gas produced from renewable sources.

TECHNICAL CONCEPT

The applied technical concept for the propulsion of inland ships depends on the vessel type, targeted speed and sailing profile. In order to be a case for gas and gas-electric propulsion, a vessel should meet one or more of the following criteria:

- Ships with a high energy demand and load factor benefit from the lower energy costs
- Operational area with a LNG bunkering infrastructure
- Pushers may benefit from LNG retrofitting in combination with lengthening of the hull.

ENGINE TYPES

LNG power offers a number of engine configurations for inland waterway vessels. The following engine suppliers offer LNG (gas)-powered engines: Wärtsilä, Caterpillar, MAK, Rolls Royce, MAN, ABC, MTU, Mitsubishi, Hyundai, DAIHATSU, Deutz, Scania, Agco Power and Dresser-Rand Guascor. These engine manufacturers each have their own engine configurations. More engines may become available in the future.

For LNG either a full gas-engine (Otto-cycle) or a dual-fuel engine (Diesel-cycle) can be used. In case of the dual-fuel engine, the ratio of diesel and gas is variable.

DUAL FUEL ENGINE (Diesel-cycle)

In dual-fuel mode, natural gas is fed into the engine's intake system. The air-natural gas mixture is then drawn into the cylinder, just as it would be in a spark-ignited engine, but with a leaner air-to-fuel ratio. Near the end of the compression stroke, diesel fuel is injected and ignites the natural gas. A dual-fuel engine can operate on pure diesel fuel or a mixture of diesel and natural gas, delivering the same power density, torque curve and transient response as the base diesel engine.

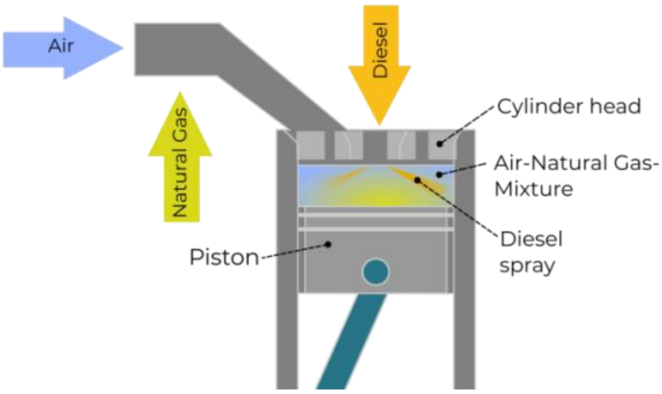


Figure 7: DUAL FUEL ENGINE (Diesel-cycle)

GAS ENGINE (Otto-Cycle)

Mono-fuel gas-engines work with the Otto principle and have a spark-ignition. They also have a different characteristic which is a bit more suited for gas-electric applications in gensets than for direct drives.

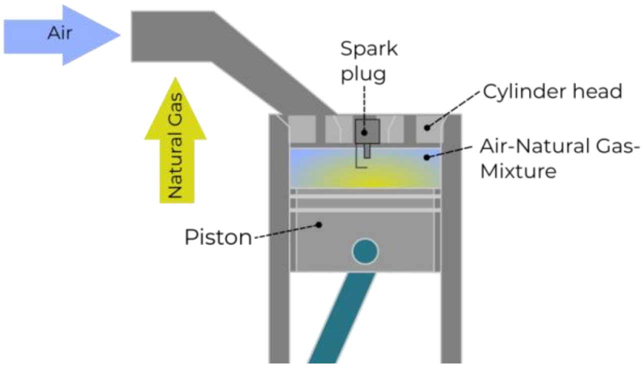


Figure 8: GAS ENGINE (Otto-Cycle)

PROPULSION CONCEPTS

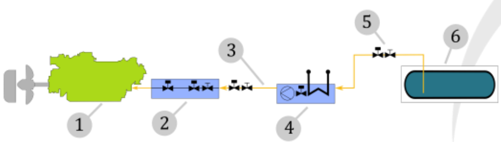
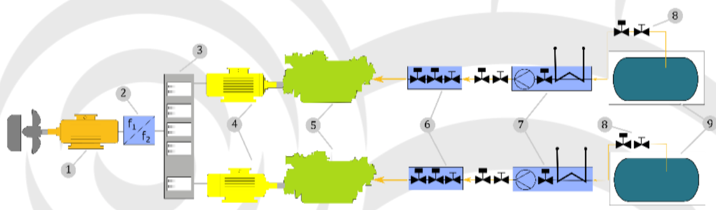
Basically, one can divide between direct drive and gas-electric driven propulsion concepts.

DIRECT DRIVE

The direct drive system with a gas engine is comparable to a diesel direct drive system. In the context of the required redundancy, it may be necessary to install two independent gas supply systems including a tank for multi screw vessels. A single screw vessel has the option to use the bow thruster (360° thruster) as redundant propulsion device in case the gas system fails. The bow thruster then also needs an independent energy source.

GAS-ELECTRIC SYSTEM

The design of the gas-electric system is comparable to that of the diesel-electric system: it uses gas gensets and electric drive motors. ES-TRIN 2019 requires a redundant electric energy source. One solution, the installation of two gensets is shown below. The gensets can be of different size.

Direct drive	Gas electric system
	

1. *Engine:* In the engine the gas is burned. The two main engine types are dual-fuel engines that run on diesel and gas and pure gas engines. In case of a dual-fuel engine, an additional diesel tank is necessary.
2. *Gas Valve Unit (GVU):* It controls the gas flow to the engine and can also perform an emergency stop.
3. *Pipes:* The pipes are double walled. The space between the inner and the outer pipes is flooded with Nitrogen. Each pipe has an automatic and a hand operated valve; sections of pipes also have a release valve. The automatic valves are closed at an emergency shutdown.
4. *Cold Box:* In the Cold Box the LNG is evaporated. Then the gas is pressurized. The energy (heat) for the evaporation often comes from the cooling water of other engines on board. This part of the installation is also known as gas treatment system.
5. *Safety Systems:* Pipes and tanks have safety valves to protect them from overpressure. All systems are redundant. This means that there are at least two individuals of each safety system in case one fails.
6. *LNG Fuel Tank*

1. *Electric Motor:* The electric motor drives the propeller at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted.
2. *Frequency Converter:* The frequency converter supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on board energy grid. The rotational speed of the electric motor is controlled, by varying the output frequency.
3. *Main Switch Board:* The main switch board distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion systems, hotel load, pump systems and so on. It could be designed as a single AC or DC rail, which can be separated in a starboard and portside system.
4. *Generator Set:* The generator set can consist of any combustion engine (e.g. diesel or LNG) and an electric generator. The combustion engine drives the generator to convert the chemical energy from fuels to electric energy. The generator can provide AC or DC power, depending on the selected main switch board and frequency converters.
5. *Gas or Dual-Fuel Engine:* In the engine the gas is burned. The two main engine types are dual-fuel engines that run on diesel and gas and pure gas engines. In case of a dual-fuel engine, an additional diesel tank is necessary.
6. *Gas Valve Unit:* The Gas Valve Unit (GVU) controls the gas flow to the engine and can also perform an emergency stop.
7. *Cold Box:* In the Cold Box the LNG is evaporated. Then the gas is pressurized. The energy (heat) for the evaporation often comes from the cooling water of other engines on board. This part of the installation is also known as gas treatment system.
8. *Safety Systems:* Pipes and tanks have safety valves to protect them from overpressure. All systems are redundant. This means that there are at least two individuals of each safety system in case one fails.
9. *LNG Fuel Tank*

EQUIPMENT FOR GAS POWERED INLAND VESSELS

Besides engines, special safety provisions (crew training, bunkering requirements) and additional equipment are required to propel an inland waterway vessel on LNG, like LNG tanks, systems for LNG withdrawal from a tank or a cold box.

LNG Tanks

Two different types of LNG tanks are available: Membrane Tanks and Pressure Tanks. For LNG as fuel only the Pressure Tanks (IMO Type C Tanks) are interesting. They are mostly cylindrical and have either foam or a vacuum insulation. For the vacuum insulation the space between the inner and outer hull is filled with perlite, an insulation material, then the vacuum is drawn. Another option is foam insulation; here the heat transfer is higher.

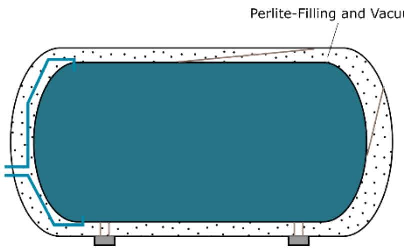


Figure 9: Pressure tank - vacuum insulated

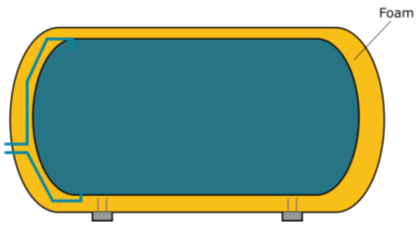


Figure 10: Pressure tank - foam insulated

Systems for LNG withdrawal from the tank

There are two different methods available to extract the LNG from the tank.

Cryogenic pump: The pump is suited for the low temperature of the LNG. Since cryogenic pumps are quite costly, this is not a widespread solution.

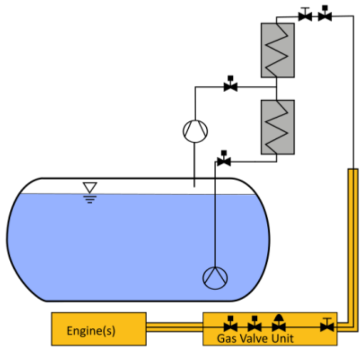


Figure 11: Cryogenic pump

Pressure-build-up system (PBU): The PBU consists of heat exchanger that evaporates a small amount of LNG. The resulting gas is fed back into the tank and the rising pressure then causes LNG to be forced out of the tank. The PBU system is a common solution for LNG on inland vessels.

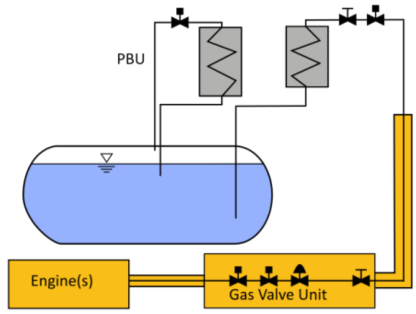


Figure 12: Pressure-build-up system (PBU)

Cold Box

In the cold box the LNG is prepared for the combustion in the engine. This means it is evaporated and adapted to the pressure that the engine demands. The complete components in the cold box are suitable for cryogenic temperatures. For insulations the cold box is often filled with perlite.

SPECIAL SAFETY & OTHER REQUIREMENTS

CREW SKILLS

The qualification "LNG expert" (Directive of the European parliament and of the council on the recognition of professional qualifications in inland navigation) is necessary for at least one crew member of an LNG powered vessel.

BUNKERING & BUNKERING INFRASTRUCTURE

Currently, a common temporary solution is LNG bunkering by LNG fuelling trucks. The fixed LNG bunkering infrastructure is under construction along the European waterways.

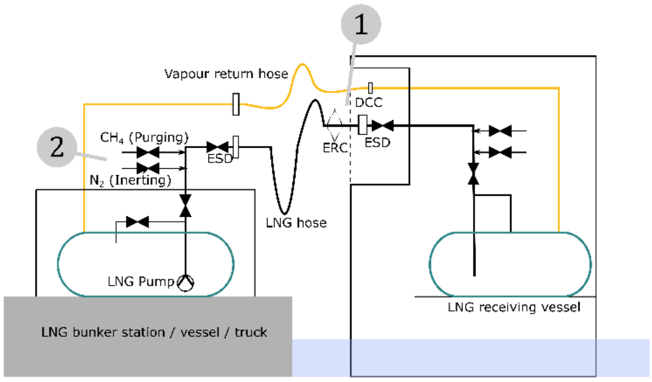
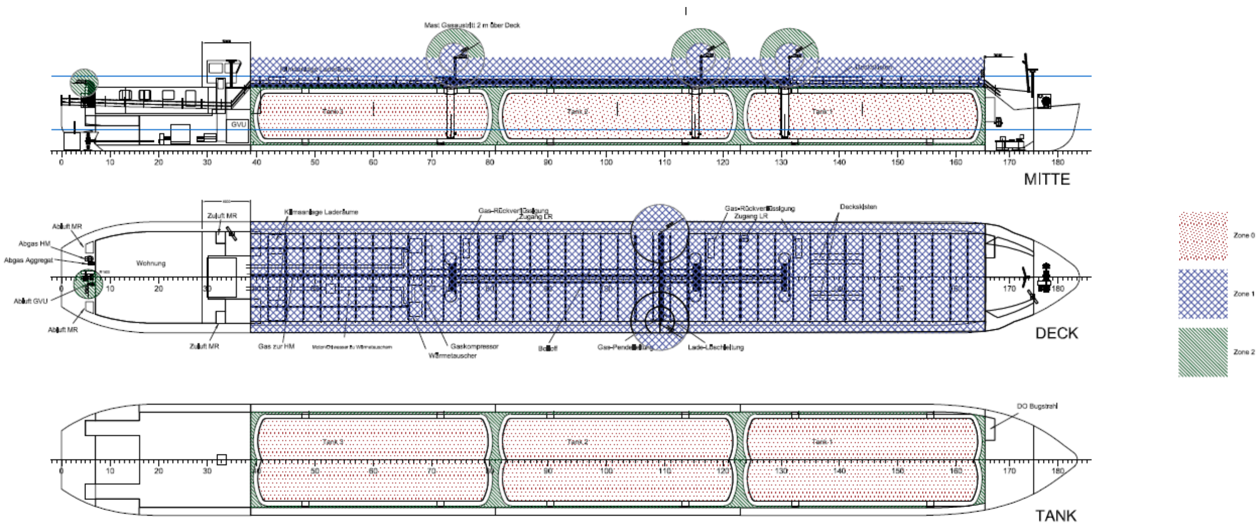


Figure 13: Bunkering scheme

1. The LNG is transferred via a flexible reinforced hose that is held and guided by a crane. The connection between the hose and the tank is made with a dry cryogenic coupling (DCC). The use of automatic and manually operated shut-off valves (ESD) is necessary to interrupt the charging process at any time. ESD valves have the effect of an emergency stop switch, i.e. they stop the entire charging process. The emergency release coupling (ERC) is the design breakpoint within the system. According to the regulations, the manual activation devices must be operated both on board and also be available on land.
2. Before the transfer starts, the transfer line is inerted with Nitrogen. Through the vapour return hose the bunker station takes back the gas in the fuel tank during filling. After the bunkering the LNG lines have to purged, to ensure no LNG remains there.

EX-ZONES

Once the vessel shall be equipped with an LNG-system, the establishment of ex-zones is mandatory and an important aspect of the safety concept. Especially for retrofitting it is important to plan the zones in an early stage. There are three different types of EX-Zones (1999/92/EC) illustrated for a LNG tanker with gas engines below:



Zone 0: Location where an explosive atmosphere is present continuously or for long periods or frequently.

Zone 1: Location in which an explosive atmosphere occurs occasionally during normal operation.

Zone 2: Location where an explosive atmosphere is not liable to occur during normal operation or, if it does, is only short-lived (foreseeable abnormal operation).

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

INVESTMENT COSTS

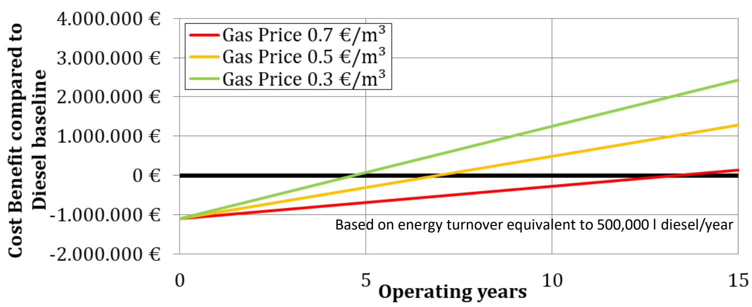
It is possible to convert diesel engines to use LNG as an alternative fuel. Alternatively, the old diesel engine is replaced by a new gas or dual-fuel engine. The investment is dependent on the engine power and size and type of ship. As a first estimate for an inland ship an investment for the whole LNG system of about 1.2 Mio € (2018) can be assumed. This includes the costs of an engine, a tank system and LNG preparation equipment like the cold box and installation. Operational costs are dependent on the LNG price development, the bunker contract and the general energy consumption of the vessel on its route. Due to the high investment, it is best to install the LNG on board of larger ships with high energy / fuel consumption.

The sailing range of an LNG-propelled vessel depends on the capacity of the fuel storage tank. For example, the ship EIGER-NORDWAND has a fuel storage tank with a capacity of 60 m^3 which enables the vessel to sail from Rotterdam to Basel and back (approx. 1700 km) without any refuelling. Currently, it is only possible to perform truck-to-ship bunkering at locations such as the ports of Amsterdam, Rotterdam, Antwerp and Mannheim. The fixed LNG bunker stations are under construction (shore-to-ship bunkering) in Cologne, Germany and in Antwerp, Belgium. In the Danube region, LNG is available in Ruse, Bulgaria (as of 2016) and will be available in Bratislava, Slovakia (as of 2020), in the near future in Hungary and Austria. With deployment of more LNG bunkering stations for inland vessels (in line with the Directive on alternative fuels infrastructure 2014/94/EU by 2030 in inland ports), a requirement for a big capacity tank will diminish.

Contrary to diesel, the quantity of LNG is being expressed in kilograms and not in litres. An indicative price estimate for a ton of LNG is 400 €[2]. LNG becomes an interesting economic alternative to diesel, when the yearly diesel consumption of the ship is in the range of 500,000 l (425 t).

Various European countries offer a subsidy programmes or public support schemes to retrofit inland vessels to LNG propulsion. Examples are France, Germany or the Czech Republic. A model State Aid scheme to be deployed in Danube countries is part of the outcomes of the project GRENDEL.

OPERATIONAL COSTS



The higher investment cost is earned back depending on the energy consumption and the price gap between diesel and LNG. The assumed diesel price in the example is 0.70 €/l. The green line indicates the optimistic scenario with an ROI after 4 years; the red line a pessimistic scenario with and ROI after 14 years.

ECONOMIC DRIVERS

- Price gap LNG – diesel reduces fuelling costs for barge operators. Price gap is expected to widen due to massive increase of LNG liquefaction in next few years and due to spot market developments.
- Cost reduction in fuelling results in higher profitability, lower transport costs and higher demand of inland water transport services.

[2] Estimated based on: www.dnvgl.com/maritime/lng/current-price-development-oil-and-gas.html

- Switch to LNG triggers modernisation of fleet and facilitates additional measures increasing energy efficiency.
- LNG can become a commodity (cargo) which needs transportation on European rivers.

CONSIDERATIONS FOR DEPLOYMENT

- Strongly dependant on the infrastructure that is yet under construction
- Certification of personnel
- Restrictive safety rules
- Risk assessment is necessary (e. g. HAZID study)
- Bunker process requires a checklist
- Mainly opportunity for vessels having a large fuel consumption per year
  - Benefit from savings in fuel costs to gain back high investment costs

7.2 Diesel-electric propulsion

The concept of electrical propulsion systems is not new. The first ships with diesel-electric propulsion were in operation as early as 1904 and the concept has obviously made a lot of progress since then. The future belongs to green propulsion technologies. Diesel-electric propulsion combines the high efficiency in matching use-cases, low noise levels and environmental sustainability due to potentially lower emissions. This section offers insight into diesel-electric propulsion, ranging from relevant regulations, technical concepts, information on economics and environmental sustainability as well as references to deployed examples.

REGULATIONS

Regulations for diesel-electric installations are set in the **European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN 2019)** which is updated regularly. If a classification of the vessel is necessary, there are also additional **rules from the classification societies available**. Due to the regulations a diesel-electric propulsion system must consist of at least two generator sets, one main switch board, one frequency converter and one electric motor on the propeller shaft. One of the generator sets must be able to ensure a safe ship operation for at least 30 minutes in case of a failure of the second generator set.

The emission limits of the diesel engines, which are used to drive the electric generators, are put into force in 2019, and 2020 for larger engines respectively, according to **Regulation (EU) 2016/1628 (NRMM)**. To comply with the emission limits, it is possible to add an exhaust gas after-treatment to the diesel engine (see section 7.3 for exhaust gas after-treatment technologies).

Looking towards future technologies, it is possible to **combine diesel generators with batteries or fuel cells**. In case of using an alternative energy source, the energy source must comply with the same regulations on safety and redundancy as a diesel generator: at least two independent energy sources must be installed on board, each of them providing enough energy to achieve the vessel's minimum required manoeuvrability for at least 30 minutes.

TECHNICAL CONCEPT

The applied technical concept for the propulsion of inland vessels depends on the vessel type, targeted speed and sailing profile. To benefit from a conversion to diesel-electric propulsion, a vessel should meet one or more of following criteria:

- High electrical power demand with high degree of varying loads
- High degree of partial load for propulsion

- High comfort demands
- High demands towards redundancy
- High demands towards manoeuvrability

A diesel-electric drive train consist of energy sources, switch boards, electrical control units and electric main propulsion motor(s). A common setup of a diesel-electric drive train is shown in the figure below.

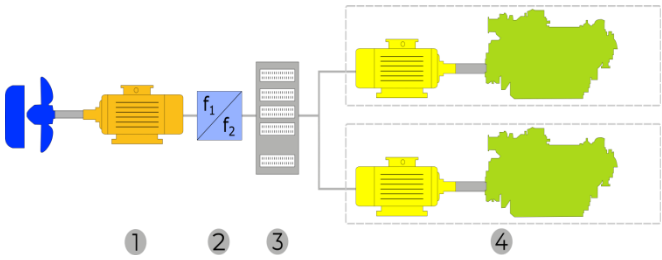


Figure 14: Setup of a diesel-electric drive train

1. *Electric Motor:* The electric motor drives the propeller at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted.
2. *Frequency Converter:* The frequency converter supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on-board energy grid. The rotational speed of the electric motor is controlled by varying the output frequency.
3. *Main Switch Board:* The main switch board distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion systems, hotel load, pump systems and so on. It could be designed as a single AC or DC rail, which can be split into a starboard and portside system.
4. *Generator Sets:* Each generator set can consist of any combustion engine (e. g. diesel or gas) and an electric generator. The combustion engine drives the generator to convert the chemical energy from fuels to electric energy. The generator can provide AC or DC power, depending on the selected main switch board and frequency converters.

ENGINES FOR DIESEL-ELECTRIC PROPULSION

Any type-approved diesel engine for inland ships (NRMM Stage V category IWP/IWA or NRE and Euro VI truck engines after appropriate marinization) can be used. In combination with an electric generator, the system is known as genset (generator set). The diesel engine must comply with relevant regulations and provide enough power to drive the generator. For the electric propulsion motors different types are applicable.

ASYNCHRONOUS MOTOR	**SYNCHRONOUS MOTOR**
The asynchronous motor is the most widely used industrial motor. It can be connected directly to the three-phase mains and is very robust and easy to build. The asynchronous motor takes its name from the fact that it does not rotate exactly with the mains frequency. It only has a torque if its speed	For synchronous motors, the speed of the motor is equal to the mains frequency divided by the number of pole pairs. The rotor of a synchronous motor is permanently magnetized and follows the rotating field of the stator. Usually, the

deviates from the synchronous speed. In the operating range, the torque is proportional to this deviation. This type of electric motor is characterized by low investment costs and small dimensions. Its nominal rate of revolutions is usually too high to be used as a direct drive. A gearbox between electric motor and propeller shaft is necessary. The gearbox increases the investment costs, lowers the efficiency of the drive train and could be a point of failure. If the advantages of asynchronous motors and the disadvantages of the gearbox are balanced correctly, a cost and energy efficient drive train can be designed.

speed is given in revolutions per minute (rpm). This type of electric motor is characterized by high energy efficiency, low nominal rate of revolutions and a good torque/speed characteristic. This motor can be used as a direct drive, without a gearbox between motor and propeller shaft. Its large outer dimensions are disadvantageous like the high investment costs. Using a synchronous electric motor for the propulsion system leads to an efficient drive train with a sensitive control.

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

In contrast to direct drives, the propeller of the diesel-electric propulsion is operated by an electric motor, which draws power from a diesel generator. Since the genset can be replaced by other energy sources like a gas genset, a battery or a fuel cell system, this concept can be regarded as a bridge technology. Another advantage of the diesel-electric concept is that the gensets are produced in larger quantities than engines for inland waterway vessels, which can result in a financial advantage.

INVESTMENT COSTS

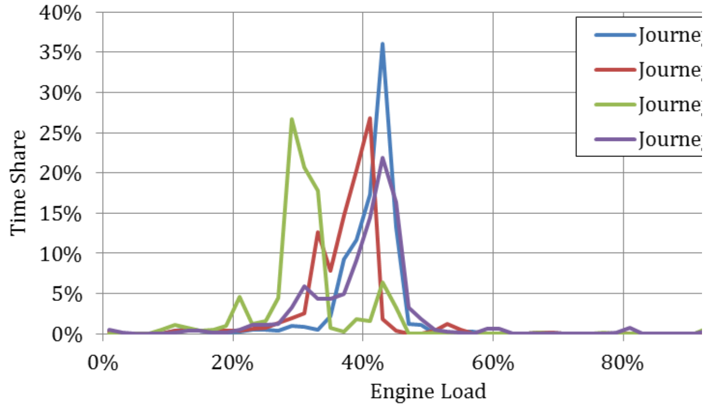
With a diesel-electric drive, additional costs incur for the electric motor, frequency converter and extended main switchboard. In the layout of the drive train it is aimed for matching the distribution of power with the operational profile so that diesel generators are either used in their sweet spot or not running.

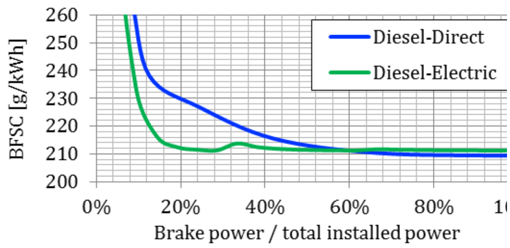
Cost Category	Costs in EUR
Gensets	350 EUR/kW
Electric motor	120 EUR/kW
Installation costs	30,000 EUR for conversion, wiring and power management

ECONOMIC OPERATIONS

Depending on the operational profile, diesel-electric propulsion can significantly **reduce energy consumption and emissions** since it makes it possible to adjust propulsion needs to actual operational conditions. While direct drives have to cover the whole power range, diesel-electric drive trains consist of at least two gensets with suitable distribution of power. This allows using diesel engines more efficiently by switching off a genset when it is not needed. This leads to optimised loads of the engines. Due to the better fuel efficiency of the diesel engines at the optimum load, the operational costs and emissions are decreased with the reduced fuel consumption.

A common example for partial loads is the difference between upstream and downstream sailing. Most downstream sailing vessels only need less than half of the power needed upstream. When the vessel is sailing downstream at least one genset can be switched off. Other ships have an operational profile similar to the left plot below. Here engine loads were measured over several journeys including upstream, downstream and canalized sections without currents. Most of the time the vessel is operating at engine loads of less than half of the installed power. Only on small sections of the waterways and for emergency stops the full power is required.





Power [%]	Weighting E2/E3
100	0.20
75	0.50
50	0.15
25	0.15

In these cases, the additional losses of energy conversions are overcompensated by the reduced fuel consumption of gensets either running in their sweet spot or stopped. The small plot on the right-hand side above shows the specific fuel consumption over the whole load range of a single diesel engine (blue) and a setup of three smaller gensets (green) including all losses. The overall efficiency of the diesel-electric setup is higher up to 55 % load.

The table on the right-hand side contains the test cycles E2 (constant engine rates) and E3 (variable rates) according to ISO 8278 used for the type approval of engines. For each of the four power levels a weighting factor is given. These weighting factors represent the relevance of the engine's working point for certification. Use-cases with an operational profile similar to this distribution are usually more energy efficient with a conventional direct drive and do not benefit from a diesel-electric setup.

BENEFITS

- Engines running in their sweet spot
- Low noise and reduced vibrations
- Increased efficiency for suited operational profiles
- Lower emissions of air pollutants
- More flexibility to generate auxiliary energy
- Easier implementation of batteries and fuel cells
- Additional freedom for engine positioning
- Trend to better manoeuvrability
- Highly redundant designs possible

DOWNSIDES

- Additional losses
- Higher weights
- Increased space requirements
- Higher investment costs

CONSIDERATIONS FOR DEPLOYMENT

Conventional direct propulsion layout is limited to the selection of a proper main engine matching the power demand and the propeller characteristics. Electric propulsion systems need to be designed specifically for the individual use-case. A detailed knowledge of the operational profile helps to distribute the total power over the gensets. The power management links the complete system taking into account the dependencies between the various components. To obtain a functional propulsion system, it is recommended to acquire the complete electrical system from the same provider.

The electrical system increases the weight of the machinery. This can be offset by less fuel being transported and / or the arrangement of components in different places. If a ship is suitable to retrofit a diesel-electric system also depends on the available space and the mechanical integration of the electric engine with the existing engine base.

In the case where batteries are included in the system, the design also involves providing space for the battery (20 % of the installation as a first estimate) and the safety elements (ventilation, battery temperature control, etc.). The battery packs can also be used to optimize the weight distribution and reduce ballast requirements without affecting operability at very low water levels too much.

7.3 After-treatment

Diesel engines emit exhaust gas, which includes poisonous components, such as nitrogen oxide (NO_x), sulphur oxide (SO_x) and particulate matter (PM) causing environmental pollution and damage to human health. In line with the EU's air quality policy, the objective is to progressively reduce the emissions from new engines being brought on the market and, thereby, replace the old, more polluting ones over time. For these reasons, the Regulation (EU) 2016/1628 enforces more stringent limits to gaseous and particulate pollutant emissions, so called Stage V, for engines being used for inland vessels. With this emission regulation after-treatment solutions will be required for diesel-propelled inland waterway vessels in the future. This section offers insight into after-treatment solutions, ranging from relevant regulations and technical concepts to information on economics and environmental sustainability.

REGULATIONS AND SOLUTIONS IN DEVELOPMENT

REGULATIONS

The requirements relating to gaseous and particulate pollutant emissions for Stage V engines are regulated in Regulation (EU) 2016/1628. Amongst other engines for non-road machinery it is relevant for the categories IWP (engines for inland waterway vessels propulsion), IWA (auxiliary engines for inland waterway vessels) and NRE (non-road engines that may replace IWA and IWP engines with less than 560 kW). The emission limits for CO, HC, NO_x and particle mass are greatly reduced. In addition to the reduction of the particle mass the new regulation restricts the number of particles for larger engines. In order to meet the new emission standard, technical solutions will become more complex. Internal combustion control concepts were up to now largely sufficient to comply with the emission limits. To fulfil the emission limits in the future, external device technologies will be required. For the reduction of NO_x in the exhaust gas of diesel engines a **S**elective **C**atalytic **R**eduction (SCR) with an additional catalytic stage for CO and HC will be a possible choice. Sulphur oxide is toxic for most catalyst. Therefore, the fuel used with these technologies should harmonise with the standard EN 590 for diesel. To reduce particle mass and particle number a **D**iesel **P**article **F**ilter (DPF) system will be necessary.

SOLUTIONS IN DEVELOPMENT

Not all details how to meet the Stage V emission limits in inland waterway vessels are fully clear today. However, three options are considered:

Solution 1 lies with the engine manufacturers

It is expected that some engine manufacturers will come with an overall solution: a combination of a diesel engine with after treatment, where the engine manufacturer is the responsible party. With this solution the vessel operator will get a NRMM Stage V emission certificate on an ex-works basis, whereby there is no need for emission tests on-board.

Solution 2 lies with the suppliers of after-treatment

It is expected that some suppliers of SCR catalysts and DPF will come with an overall solution: after-treatment combined with a diesel engine, where the supplier of the SCR catalyst and diesel particulate filter is the responsible party. With this solution the vessel operator will receive a NRMM Stage V emission certificate on an ex-works basis, whereby there is no need for emission tests on-board.

Solution 3 lies with emissions measurement systems on board

It is expected that as an alternative optimisation solution the vessel operator can meet the Stage V emission limits with an existing diesel engine in the near future. This scenario could eventually serve as a transition solution for example, by adding an EU Stage V ready SCR catalyst and diesel particulate filter combined with on board emission monitoring, measuring emissions in real time, whereby the vessel operator can demonstrate the level of emissions.

TECHNICAL CONCEPT

Emissions from inland vessels using combustion engines contain several components which must fulfil limits. To fulfil these limits different exhaust gas after-treatment technologies will be used. In the following four technologies are presented which contribute to the compliance with the limit values of Stage V.

AFTER-TREATMENT TECHNOLOGIES

Exhaust gas recirculation (EGR)

The **nitrogen oxide (NO_X)** concentration in the exhaust gas of a diesel engine is reduced by the **Exhaust gas recirculation (EGR).** The concentration of NO_X depends on the production rate of NO_X which grows exponentially with rising temperature. To **reduce** the peak temperature and the oxygen concentration a part of the exhaust gas is returned to the combustion chamber. This effect could be enhanced by cooling the recircled exhaust gas. Lowering the combustion temperature to reduce the NO_X concentration is limited, because the production of soot particles is favoured at lower temperatures and the engine power is affected. In addition, a residue of HC and CO remains in the exhaust gas.

Diesel oxidation catalyst (DOC)

To remove the residue of HC and CO from the exhaust gas by about 90 % a **Diesel Oxidation Catalyst (DOC)** is used. With the after-treatment component DOC the HC and the CO are oxidized into water (H_2O) and carbon dioxide (CO_2). In combination with the EGR the exhaust gas will be influenced for further after-treatments like SCR and DPF. The process conditions in the DOC are not suitable to degrade the NO_X concentration by reduction.

Diesel particle filter (DPF)

A **Diesel Particle Filter** reduces the particle matter from the engine exhaust gases. In addition, for Stage V engines the number of particles leaving the DPF is restricted by a number of 1.0e12 particles per kWh. The size of the counted particles is larger than 23 nm. Separating the particles from the exhaust gas is done by flowing through a porous material. The separated particles reduce the flow through the DPF and change the pressure difference between in- and outflow of the DPF. At a maximum pressure difference the collected particles must be removed by changing the filter or filter regeneration. During the filter regeneration the collected particles, mainly soot, are burned to clean the filter. Afterwards the clogging particles are removed, the pressure difference is changed and the operational condition of the DPF is normalized. The ash residue increases with each filter regeneration. The increase of ash is much slower than the growth of soot and therefore the time is much larger until the filter is plugged with ash. If possible, the filter could be cleaned or it must be replaced. To start the filter regeneration a higher temperature is needed. This can be done by heating or a catalyst in combination with injecting fuel in the exhaust stream to initialize the burning of soot. The **separation of soot** is **more than 90 %**.

Selective catalytic reduction (SCR)

To reduce the NO_X concentration at the exhaust gas a **Selective Catalytic Reduction** technology can be used. A reagent is injected in the exhaust gas before entering the SCR which starts a chemical reaction to convert nitrogen oxides, with the aid of the reactant as catalyst, to **diatomic nitrogen (N_2)** and **water (H_2O)**. **Ammonia (NH_3)** is suitable but toxic. Therefore, the handling will be problematic on board. To avoid these problems a urea-water solution (AdBlue) is used as reagent, which is not classified as dangerous good. After injecting the urea in the exhaust gas the Ammonium is built by dissociating the urea. Afterwards the NO_X is oxidized to N_2 and H_2O. The dosing of the urea is important. At low urea concentration the NO_x emission rises, because not all NO_X could be oxidized. If the urea dosing is too high the toxic NH_3 leaves the SCR. The usage of urea raises the operational costs. The **NO_X** emissions can be **reduced from 70 % up to more than 90 % depending on the system and configuration.**

Combinating After-treatment technologies

The exhaust gas after-treatments explained above must be combined to fulfil the Stage V emission standard. This is usually done in the following sequence: EGR, DOC, DPF and SCR.

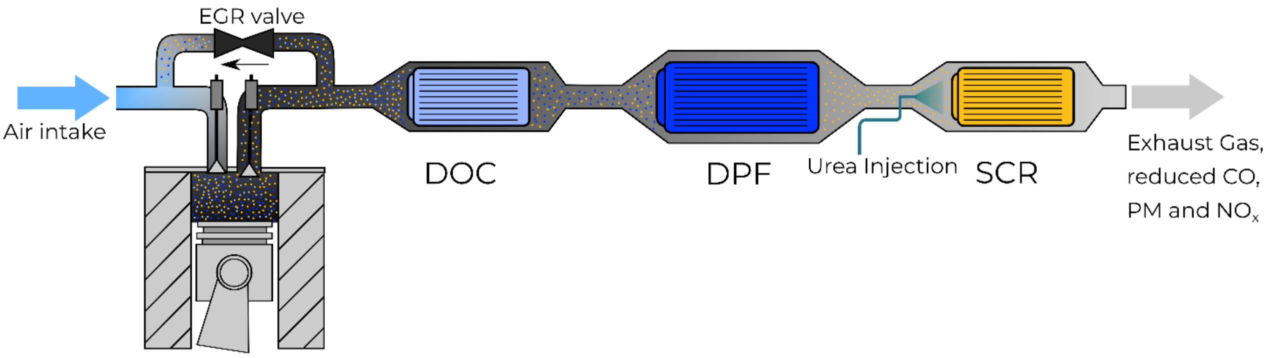


Figure 15: Exhaust after-treatment system with EGR, DOC, DPF and SCR.

Current developments aim at a combination of DOC and DPF in one component. The component could be more compact and therefore needs less space. For retrofitting combinations of DOC, DPF and SCR are thinkable, depending on the emission standard of the installed main engine and other prerequisites.

AFTER-TREATMENT DESIGN

The design of after-treatment systems depends on prerequisites like:

- Exhaust gas temperature
- Allowable back pressure of the engine
- Operational profile (e. g. operational hours)
- Available space in engine room or on the deck
- Mass flow rate of exhaust gas
- Engine maintenance condition

Figure 16: Pictures of exhaust plumes (left: engine reversing, right: typical appearance at steady state operation)

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

Reduction of emissions improves the health protection of the crew or passengers in inland waterway transportation. In addition, emissions in ports and urban areas are reduced, which is an intensively discussed topic in public.

The costs for deployment of after-treatment technology on inland vessels are influenced by a number of factors. The investment in eventually needed exhaust technology for newly built ships and new engines to reach the NRMM limits is beyond question. For retrofitting, the question arises as to whether a return on investment can be achieved. In the framework of the H2020 project PROMINENT[3] calculations for investing in exhaust gas after-treatment for different representative journeys in the Rhine or Danube region were made (*PROMINENT Deliverable D2.2*). This was done for investing into SCR only or in the combination of SCR and DPF technology. In none of the examined business cases the return of investment was reached. Financial incentives are therefore needed to reduce emissions from existing vessels.

INVESTMENT COSTS

Investment costs are provided for an example of combination of DPF and SCR for an inland vessel with a CCNR 2 engine with an engine power of 750 kW in the following table. Alternatively, a rough estimation can be made based on the engine displacement with 2 EUR/cm³ for each SCR and DPF.

Cost Category	Costs in EUR	Comment
System costs	100,000 EUR	Depending on number of DPF and SCR modules
Basis system	25,000 EUR plus 100 EUR/kW installed	
Installation costs	20,000 EUR plus one week at shipyard	

[3] www.prominent-iwt.eu (EU Horizon 2020 project from 2015 to 2018)

OPERATIONAL COSTS

Maintenance and operational costs for the example above (combination of DPF and SCR with a CCNR 2 engine of 750 kW) are estimated as follows:

Cost Category	Costs in EUR
Maintenance	6,000 – 10,000 EUR/year
AdBlue consumption	approximately 5 % of fuel consumption
AdBlue costs	0.20-0.50 EUR/l which is approximately 25 EUR/1,000 l diesel

ENVIRONMENTAL SUSTAINABILITY

Depending on the engine, operational profile and other prerequisites exhaust after-treatment can reduce air pollutants massively. Fuel consumption and the coupled CO_2 emissions remain constant or can even be lowered by optimization of engine control parameters. For example, most CCNR 2 engines are optimised to reach emission limits without after-treatment at the cost of reduced efficiency. The after-treatment system allows to regain efficiency. For proper use-cases, i. e. suitable operational profile with sufficient exhaust temperatures, suitable engine in terms of back-pressure limits and sufficient space/heat discharge capacity, retrofitted after-treatment systems are a very effective measure to improve the environmental performance of inland ships.

BENEFITS

Reducing emissions leads to further qualitative and quantitative benefits and advantages like the reduced dues listed below. These enable a return on investment which is increased with the number of participating ports, service providers or waterway authorities:

- Owner of the Green Award Inland shipping certificate e.g. benefit from reduced port rates or other advantages. The following list is incomplete (Full list of incentives at www.greenaward.org).
  - Reduction of harbour dues e.g. in
    - Port of Amsterdam, Port of Zaanstad 5 – 20 %
    - Port of Rotterdam 15 – 30 %
    - Port of Utrecht 30 %
    - Port of Papendrecht, Port of Werkendam 15 %
    - Zeeland Seaport Terneuzen 10 %
    - Port of Ghent 10 %
  - Reduction of services or products of several suppliers
- At 2019 the port of Hamburg discounts to reward particularly environmentally conscious behaviour. (Pricelist Inland shipping of port of Hamburg)
- In 2025 some parts of the port Rotterdam will be closed for inland waterway vessels with emission standard lower than CCNR 2 (see www.portofrotterdam.com).
- Reduced port dues are given at the port of Antwerp in 2019 (see www.portofantwerp.com) for inland vessels which
  - comply with the Stage V emission standard: 7 % reduction
  - have been built before 2008 and are equipped with a CCNR 2 engine: 7 % reduction
  - make use of a diesel-electric main propulsion in which the diesel engine adheres to the emission standards of the CCNR 2 norm: 15 % reduction
  - make use of a LNG or dual fuel motor (LNG used as main fuel using diesel as ignition fuel) as main propulsion: 15 % reduction

- make use of an electric motor driven by fuel cells with hydrogen as fuel: 15 % reduction

CONSIDERATIONS FOR DEPLOYMENT

INSTALLING NEW ENGINES

For inland waterway vessels the Regulation (EU) 2016/1628 defines the Stage V categories IWP and IWA of engines. Emission limits for new engines with a reference power lower or equal to 300 kW are effective from 01 January 2019 and for a reference power larger than 300 kW from 01 January 2020. Apart from limited exceptions new engines put into service after these dates will have to comply with the new limits, which usually can only be reached with exhaust gas after-treatment. However, today no IWP/IWA engines have the Stage V type approval yet. For engines with reference power lower than 560 kW it is allowed to install engines of type NRE instead of IWP. Also, EURO VI truck engines may be installed in inland ships. How far marinization of NRE engines and EURO VI truck engines affects the type approval is currently being clarified. The emission limits for these replacement options are lower or equal to the ones for IWP engines.

EXHAUST AFTER-TREATMENT UNCERTAINTIES

During the type approval engine and exhaust after-treatment are combined as unit. It is allowed to distribute the engine without the exhaust after-treatment which was installed during type-approval. The new exhaust after–treatment was therefore not tested during type-approval with the engine. This leads to uncertainties.

The manufacturer, the owner of the type-approval certificate, is responsible to give all relevant information and instructions that are necessary for the correct installation of an engine in non-road mobile machinery, including a description of any special conditions or restrictions linked to the installation or use of engine. This includes the exhaust gas after-treatment devices. Now, based on the prescribed procedure the after-treatment is replaced. There could be differences in the material of the SCR or the filter material of the DPF.

Who is responsible to ensure the emission standard?

- In case the new configuration fulfils the emission standard, the manufacturer is the owner of the type-approval.
- If the new configuration misses the emission standard, then the new manufacturer is the one who modified the system.

7.4 Fuel cell propulsion

This section offers insight into various applications of fuel cells for propulsion and auxiliary power in inland ships. Hydrogen storage options and alternative energy carriers are presented with their pros and cons in brief. Information ranges from relevant regulations, technical concepts including benefits and downsides to recommendations for further reading.

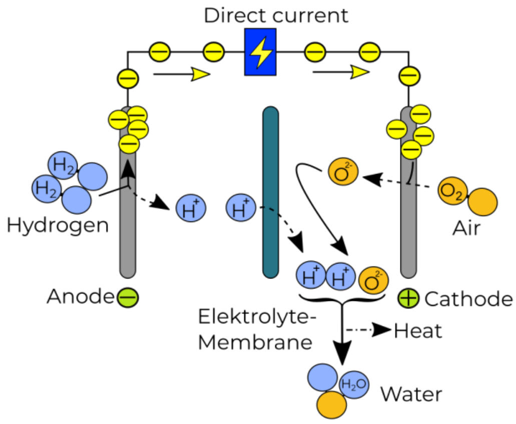
REGULATIONS

The **European committee for drawing up common standards in the field of inland navigation (CESNI)** does not consider the installation of fuel cells in its current regulation **for European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN - 2019/1)**.

The **ES-TRIN** requires that all electrical installations on board must be designed for a constant inclination of 15°. In addition, the energy supply must in principle consist of at least two energy sources. If one energy source fails, the remaining energy source must be able to provide the required energy for at least 30 minutes. This means that either the fuel cells have to be divided into (at least) two systems including the fuelling system or a battery with sufficient capacity needs to be implemented.

Classification societies like DNV GL have already guidelines for the installation of fuel cells since 2016. The predecessor Germanischer Lloyd has had regulations for the use of fuel cells since 2002 and they were the first classification society to think about this topic.

FUEL CELL FACTS



Fuel cells are energy converters that continuously convert the chemical energy of the fuel, such as hydrogen, natural gas or methanol, into electrical energy and thermal energy (heat losses) using an oxidant such as oxygen. The fuel cell can supply electricity as long as suitable fuel is available.

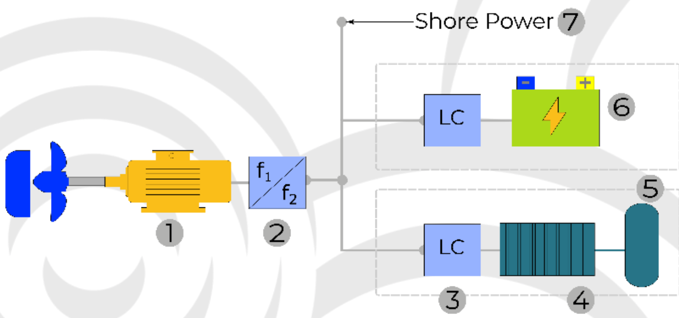
The principle of the fuel cell was invented in 1838, however the first commercial use of fuel cells came more than a century later in NASA space programs to generate power for satellites and space capsules. Since then, the improvement of the fuel cell began and nowadays they are used in many other applications, e. g. for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. The second most important application for fuel cells is as a power source for vehicles of all kinds.

With fuel cells local emission-free power generation is possible. The comparison of a fuel cell with a conventional internal combustion engine shows that no mechanical stress on components takes place because no fuel is burned. This results in no wear, vibration or generation of noise.

TECHNICAL CONCEPT

The electric motor (1) drives the propeller with constant rpm at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted. The frequency converter (2) supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on board energy grid. The rotational speed of the electric motor is controlled by varying the output frequency. The main switch board (3) distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion system. The fuel cell (4) provides the base load. The fuel is stored in the tank (5). Peak loads are absorbed by the battery (6) which can be charged either by the fuel cell or via shore power (7).

FUEL CELL TYPES



The following diagram shows the basic conversion process in a fuel cell using the example of hydrogen as a fuel.

BASIC WORKING PRINCIPLE OF FUEL CELLS

All fuel cells consist of two electrodes - the anode and the cathode. These are separated by an electrolyte with an ion-permeable membrane. After the fuel has been supplied to the anode, it is divided into electrons and protons. The free electrons flow into an outer circuit between the anode and cathode to be used as an electric current. The protons spread through the electrolyte to the cathode. At the cathode, the oxygen from the air combines with the electrons from the outer circuit and protons from the electrolyte. This results in water and heat.

Several fuel cells in a row make up a fuel cell stack. The number of individual cells that are connected in series can be used to variegate the performance of the stack and adapt it to the respective requirements.

All fuel cell types are based on the reaction of a fuel with oxygen. The electrochemical reaction generates basically electricity, heat and water. From the fuel cell, the electricity is provided as direct current (DC). If alternating current (AC) is required for further use, DC from the fuel cell is routed to an inverter is converted there to AC.

CLASSIFICATION OF FUEL CELLS

Basically, fuel cells are classified according to their operating temperature and the type of electrolyte used in the fuel cell. The following fuel cells are particularly interesting for inland waterway vessels:

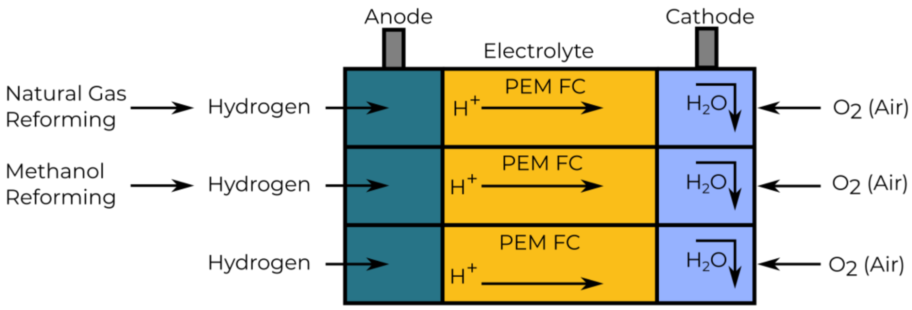
LOW TEMPERATURE PROTON EXCHANGE MEMBRANE FUEL CELL (LT-PEMFC)	HIGH TEMPERATURE PROTON EXCHANGE MEMBRANE FUEL CELL (HT-PEMFC)	SOLID OXIDE FUEL CELL (SOFC)
PEMFC uses a water-based polymer membrane as electrolyte, H_2 as fuel and O_2 as oxidant. The operating temperature is < 100°C. Due to the low temperature, only pure hydrogen can be used in PEMFC. The by-products besides electricity are water and heat. The fuel cell can be started cold without pre-heating to the operating temperature.	If the operating temperature is significantly exceeding than 100°C, PEMFC is used. These can reach up to 200°C and used mineral acid electrolyte instead of a water based one. The fuel cell must first be brought to operating temperature before it functions properly.	SOFC contains a solid electrolyte. From an operating temperature of approx. 650°C, this so-called oxide ceramic conducts the hydrogen ions through it. Some devices reach a temperature of 1,000°C. SOFC is one of the high-temperature fuel cells. An internal reforming of natural gas to hydrogen takes place in SOFC itself.

Technology	SOFC	LT-PEMFC	HT-PEMFC
Common size	1 kW-10 MW	1-100 kW	< 30 kW
Fuel	Hydrogen, Methanol, Natural gas	Hydrogen	Hydrogen, Methanol, Natural gas
Emission	CO_2, low levels of NO_X	-	CO_2, low levels of NO_X
Efficiency	60-65 %	50-60 %	50-60 %

All fuel cell systems produce neither SO_2, fine dust particles nor soot. They usually have between 10,000 and 20,000 operating hours, but the fuel cell providers are currently aiming for 30,000 h.

ENERGY SOURCES

Various energy sources can be used as fuel for fuel cells. Often hydrogen, methanol or natural gas is used.



HYDROGEN

Hydrogen (H_2) is gaseous under normal conditions (0°C and 1 bar) with a density of 0.0899 kg/m^3. Hydrogen can be transported as compressed gas or liquid and is the most commonly known chemical element. The most advanced processes for the production of hydrogen are reforming and water electrolysis.

When hydrogen is used in the PEMFC, attention must be paid to hydrogen purity. In principle, any hydrogen contamination can impair the performance and service life of the fuel cell system. The required purity is particularly difficult to achieve during the reforming process from natural gas or methanol. The hydrogen purity should be above 99.99 Vol.-%.

Liquid Organic Hydrogen Carrier (LOHC) is a chemical hydrogen storage. With the help of liquid hydrogen carrier materials, large quantities of hydrogen can be saved, stored and transported without loss and under ambient conditions. The resulting LOHC+ is non-toxic and does not have to be classified as dangerous goods. The existing conventional fuel infrastructure can be used for the transport, whereby no evaporation of stored hydrogen takes place (storage for several months without losses possible). During dehydrogenation a further catalytic reaction takes place, which releases the hydrogen molecules from the carrier liquid. The LOHC-, which is a remaining product, no longer contains hydrogen and must be collected and stored in a separate tank for further use and reloading with hydrogen. The hydrogen can be used as fuel for a fuel cell. The LOHC can bind more hydrogen per litre than the same amount of compressed gas at 700 bar.

METHANOL

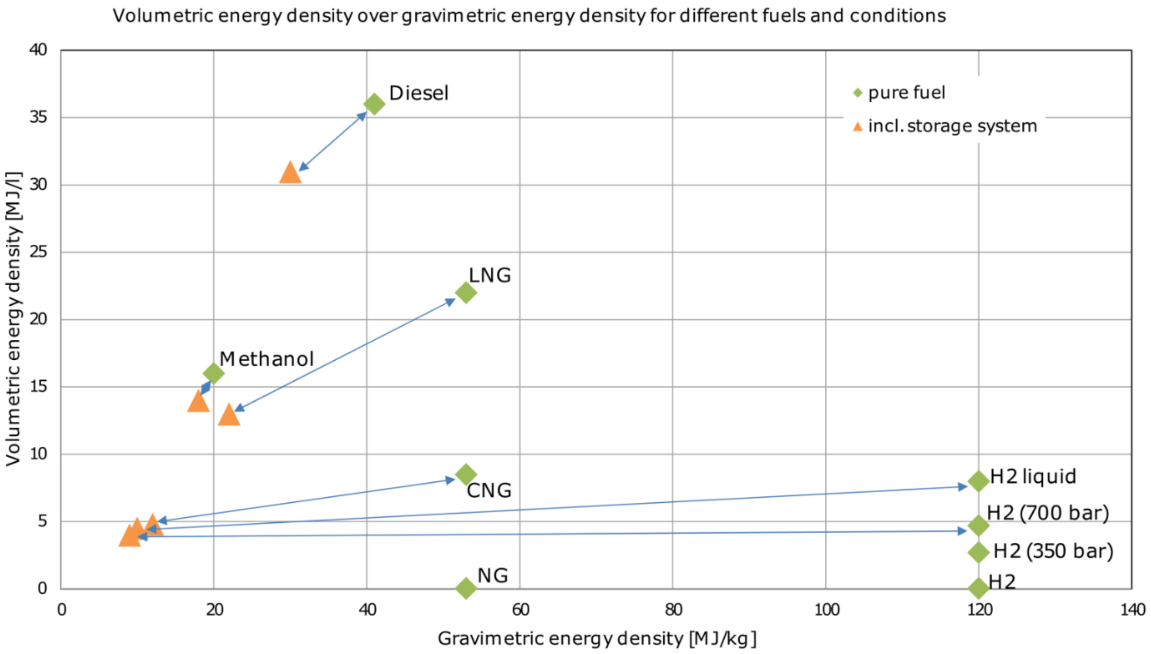
Methanol is the simplest member of the group of alcohols with the molecular formula CH_3OH. It is a clear colourless liquid with a density of 0.79 kg/l. It is toxic by ingestion, skin contact or inhalation. Due to the liquid property of methanol (it remains liquid up to a temperature of 60°C), handling is similar to that of diesel or petrol, i. e. storage takes place in simple tanks.

To use the methanol in a PEMFC, the contained hydrogen is separated in a reformer on board. Reforming is the transformation of hydrocarbons, alcohols and other hydrogen-containing compounds into hydrogen.

NATURAL GAS (METHANE)

Natural gas is a combustible, naturally formed gas mixture that comes from fossil sources. Natural gas can be stored and transported in both liquid (LNG) and gaseous (CNG) form. In addition to natural gas from fossil sources, biogenic and even synthetic natural gas can be produced via electrolysis. There are several processes for producing gases with a high artificial methane content.

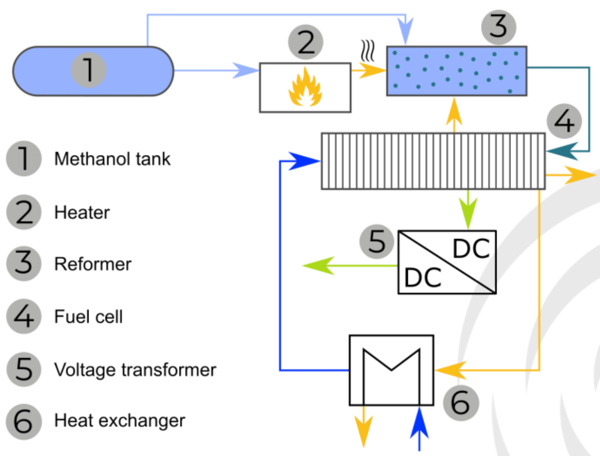
The individual energy sources that can be used have different energy densities:



COMPONENTS ON BOARD

The fuel cell system as a propulsion system for a ship often consists of several components. These include the fuel cell, an electric motor, accumulators and partly a reformer. A negative property of the fuel cell is its own inertia to react. This inertia is balanced by an accumulator. It must also be taken into account that a fuel cell needs some time to reach operating temperature, this time difference is also compensated by the accumulator. The fuel cell supplies direct current, the energy produced is transmitted to an electric motor for propulsion. This electric motor, for example, generates the rotary motion for the propeller shaft. The energy requirements for all electrical equipment on board a ship can be supplied directly from the fuel cell or accumulator without detours. The arrangement of the fuel cell and the accumulator can be either parallel or in series.

Methanol system for a HT-PEMFC

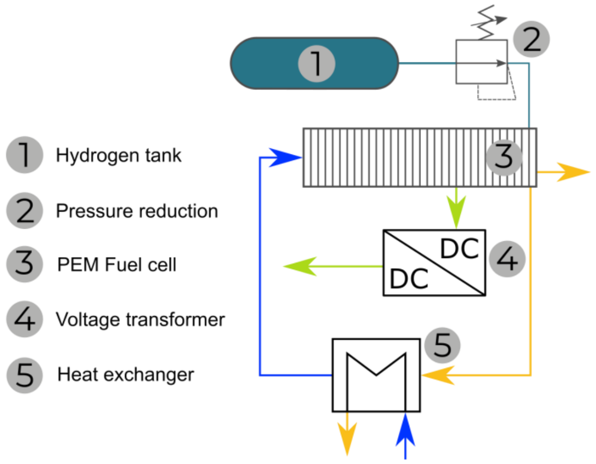


From the methanol tank (1) the fuel is taken to the reformer unit (3) to extract the hydrogen from it. The process needs heat which is produced by burning an amount of methanol in the heater (2).

The pure hydrogen is then fed into the fuel cell (4). Some of the reaction heat in the fuel cell is fed back in the reformer. The remaining heat is emitted in a separate heat exchanger system (6).

The voltage of the electric current produced is transformed into the usual on-board voltage by the voltage transformer (5).

Hydrogen system for a HT-PEMFC



The hydrogen's high pressure in the tank (1) is lowered to a for the fuel cell suitable amount in the pressure reduction unit (2). From there it is fed into the fuel cell.

The voltage of the electric current produced is transformed into the usual on-board voltage by the voltage transformer (4).

The reaction heat is emitted in a separate heat exchanger system (5).

INVESTMENT AND OPERATIONAL COSTS

The investment costs as well as the operating costs vary depending on the fuel cell used.

Cost category	Exemplary cost
Hydrogen storage	900 €/kg
LT-PEMFC system	2,000 – 3,000 €/kW
Battery	700 €/kWh
Engine	120 €/kW
Conversion	50,000 €
Hydrogen @ 700 bar	10 €/kg
Methanol	0.30 €/l
Natural Gas H	1.10 €/kg

BENEFITS

- High efficiency at full load and (depending on application) at partial load
- Good controllability
- Good performance extension due to modular design
- Increased comfort (low noise and vibrations)
- Low maintenance
- High development potential

DOWNSIDES

- High investment costs
- Operating experience in field test still low
- Durability maybe shorter compared to combustion engines
- Few suppliers

CONSIDERATIONS FOR DEPLOYMENT

The fuel cell technology is in principle ready for use and represents the ideal energy system depending on the application requirements. The right choice of components can be worked out individually. There are a number of requirements for economic and efficient use:

- Fleet size:
  - Individual deliveries are usually more expensive than mass deliveries
- Infrastructure:
  - If a fuel infrastructure for refuelling already exists, it can usually be used economically
  - If this infrastructure has to be created, its cost-effectiveness must be examined on a case-by-case basis

UPCOMING VESSELS AND PROJECTS

Vessel /Project	Description
MS Antonie	A cargo vessel owned by NPRC shall use hydrogen as fuel. The project partners are NPRC and Nouryon. ⓘ togetherwecandosomuchmore.nl/waterstofschip
Future Proof Shipping	An inland vessel shall be equipped with a hydrogen fuel cell system for propulsion. ⓘ www.futureproofshipping.com
Fuel-Cell Electric energy system for inland navigation and short-sea vessels	A Dutch consortium consisting of Nedstack, MARIN, Damen Shipyards Group, Future Proof Shipping, Marine Service Noord and Holland Ship Electric develops a marinised fuel cell system. ⓘ nedstack.nl/dutch-maritime-consortium-develops-fuel-cell-electric-energy-system-for-inland-navigation-and-short-sea-vessels
FLAGSHIPS project	Development of a fuel cell powered pushboat in Lyon. ⓘ flagships.eu

7.5 Battery electric propulsion

This section offers insight into battery electric propulsion, ranging from relevant regulations, technical concepts, information on economics and environmental sustainability as well as references to deployed examples. Batteries can be used as the sole power source or in combination with a more conventional, e.g. Diesel-electric drivetrain.

INTRODUCTION

Ship operation without local emissions of air pollutants and CO_2 can be realised with electric drives based on batteries and/or fuel cells. While electric drives are common since decades in the railway sector based on catenaries or conductor rails, modern electro mobility on the road virtually emerged few years ago and is spreading quickly. Electric cars and urban busses are becoming technically and economically more and more competitive, even though the cruising range is still limiting for many applications. In inland navigation the limitations regarding volume and mass often are less critical than for road vehicles. However, the requirements in terms of power and capacity are challenging. Additionally, the lifetime, investment costs per capacity, charging infrastructure and the sustainability of the supply chain require a detailed assessment for individual applications.

Nevertheless, batteries will be used more and more in different applications of inland navigation. Smaller passenger vessels or car ferries with limited range of operation in densely populated areas are most suitable for early adoption. Even long-haul cargo vessels can benefit from batteries and reduce emissions and exposure of the population to air pollutants temporarily. Batteries with moderate capacity can be used to switch off combustion engines.

es of x-electric ships while operating in ports, passing sensitive areas or when berthed. Incentive schemes like the Dutch Green Award level Platinum with reduced fees for ships capable of several hours of emission-free operation contribute to business cases for these hybrid drivetrains.

Depending on requirements of the individual application, batteries may be permanently installed on the ship or exchangeable. Batteries in standardised ISO containers can be replaced and handled with common port equipment. This model does not require powerful electric infrastructure and time for charging at the quay. It even allows alternative business models, referred to as “energy as a service” or “pay per use”, where utility companies invest in the battery containers and charge the batteries, possibly stabilizing the electric grid. Ship owners and operators only pay for the energy used. As long as the charging infrastructure for propulsion batteries permanently installed is not sufficient, emissions and exposure can be reduced even if the batteries are charged during operation with gensets. This requires a smart power management on board of the ships to run the gensets at optimum load. Hybrid systems of growing complexity will be installed more frequently during the coming decades. Almost all systems with fuel cells or solar panels etc. require batteries for peak-shaving and buffering of energy.

REGULATIONS

The **European Committee for the Development of Standards in Inland Navigation** (**CESNI**) has already compiled in 2017 a chapter called **Requirements for Electrical Appliances and Installations (Chapter 10)** in the **European Standard for Technical Requirements for Inland Navigation Vessels (ES-TRIN 2017)**. Further, in 2019 Chapter 11 **New requirements for electrical propulsion systems** was added to **ES-TRIN 2019**.

For the use of lithium-ion batteries, the requirements of the European Standards **EN 62619:2017** and **EN 62620:2015** can be applied.

Lithium-ion batteries shall be equipped with systems which include at least the following functionalities:

- Cell protection (short circuit external, internal, overcurrent, deep discharge, etc.)
- Charge control, if not via the charger
- Load management
- Determination of the state of charge
- Balancing the cells
- Thermal management

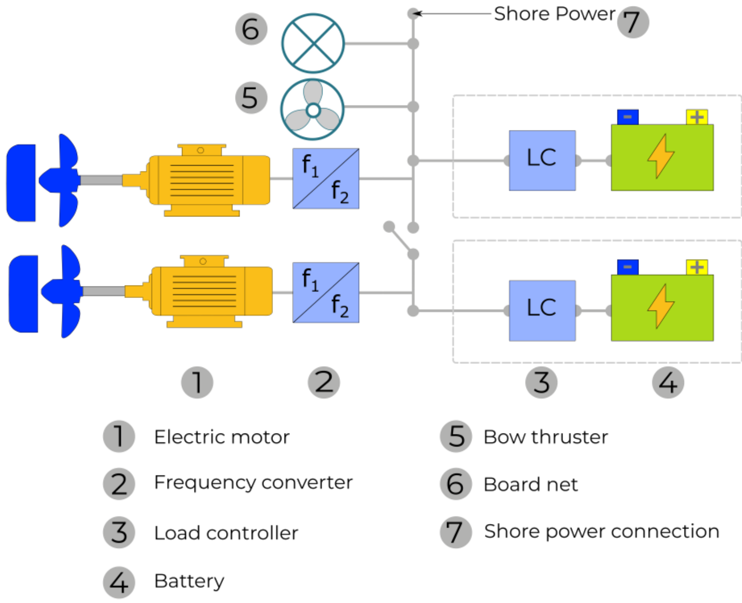
If a classification of the vessel is necessary, there are also additional rules from the classification societies available. Due to the general regulations of ES-TRIN an electric propulsion system must consist of at least two separated power supply systems, one main switch board, one frequency converter and one electric motor on the propeller shaft. One of the systems must be able to ensure a safe ship operation for at least 30 minutes in case of a failure of the second battery system. It must be ensured that the capacity of batteries or accumulators shall enable the safe reaching of a berth under the craft's own power at all times and under all conditions.

According to the **ES-TRIN 2019**, Chapter 10 and 11, the batteries must be located outside of apartments, holds, wheel houses and passenger cabins. Furthermore, they must be protected against extreme temperatures and water. Charging devices must be designed to charge the battery within a maximum of 15 h to 80 % of its nominal capacity without exceeding the maximum allowed charging current of the battery. The charging device must be specified to charge the selected type of battery.

The electric propulsion motors must be designed according to their operational profile including temporarily overloads and the effects of manoeuvres. The power electronics for electric propulsions must be designed for the anticipated loads, including overload and short circuit, during all operating and manoeuvring conditions. Finally, the operating state of the electric vessel propulsion and its principal components has to be displayed in the wheelhouse and in the propulsion installation. If this monitoring has a malfunction, the current state must be observable on site of each component.

TECHNICAL CONCEPT

The battery electric propulsion system consists of rechargeable batteries, electric switch board and an electric propulsion system.



The electric motor (1) drives the propeller with constant rpm (revolutions per minute) at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted. The frequency converter (2) supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on board energy grid. The rotational speed of the electric motor is controlled by varying the output frequency.

The load controller (3) distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion systems, bow thruster (5), board net (6), pump systems, etc.. It can be designed as a single AC or DC rail, which can be split in a starboard and portside system. The batteries (4) can be charged via a shore power connection (7).

A battery is an electrochemical energy storage device and a converter that provides the flexibility and freedom to store unused or excessive energy and then use the energy to benefit the operation of the ship. The electrical energy is stored by chemical reactions that are electrically driven. Batteries are basically divided into primary and secondary batteries. With primary batteries, the chemical energy is converted into electrical energy once, while secondary batteries (accumulators) can be repeatedly discharged and recharged. To recharge the accumulator the chemical reaction is returned by a voltage application. There is a loss in heat leading to different temperatures in the battery and an acceleration of aging. In the following only secondary batteries, known as accumulators, are treated.

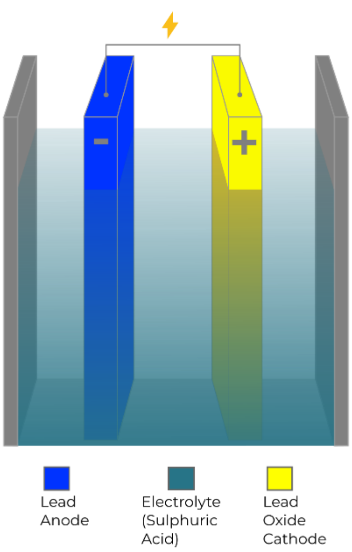
BATTERY TYPES

Beside all varieties of different batteries, they all share about the same construction. A battery cell consists of two electrodes, the negative anode and the positive cathode, which are enclosed by an electrolyte. The electrolyte can be made of liquid, gel or solid materials. For both electrodes and electrolyte different chemical matters are used. The current negative charge converts from the cathode to the electrolyte while the anode absorbs it. The process is triggered by the electrolysis (see section7.4 for details about fuel cells). The whole chemical reactions happen at the surface of the electrodes. The chemical active material diffuses through pores of the electrodes, reacts with the electrolyte and has to be transported. Otherwise the reaction is broken because the capacity of the cathodes is limited. That would lead to an increase of the discharging current. Often there is a separator used between the electrodes. The separator is semi-permeable, meaning that the ions are able to pass the separator while the electrons are filtered. The cell voltage and electrical characteristics depend on the electrochemical potential of the electrodes' materials. Usually, a battery consists of multiple cells, to increase the battery voltage and capacity.

Discharging of a battery means to convert chemical energy to electrical energy. If the battery is discharged more than the specific value of the final discharge voltage, a damage of the battery is possible. In addition to that a self-discharge process of a battery caused by undesirable reactions in it has to be taken into account. For charging a battery, current has to be spread. All reactions are returned but the controlled reversal is not perfect for most cases. Therefore, the number of charges is bounded.

LEAD-ACID BATTERIES

The lead-acid cells have a nominal voltage of 2 V. Both electrodes are made of lead; sulphuric acid is used as electrolyte. This battery type is approved by more than a hundred years of practice and further development. It is the current state of art for power backup system on board. These batteries require only little maintenance and are excelled by a long lifetime. The service life is up to approx. 2,000 cycles. A disadvantage of this type is its low energy density. For high capacitive battery systems, a lot of space and displacement reserve must be available on board. Generally, lead-acid batteries can supply very high discharge currents, particularly in short term.

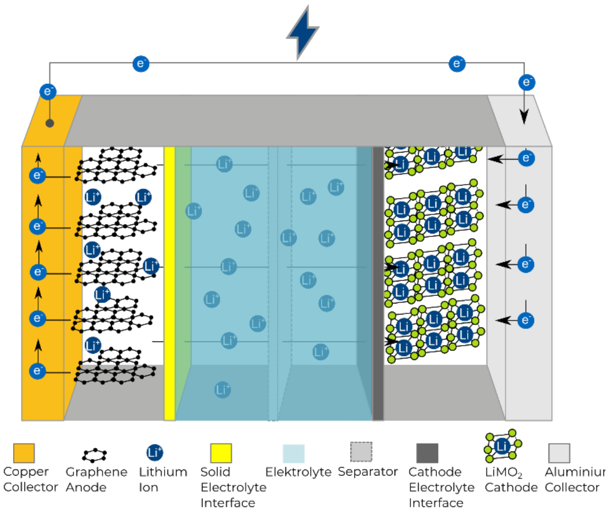


The charging current is quite low compared to the discharge currents. This requires a long time span at the pier to charge the batteries.

- specific energy [Wh/kg]: 25 – 50
- energy density [Wh/l]: 50 – 100
- power density [W/kg]: 75 – 300

LITHIUM-ION BATTERIES

There are various electrode combinations for lithium-ion (Li-ion) batteries. The materials used are influencing important properties of the batteries, because of their different electrochemical potentials and chemical characteristics. The "lithium nickel manganese cobalt dioxide" and the "lithium iron phosphate" batteries are essentially considered here. Lithium is the smallest and lightest metallic element. Compared to lead-acid batteries, it is the ideal raw material for much lighter and more powerful energy cells. The nominal cell voltage is approx. 3.6 V, varying by the used electrode materials.

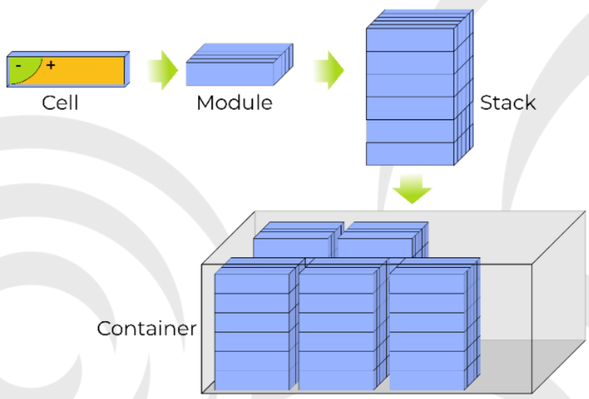


Li-ion cells are particularly popular because of their advantages in terms of storage capacity, cycle stability, self-discharge rate and high energy density. Beside high discharge currents, high charge rates can be applied too. However, they are relatively temperature sensitive. The ideal operating temperature is between 10°C and 35°C. In order to ensure the longest possible battery life, the charging process must be controlled by power electronics.

- specific energy [Wh/kg]: 180 – 260
- energy density [Wh/l]: 200 – 350
- power density [W/kg]: up to 5000

BATTERY SYSTEMS

Maritime battery systems typically consist of several thousand cells. It is, therefore, important that each cell works consistently with all other cells. The individual battery cells are interconnected to form battery modules, whereby the required voltage is reached. Due to the networking of these units, large systems with a high capacity can be assembled. The battery systems can be integrated into the hull of the ship or can be installed in separate battery cabinets.



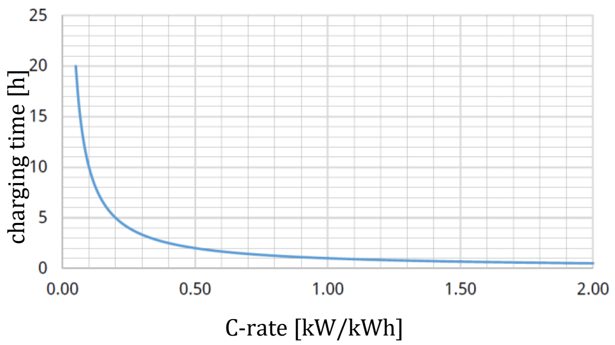
A superordinate battery management system collects the information on all modules of the containers and makes it available to the skipper. At the same time, the management system coordinates the charging and discharging processes in order to optimise the service life of all cells. The battery cabinets must be air conditioned, to keep the cells within an optimal temperature range.

CHARGING POWER AND NETWORK LOAD

In addition to the batteries on board, the ship must also be equipped with the control technology for the charging process. For charging the battery via the shore connection of the ship, the requirements of DIN EN 16840 must be fulfilled. Within these standards electrical installations for supplying inland waterway vessels with electrical energy, 400 V, 50 Hz and a current strength of at least 250 A are described.

CHARGING TIME

The charging time of a battery depends on various factors. There are different possibilities for charging, which also affect the type of installation in the ship. Sufficient power must be available both for the electric load on board, possibly including e.g. reefer containers, and for batteries to be charged. A generally valid determination of the charging time as a function of the charging capacity and the battery capacity to be charged is defined by the C-rate. The C-rate defines the charging or discharging power as a function of the battery capacity. 1 C corresponds to a charging power at which the battery is fully charged in one hour.



$$C - rate = \frac{charging\ power}{battery\ capacity}$$

Often there are different phases of charging. Firstly, the battery is protected by charging it slowly to test whether the final discharge voltage is below the critical threshold. After that the most part of the energy is supplied. At least the rest of missing energy is added. For taking care of the battery the intensity of the current is degraded. During the charging process, there is always a loss in heat and during further side reactions.

Degradation Mechanisms and Lifetime

The service life is a very important aspect of the energy storage system. It is difficult to determine the exact length of the lifetime because many factors play a role. One important factor to extend the lifetime of batteries is the depth of discharge (DoD): If a battery is very often discharged to very low levels, the lifetime of the battery will decrease. To achieve a good performance of the battery for several years, the capacity should be planned to be at least 20 % higher than the required capacity. This design ensures a low DoD and a careful usage of the battery. In any case of emergency, the battery can provide more power than the capacity required for normal operation. This ensures a safe operation of the ship, even if the planned DoD is reached. The service life itself is less often measured in time, rather in charging and discharging cycles.

A cycle results from the charging and discharging of a battery and is completely achieved when the amount of energy corresponding to the storage capacity has been completely used. Using smaller batteries with a higher amount of charging and discharging cycles is less expensive at the initial investment costs, but leads to a shorter lifetime and an earlier need for reinvestments. On the other hand, if a ship is capable to have twice the capacity installed, the lifetime of the batteries is twice as long as the lifetime of the smaller batteries, but the initial investment is higher.

Electric Propulsion System

The electric propulsion system must consist of a suitable electric propulsion motor connected with the propeller shaft and a compatible speed controller.

ASYNCHRONOUS MOTOR	SYNCHRONOUS MOTOR
The asynchronous motor is the most widely used industrial motor. It can be connected directly to the three-phase mains and is very robust and easy to build. The asynchronous motor takes its name from the fact that it does not rotate exactly with the mains frequency. It only has a torque if its speed deviates from the synchronous speed. In the operating range, the torque is proportional to this deviation. This type of electric motor is characterized by low investment costs and small dimensions. Its nominal rate of revolutions is usually too high to be used as a direct drive. A gearbox between electric motor and propeller shaft is necessary. The gearbox increases the investment costs, lowers the efficiency of the drive train and could be a point of failure. If the advantages of asynchronous motors and the disadvantages of the gearbox are balanced correctly, a cost and energy efficient drive train can be designed.	For synchronous motors, the speed of the motor is equal to the mains frequency divided by the number of pole pairs. The rotor of a synchronous motor is permanently magnetized and follows the rotating field of the stator with a phase difference. Usually, the speed is given in revolutions per minute (rpm). This type of electric motor is characterized by high energy efficiency, low nominal rate of revolutions and a good torque/speed characteristic. This motor can be used as a direct drive, without a gearbox between motor and propeller shaft. Its large outer dimensions are disadvantageous like the high investment costs. Using a synchronous electric motor for the propulsion system leads to an efficient drive train with a sensitive control.

Requirements for the Charging Infrastructure

For re-charging via a shore power connection there are two types of construction available:

- Electric charging station with integrated single-core sockets
- Electric charging station with spatially separated transfer station with integrated single-core sockets

The required infrastructure for battery systems essentially consists of suitable charging stations or suitable crane systems for ISO containers for changing battery packs. The dimensions specified in standard 668 and the maximum weight of approx. 30 t should not be exceeded by the container.

The existing shore power infrastructure is usually too weak for loading large batteries. The operators of the electrical power grids at the quay edge would have to provide connected loads in the megawatt range. In the background, the energy must be provided in the entire electrical network by power plants.

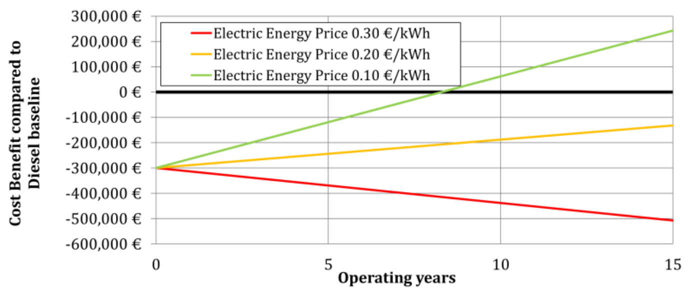
For charging the batteries on board, the existing low-voltage grid with 400 V three-phase current seems unsuitable. Due to the relatively low voltage, a high current must flow for high charging capacities. To transport large currents through a cable the connection cables must have a large cross-section.

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

INVESTMENT COSTS

Cost category	Exemplary costs
Battery	500 EUR/kWh
Electric motor	120 EUR/kW
Installation costs	30,000 EUR for conversion, wiring and power management

ECONOMIC OPERATIONS



The amortisation time of the battery depends on the electricity price. Reduced or no taxation of electric energy for shipping are discussed as well as new cost models like "energy as a service". In that case, the ship would lease the battery and pay for the electricity consumed. The example is calculated for a ferry with an annual energy demand corresponding to 100 m^3 diesel. The installed battery would provide energy for one day of operation.

BENEFITS

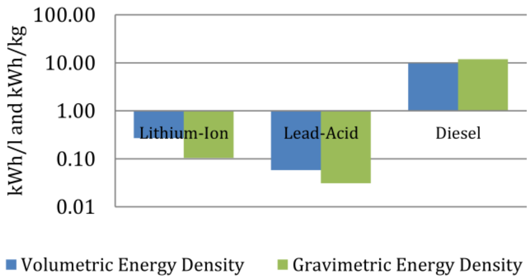
- Good controllability
- Good ability to retrofit due to modular design
- Increased comfort (noise and vibrations)
- Low maintenance
- Near-zero local emission of CO_2 and air pollutants
- Reduced noise emissions
- High development potential
- Low operating costs
- Potential of renewable energy as a source

DOWNSIDES

- High investment costs
- Operating experience in field test still low
- Shorter service life to market-dominant products (combustion engine)
- Few suppliers
- Due to lower energy density, more weight and space for the same energy storage compared to combustion fuel
- Restricted operating range due to battery capacity

ENERGY DENSITIES

The graph compares the energy densities of lithium-ion batteries, lead-acid batteries and diesel fuel. It can be seen that the storage of the same amount of energy in a battery rather than in diesel requires both more space and weighs more.



ENVIRONMENTAL SUSTAINABILITY

Accumulators with a high living cycle are the better choice in terms of environmental sustainability. In comparison to combustion engines, electric ones do not emit exhaust in operation; therefore local exhaust can be reduced or omitted. However, for an overall environmental analysis, also the power generation has to be taken into account. Since not all the power is yet provided by renewable energy, the total benefit has to be seen critically. Nevertheless, with the expected increasing share of renewable energies, the balance will get positive.

The materials used for the accumulators, with regard to the acids used as the electrolyte, can be (if leaking) extremely harmful for water organisms.

CONSIDERATIONS FOR DEPLOYMENT

The battery industry is working on alternative and more advanced batteries, which are lighter as well as with a higher energy density and cycle stability. Examples for that are graphene batteries and silicon air batteries.

Ships which have to travel far distances could be advanced with solar panels to constantly recharge the battery system. This system could also be applied to ships travelling a short distance to eventually eliminate the recharging process in harbours completely in order to save time and improve the river transport economically.

DEPLOYMENT EXAMPLES

SANKTA MARIA II

Operator: local congregation Oberbillig
Location: Germany, Oberbillig
Organisers: local congregation Oberbillig
In operation: 2015

ⓘ www.oberbillig.de

Vessel type: ferry

ENI: 04813080

Vessel size: 28.0 m × 8.6 m (L × W), Draught: 0.83 m

Propulsion: All-electric ferry driven by 4 Sail-Drive electric motors with 20 kW each. The electricity for the electric motors comes from two lithium polymer battery blocks with a capacity of 252 kWh, which are charged daily via a 63 A shore power connection in Oberbillig. In addition, 15 solar modules with 360 W each and a total output of 5.4 kW are installed on the ferry, the solar power is fed into the batteries for the 24 V onboard power supply.

Benefits: Battery capacity of 6.5 h drive at 5 km/h, charging 5 hours

SENDO LINER

Vessel type: inland dry cargo vessel

ENI: 02338022

Vessel size: 110 m × 11.45 m (L × W), Draught: 3.2 m

Operator: Sendo Shipping

Location: Netherlands

Organisers: Sendo Shipping, Concordia Damen, EST-Floattech, Oswald Elektromotoren

In operation: 2019

ⓘ www.sendo-shipping.nl

Propulsion: Diesel-electric drive in combination with a battery pack: two electric motors of 350 kW each driving the propellers, two generators of 430 kW each are installed in the bow. The battery pack has a capacity of 564 kWh and is usually charged with the generators. About 95 % of the time only one of the two generators is used. The battery pack ensures that the vessel is able to sail for up to 3 hours without emissions. The battery pack also serves as a buffer when more power is needed temporarily.

Benefits:

- No local emission of CO_2 and air pollutants in sensitive areas

- Reduced noise level onboard and reduced noise emissions to the environment

- Reduction of fuel consumption and CO_2 emissions compared to similar vessels by 32 %

7.6 Drop-in fuels

This section offers information on drop-in fuels that can be used in pure form or as a blend replacing conventional diesel without major engine conversions. Depending on the feedstock and upstream chain of the fuel production it can contribute to the decarbonisation of inland shipping significantly. Information on economics and environmental sustainability as well as references to recent applications is given here.

REGULATIONS

EN 15940:2016 for paraffinic diesel fuels includes HVO, GTL, BTL and CTL as well as diesel. EN 14214 is for biodiesel (FAME).

DROP-IN FUELS FACTS

Drop-in fuels are a synthetic and completely interchangeable substitute for conventional petroleum-derived hydrocarbons (gasoline, jet fuel, and diesel), meaning it does not require adaptation of the engine or the fuel system. It can be used “as it is” in currently available engines, either blended with conventional fuels, or even in pure form. However, engine OEMs should be contacted regarding warranty, risk of losing type approval and recommendations for adapted lubricants. In many cases the emission profile can be improved with optimisation of engine control parameters.

TECHNICAL DETAILS

X TO LIQUID (XTL)

XTL fuels (also known as Fischer-Tropsch fuels) are various synthetic fuels that convert a solid or gaseous energy carrier into a carbonaceous fuel, which is liquid at normal temperature and pressure levels. The "X" is a variable and is replaced by an abbreviation of the original energy carrier, while "TL" stands for "to Liquid". The abbreviations GTL (Gas-to-Liquid) for the use of natural gas or biogas, BTL (Biomass-to-Liquid) for the use of biomass and CTL (Coal-to-Liquid) for the use of coal as a source of energy are currently used.

HYDROTREATED VEGETABLE OIL (HVO)

HVO is a mixture of straight-chain and branched paraffins, the simplest form of hydrocarbon molecules under the aspect of clean and complete combustion. Typical carbon numbers are C15 ... C18. In addition to paraffins, fossil diesel fuels contain also significant amounts of aromatics and naphthenes. Aromatics impair a clean combustion. HVO, on the contrary, does not contain aromatics, and its composition is similar to that of GTL and BTL diesel fuels, which can be produced by the Fischer-Tropsch synthesis from natural gas and gasified biomass.

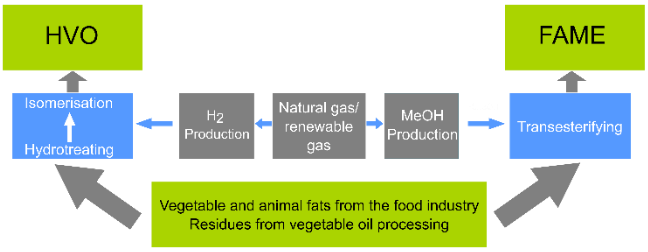
BIODIESEL

Biodiesel, chemically fatty acid methyl ester (FAME), is a fuel that is equivalent in use to mineral diesel fuel. The chemical industry produces biodiesel by transesterifying vegetable or animal fats and oils with monohydric alcohols such as methanol or ethanol. Biodiesel mixes with conventional diesel in any ratio. Many countries therefore use biodiesel as a blending component for conventional diesel fuel.

	Conventional Diesel	GTL	HVO	Biodiesel
Cetane number	>51	70	>70	54–56
Density [kg/m^3]	820	820	780	875

Energy density [MJ/kg]	42.9	44.0	44.1	37.2
Volumetric energy density [MJ/l]	35.2	36.1	34.4	32.6
Toxicological evaluation				
Water hazard class*	2	1	1	1
Carcinogenic	Yes	No	No	No

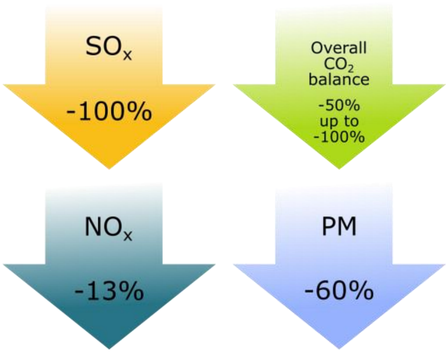
*Water hazard classes: 1: slightly hazardous to water, 2: hazardous to water



As it can be seen within the graphic illustration, the process of HVO production differs from the production process for biodiesel (FAME), as it is a catalytic process with hydrogen (hydrogenation); compared to the esterification process used for FAME production.

BUNKERING & ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

The drop-in fuels are bunkered nowadays mostly via truck. Some bunkering companies offer them also from their bunker vessels. The pure drop-in fuels GTL and HVO are about 5 % more expensive than conventional diesel fuel.



The use of HVO or GTL can reduce the NO_X emissions by up to 13 % and the PM emissions by up to 60 % if used pure. Blended the reduction of these emissions is proportional to the ratio of HVO or GTL. The amount of SO_X emissions drops by 100 %, when pure HVO or GTL is used. When considering the overall balance of the CO_2 cycle, emissions can be reduced between 50 % and 90 % for renewable feedstock compared to conventional diesel. Energy consumption during harvesting and transport of the raw materials is included in this calculation. If the starting material of the drop-in fuels is waste and residues, a 100 % reduction can be assumed when observing the overall CO_2 balance.

CONSIDERATIONS FOR DEPLOYMENT

The following aspects may be of interest for deployment:

- Engine parameters can be optimized in some cases
- Very interesting especially for cabin vessels, as unpleasant emissions for passengers are significantly reduced

7.7 Euro VI truck and NRE engines

As an alternative to engines with a dedicated type approval for inland ships (Stage V classes IWA and IWP) marinised engines of class NRE with power up to 560 kW and Euro VI truck engines may be installed on inland ships. These engines are usually more compact and have shorter product cycles due to the larger market demand. However, it needs to be ensured that the type approval is not lost due to the marinisation. This section gives an insight into regulations and technical details as well as economic aspects.

REGULATIONS

The CESNI Committee regularly publishes in the ES-TRIN the European Standard of Technical Requirements for Inland Waterway Vessels. The uniform requirements contained in ES-TRIN ensure the safety of inland waterway vessels, taking into account both the requirements of Directive 2006/87/EC and the Rhine Vessel Inspection Regulation. References to ES-TRIN are included in the EU and CCNR legal frameworks.

About the use of Euro VI truck and NRE engines for the main propulsion, the CESNI requires the following:

1. An NRE category engine may be used in place of an IWA or IWP category engine if its power output is less than 560 kW. This engine shall comply either with the additional technical requirements for devices for preventing NO_x emissions for NRE category engines in appendix 1 of annex IV, or those for IWA or IWP category engines in appendix 2 of annex IV of delegated regulation (EU) 2017/654.
2. An engine with an EU Euro VI certification for heavy goods vehicles under regulation 595/2009/EC or UNECE regulation R49-06 may also be used in place of an NRE category engine provided that a technical service recognised under Regulation (EU) 2016/1628 recognises that this engine complies with the additional technical requirements.

Note 1: These engines shall also meet the requirements of Directive (EU) 2016/1629 or RVIR and the associated ES-TRIN 2017 relevant for the vessel application (especially the specific requirements concerning exhaust gas after-treatment systems in Article 9.09).

Note 2: Marinisation may change the engine so that the type approval may need to be revised by the engine manufacturer or a new one issued. In addition, the company that makes the marinisation could, intentionally or unintentionally, become the manufacturer (see questions 17 and 18).

Source and reference for further reading:

https://www.cesni.eu/wp-content/uploads/2018/11/FAQ_Engines_en.pdf

TECHNICAL CONCEPT

Euro VI truck engines and NRE can be employed for direct propulsion or for a diesel-electric concept (see section 7.2). Before they are used, however, some changes (referred to as marinisation) must be made, which are also described below.

NRE ENGINES

According to Directive (EU) 2016/1628 category NRE engines are all engines suited to move, or to be moved, by road or otherwise, that not explicitly excluded or included in any other category. These engines with a reference power of less than 560 kW may be used in place of Stage V motors of categories IWP and IWA. NRE engines have Stage V emission limits slightly differing from the limits for IWP/IWA engines (identical or more stringent). The table below compares the relevant limits. However, it has to be noted that this comparison is not completely fair since the different engine categories are linked to differing test cycles (ISO 8178). The test cycles define the operating points in terms of engine speed and torque together with weighting factors. For example, class IWP-v-4 is approved according to test cycle E3 while NRE engines are tested according to C1.

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NOx	PM	PN	A
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	NRE-v-6 NRE-c-6	130≤P≤560	all	3.50	0.19	0.40	0.015	1×10^{12}	1.10
Stage V	IWP-v-3 IWP-c-3	130≤P<300	all	3.50	1.00	2.10	0.100		6.00
Stage V	IWP-v-4 IWP-c-4	P≥300	all	3.50	0.19	1.80	0.015	1×10^{12}	6.00

EURO VI TRUCK ENGINES

The Euro VI heavy duty emission standards were introduced by Regulation No 595/2009/EC. The emission limits, which are stricter than the Stage V values, are meant for the World Harmonized Stationary Cycle (WHSC) and the World Harmonized Transient Cycle (WHTC). Again the comparability of the emission limits is limited by the differing test cycles.

	CO	NMHC	CH4	NOx	PM	PN
	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	
WHSC	1.50	0.13	0.40	0.01		8.0×10^{11}
WHTC	4.00	0.16	0.50	0.46	0.01	6.0×10^{11}

EXHAUST GAS AFTER-TREATMENT SYSTEM

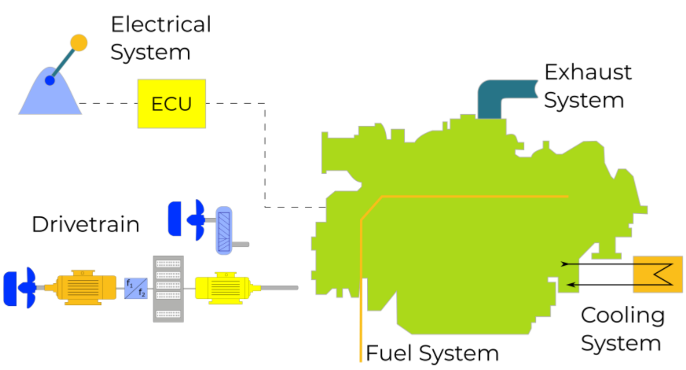
To reach the emission limits listed above all engines need to be equipped with an exhaust gas after-treatment system. Most engines are already equipped with these systems by the manufacturers. Details and background information on the after-treatment systems can be found in section 7.3.

MARINISATION

A much-discussed topic is the loss of type approval after marinisation. For Euro VI and NRE engines, it is the responsibility of the technical services to determine whether a modification leads to a loss of type approval. It is therefore very important that the marinisation company works closely with the technical services and the original equipment manufacturer (OEM).

Another issue that must be considered when installing a road engine in a ship is the emergency running mode of the road engine. According to ES-TRIN, this mode is not permitted for ships. It must therefore be clarified with the manufacturer beforehand whether the emergency running mode can be switched off or whether the engine has a fire-truck mode, which also does not allow a reduction in performance in the event of a malfunction. Other adjustments, which need to be performed, are described below:

PARTS FOR MARINISATION



ELECTRICAL SYSTEMS

Modifications of the electrical system include motor control, throttle control, monitoring system. In some cases, the software of the engine control unit (ECU) must also be adapted. In contrast to the torque request in truck operation, a speed request is required in on-board operation.

FUEL SYSTEM

The injection lines have to be replaced with a double-walled design.

DRIVETRAIN

A suitable gearbox is required in direct drives to match the propeller and engine characteristics. If the engine power is not sufficient for direct drive, a diesel-electric system is a suitable option.

EXHAUST SYSTEM

Both Euro VI and NRE engines require an exhaust gas after-treatment system to reduce PM and NO_x according to the emission limits. For most engines the DPF and SCR systems are provided by the engine manufacturer. The systems are mostly of small size; nevertheless, they must be fitted in the engine room.

COOLING SYSTEM

The Euro VI or NRE engine needs to be connected to the water-cooling system on board. Also, the connection of the charge air cooler with the water-cooling circuit is necessary.

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

INVESTMENT COSTS

Investment costs are provided for an example with a replacement of a 300 kW engine. Dependant on the operational profile of the vessel, it may be beneficial to go for a diesel-electric installation.

Cost Category	Costs in EUR	Comment
Marinised 300 kW Euro VI truck engine	about 50,000 EUR	
Installation cost	10,000 to 20,000 EUR plus one week at shipyard	Strongly dependant on system
Optional Electric Engine	120 EUR/kW	

OPERATIONAL COSTS

Operational costs for the example above are estimated as follows:

Cost Category	Costs in EUR
AdBlue consumption	approximately 3.5 % per litre diesel
AdBlue costs	0.20-0.50 EUR/l

ENVIRONMENTAL SUSTAINABILITY

Since the Euro VI engines have an on-board SCR and DPF system to reach the latest emission standards, they also emit significantly less air pollutants. In addition, there can also be a saving of diesel in operation. However, this is different for each application. In addition, the engine can be integrated not only as a direct drive but also in a diesel-electric drive concept. Fuel savings can also be achieved here. More information about the diesel-electric drive can be found in section 7.2.

CONSIDERATIONS FOR DEPLOYMENT

BENEFITS

- Modern technologies
- High emission standards
- Engine and after-treatment in one compact system
- Proven quality and reliability
- Low noise level
- High production numbers

DOWNSIDES

- No long-term experience in marine environment
- Lifetime expectation not confirmed
- High effort for conversion
- Power limits insufficient for many direct drives

8 New regulations and their consequences

This section provides information about the new Regulation (EU) 2016/1628 on requirements relating to pollutant emission limits for non-road mobile machinery (NRMM) This is the most important regulation related to applicable changes to IWT. Another applicable regulation is the European Standard on Technical Requirements for Inland Navigation vessels (ES-TRIN) which is constantly updated and mentioned in the section regulations for each of the greening technologies.

In 2016 the European Parliament and the Council have adopted the new Regulation on requirements relating to pollutant emission limits for non-road mobile machinery (Regulation (EU) 2016/1628, hereinafter as well "NRMM Regulation"), which **applies** as well **to inland waterway vessels**. The regulation applies to new builds and also to new inland waterway vessel engines used for conversion.

The objective of the Regulation is to progressively improve the air quality by reducing the pollutant emissions from non-road mobile machinery and by gradually phasing out the most polluting engines.

The NRMM Regulation defines emission limits for NRMM engines for different power ranges and applications. It also lays down the procedures engine manufacturers have to follow in order to obtain type-approval of their engines – which is a prerequisite for placing their engines on the EU market.

The EU Regulation sets the emission limits for so called Stage V engines, which replaces Stages I to IV and thereby the limits according to CCNR II. The consequences are that new limits are imposed on vessel owners regarding engine performance (its power range (kW)), when installed after the effective date of the regulation. For main and auxiliary engines with a reference power of less than 300 kW, the EU Stage V emission standards will enter into force on 1 January 2019. The implementation date for main and auxiliary engines with a reference power equal and above 300 kW, is set for 1 January 2020.

The Stage V calls for limit values for emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) for internal combustion engines installed in inland waterway vessels. It as well sets the limits for emissions of ultrafine particulate pollutants (PM).

Under the EU Stage V, engine emissions must be significantly reduced. The Stage V emission limits, according to the table below, are applicable to IWP and auxiliary (IWA) engines over 19 kW, regardless of the type of engine ignition.

Table 8: Stage V emission limits overview

Engine subcategory	Power range (kW)	Date [1]	CO (g/kWh)	HC [a] (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	PN (#/kWh)
IWP/IWA-v/c-1	$19 \leq P < 75$	2019	5.00	($HC + NO_x \leq 4.70$)		0.30	-
IWP/IWA-v/c-2	$75 \leq P < 130$	2019	5.00	($HC + NO_x \leq 5.40$)		0.14	-
IWP/IWA-v/c-2	$130 \leq P < 300$	2019	3.50	1.00	2.10	0.10	-
IWP/IWA-v/c-2	$P \geq 300$	2020	3.50	0.19	1.80	0.015	1×10^{12}

(1) IWP - engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion (2) IWA - auxiliary engines exclusively for use in inland waterway vessels

(3) Dates of application of the State V emission limits for engine categories (placing on the market of engines)
(a) A = 6.00 for gas engines

PM: ultrafine particulate pollutants (PM)

CO: carbon monoxide (CO), HC: hydrocarbons

NO_x: nitrogen oxides (NOx)

9 Efficient fleet management solutions

Facing the economic boundary conditions, the current Danube fleet and the general long life-cycles of inland ships, fleet modernization is a long process. The GRENDEL fleet investment plans summarized in GRENDEL output 3.3 show the corresponding investment needs per fleet operator, per country and for the whole Danube region. The intended state aid schemes and the implementation of funding options and incentives are important parts of a holistic approach support the modal shift towards a modern and environmental friendly inland navigation sector on the Danube. In addition to the installation of new systems and the preparation of maintenance plans for existing systems is an important measure. This ensures that the systems are always in good condition, reduces emissions and prevents sudden total failure due to poor or no maintenance. If a sufficient budget is set for maintenance and, if it has not been fully spent, savings are made. The reserves created can be used to finance parts of the modernization.

A first step towards efficient fleet management is the know-how transfer to ensure that Danube fleet operators and other IWT stakeholders gain comprehensive up-to-date knowledge on viable solutions for efficient fleet management in the context of greening technologies. This includes the financial, operational and environmental impact when deploying greening technologies. Therewith the know-how transfer is representing the basis in order to facilitate investment decisions.

Here the decision support tools can provide important input to gather information on potential greening decisions, help to monitor costs and to assess greening options for new-builds or retrofits. Decision support tools are described in the GRENDEL deliverable D 3.1.2. The fact sheets published as GRENDEL deliverable D 3.1.3 offer quick and easy access to the most relevant information on promising greening technologies including costs. In the following several exemplary deployment examples of selected greening measures are listed.

DEPLOYMENT EXAMPLES FOR GAS AND GAS-ELECTRIC PROPULSION

MS EIGER-NORDWAND

RETROFIT

Operator: DCL Barge B.V.

Location: Netherlands, Rhine

Organisers: DCL Barge, Koedood, Wärtsilä

In operation: 2014

ⓘ www.danser.nl

Copyright: © DCL Barge

Vessel type: inland container vessel

ENI: 02324957

Vessel size: 105 m × 11.45 m (L × W), Draught (max): 3.55 m

Propulsion: 2 dual-fuel Wärtsilä 6L20DF, 900 kW each at 1,200 rpm

Tank capacity (LNG): 60 m³ (gross) sufficient for the roundtrip Rotterdam - Basel

LNG tank: Vacuum-insulated double-wall pressurised tank IMO type C

Benefits: fuel consumption reduction by approximately 20 %

MS SIROCCO

Operator: Chemgas Barging s.a.r.l

Location: Luxemburg, Rhine

Organisers: Chemgas Barging

In operation: 2015

ⓘ www.chemgas.nl

Copyright: Chemgas Barging s.a.r.l.

Vessel type: LNG-fuelled type G tanker

ENI: 02324789

Vessel size: 110 m × 11.40 m (L × W), Draught (max): 3.15 m

Propulsion: Single 8L20DF Wärtsilä main engine capable of running on LNG & marine gasoil

Tank capacity (LNG): 88 m³ (gross)

LNG tank: Single wall independent vacuum-insulated pressure tank with design pressure of 10 bar

RPG BRISTOL

RPG STUTTGART

RPG STOCKHOLM

Operator: Shell Trading BV

Location: Netherlands, Rhine

Organisers: Plouvier Transport NV/ Intertrans Tankschiffahrt AG

In operation: 2017

⍰ www.plouvier.be

Copyright: © Plouvier

Vessel type: LNG-fuelled type C tanker

ENI: 02337327

Vessel size: 110 m × 11.40 m (L × W), Draught (max): 3.21 m

Propulsion: Wärtsilä 6L20 DF dual fuel engine, 1100 kW

Bunker capacity (LNG): 60 m³

LNG tank: Wärtsilä LNGPac

DEPLOYMENT EXAMPLES DIESEL-ELECTRIC PROPULSION

TMS Bilgenentöler 10

Operator: Bilgenentölungsgesellschaft (BEG)

Location: Regensburg (DE)

Organisers: Rensen-Driessen, Dolderman, Baumueller

ⓘwww.bilgenentoelung.de

Vessel type: bilge oil boat

ENI: 04812720

Vessel size: 40 m × 7.30 m (L × W)

Propulsion: Two 178 kW electric motors on one shaft and two gensets with 340 kVA from Caterpillar C 9.3.

Benefits: Low noise and combined supply of electric energy for propulsion, bow-thruster, pumps and separator.

MS NADORIAS

RETROFIT

Operator: Sendo Shipping

Location: Netherlands

Organisers: MCS, Sendo Shipping, Koedood, Hybrid Ship Propulsion

In operation: 2009 (2014)

ⓘ www.sendo-shipping.nl

Source: www.ppmc-transport.org

Vessel type: inland container vessel

ENI: 02331393

Vessel size: 110 m × 11.45 m (L × W)

Propulsion: Conventional diesel setup changed to hybrid: electric engine (385 kW) powered by two gensets (205 kW each, in the bow) was added to the 1250 kW main engine.

About 85 % of the time the ship sails with the electric motor driven by one of the gensets. When more power is required, the second generator is started. The direct drive engine is only used when a lot of power is required (1-2 hours per week).

Benefits: Reductions in fuel consumption by 15 %, maintenance costs by 60 %.

DEPLOYMENT EXAMPLES AFTER-TREATMENT

PB DONAU

Owner: Frank Rycquart

Location: Antwerp, Belgium

Equipped by: Multronic NV

After-treatment since: 2017

ⓘ www.multronic.be

© William Hill, MarineTraffic.com

Vessel type: Push boat

ENI: 06105358

Vessel size: 22.5 m × 10.0 m (L × W), Draught: 2.35 m

Propulsion: 2 Caterp. 3512 (CCNR2)

Exhaust after-treatment:

Starboard: SCR+DPF

Portside: SCR only

Deployed in 2017 in H2020 project PROMINENT (www.prominent-iwt.eu Deliverable 5.10)
Outcome: Starboard: emissions compliant with Stage V NRMM.

Portside: NO_X emissions compliant with Stage V NRMM

MS MAX PRÜSS

Operator: Landesamt für Natur, Umwelt und Verbraucherschutz NRW

Location: Düsseldorf, Germany

Equipped by: TEHAG Deutschland GmbH

After-treatment since: 2015

ⓘ www.tehag.com

ⓘ www.lanuv.nrw.de

© Roni Schneider, MarineTraffic.com

Vessel type: Laboratory vessel

ENI: 05803790

Vessel size: 33.0 m × 7.6 m (L × W), Draught (max): 1.10 m

Propulsion: 2 MAN Type D 2866 LXE 43

Exhaust after-treatment:

SCR + DPF (2015)

DEPLOYMENT EXAMPLES FUEL CELL PROPULSION

MS INNOGY

Operator: Weisse Flotte Baldeney-GmbH

Location: Germany, Baldeneysee, Ruhr, Rhein-Herne-Kanal

Construction year: 2006

Modification: 2017

ⓘ www.baldeneysee.com

Fotocredit: EnergieAgentur.NRW, eventfotograf.in

Vessel type: excursion boat

ENI: 04804940

Vessel size: 29 m × 4.9 m (L × W), Draught: 0.60 m

Propulsion: electric motor 80 kW, reserve diesel engine 182 kW

Fuell cell: 35 kW HT-PEM

Bunker capacity (Methanol): 330 liter

Battery capacity: 2 × 60 kWh

FCS ALSTERWASSER

Operator: ATG Alster-Touristik GmbH

Location: Germany, Hamburg, Alster

Construction year: 2008

Decommissioned : 2014

ⓘ www.alstertouristik.de

ⓘ www.proton-motor.de

Copyright: www.hzwei.info

Vessel type: excursion boat – decommissioned

Vessel size: 25.6 × 5.2 m (L × W), Draught (max): 1.33 m

Propulsion: electric motor 100 kW

Fuel cell : 2 × 48 kW LT-PEM

Bunker capacity (Hydrogen): 178 liter, tank pressure 350 bar

Battery capacity: 7 × 29 kWh

NEMO H2

Operator: *Rederij Lovers*

Location: Netherlands, Amsterdam(canals)

Construction year: 2009

In Operation: 2011

ⓘ www.lovers.nl

Copyright: vlootschouw.nl

Vessel type: excursion boat

ENI: 02333096

Vessel size: 22 × 4.25 m (L × W), Draught (max): 1 m

Propulsion: electric azimuth thruster 75 kW, electric bow thruster 11 kW,

Fuel cell: 69 kW PEM

Bunker capacity (Hydrogen): 1200 liter, 24 kg, tank pressure 350 bar

Battery capacity : 30-50 kW

DEPLOYMENT EXAMPLES DROP-IN FUELS

MS JENNY / MS WISSENSCHAFT

Owner: Albrecht Scheubner

Location: Rhine-Main-Danube

In operation: since 1987 / since 2016 on GTL

Vessel type: Container Vessel / Event Vessel

ENI: 04503240

Vessel size: 102 m × 9.5 m (L × W), Draught (max): 2.86 m

🛈 www.scheubner.de

Copyright: © A. Scheubner

Propulsion: Mitsubishi Typ S12A2-Z3MPTAW-3, 701 kW;

Verhaar Omega Jet, 261 kW

Specifics: GTL as fuel, SCR

MS FOR-EVER

Location: Alpherium-Rotterdam/Antwerp

Organisers: HEINEKEN

In operation: since 2012 / since 2019 on Bio-fuel Oil MR1-100 (GoodFuels)


Copyright: ©CCT

Vessel type: Container Vessel

ENI: 02334650

Vessel size: 90 × 10.50 m (L × W), Draught (max): 3 m

Propulsion: 2 × Scania DI-16, 386 kW; 2 × DAF

Specifics: HVO as fuel

MS ALPHENAAR

Location: Alpherium-Rotterdam/Antwerp

Organisers: HEINEKEN

In operation: since 2019

Vessel type: Container Vessel

ENI: 02338177

Vessel size: 90 × 10,50 m. (L × W), Draught (max): 3.8 m

Propulsion: 2 × Veth L-drive VL-400 with PM engine 400 kW: VSG 1300L bow thruster, 2.4 MWh Battery and Mitsubishi gensets S6R (600 kW) and 6024 (200 kW)

Specifics: HVO as fuel, up to 5 hours zero emission on batteries

DEPLOYMENT EXAMPLES EURO VI TRUCK AND NRE ENGINES

IJMEER

Operator: de Klerk

Location: Netherlands

In operation: With Euro VI engines since 2018

🛈 www.deklerkbv.nl/

Vessel type: working boat

ENI: 2325374

Vessel size: 37.58 m × 9.12 m (L × W)

Propulsion: 2 × Vink - MX 11 – 240 kW

MS WANTIJ

Operator:

Location: Western Europe

In operation: With Euro VI engines since 2018

🛈 www.wantij.org


© J. Fernhout

Vessel type: General Cargo Ship

ENI: 02326428

Vessel size: 86 m × 9 m

Propulsion: 2 × Vink - MX 13 – 355 kW, direct drive

10 Conclusion

In a comparison of transport modes, inland shipping still has considerable capacity reserves on most waterways for additional transport services. So, the desired shift of freight traffic to relieve the roads is possible. It is important to support environmentally sound transport modes like inland waterways transport and at the same time contribute to a further strengthening of IWT's environmental performance. Different technologies at different levels can be used to achieve this as discussed in section 7. At the same time, inter- and intramodal competition leads to significant cost pressure. Measures to improve the environmental compatibility of inland navigation must therefore be developed and implemented in a complex area of conflict. Essential boundary conditions are the consideration of the existing fleet and economic efficiency. Many small and micro enterprises could not comply with excessively strict legislation, even due to a lack of available financing, which would endanger the desired modal shift. But it is also not possible to modernise the fleet with public money alone.

From a technical point of view almost every ship is unique. As a result of the diversity of the fleet, very different measures can be target-oriented. Therewith, several chains of measures for each segment of the fleet are possible to meet the emission reduction goals. Furthermore, the age of the ships has an influence on the installation options and technologies to reduce emissions. For example, the design of the engine room or the investment options for an older ship can be decisive. Furthermore, some options may be too heavy for a ship frequently operating in stretches with low water depth, while another option is too voluminous for a ship limited by bridge heights or locks. Thus, the sustainable improvement of emissions requires a careful analysis of the overall situation and a multitude of initiatives and solutions.

Moreover, the awareness for energy-efficient navigation and the integration of these topics into the vocational curricula is a lasting step towards a green IWT on the Danube. Especially skills in terms of smart sailing in confined waters are very important for boatmasters and on-board personnel on the Danube. Also raising awareness amongst the on-board personnel and logisticians is to be taken into account. This could be done through training, motivation and incentive measures by use of existing or possibly retrofitted displays in combination with systems for measuring the fuel consumption. This is particularly of interest as it can already save a lot of money also freeing capacities to be used to introduce other emission reducing technologies.

With limited budget it is preferred to modernize as many ships as possible with cost-efficient measures. Advanced technologies like hydrogen fuel cell systems or battery electric ships would allow more reduction of greenhouse gas and air pollutant emissions for the single ship. But the impact on the environmental performance of the fleet would be small. For the time being these technologies can be installed in niche applications until the costs are reduced. Additionally, the assessment of greening technologies always needs to address both, the investment and the costs of operation. Some ships with a high energy throughput can have a return on investment for a LNG installation. For the majority of the fleet, however, the price gap between conventional fuel and LNG is not sufficient to compensate the costs for tank and equipment.

Retrofitting existing engines with after-treatment systems or replacing engines with Stage V or Euro VI truck engines can significantly reduce emissions. Changing to second generation biofuels like HVO as blends or pure would also reduce the carbon footprint. Diesel-electric systems can serve as bridging technology by preparing the vessels to be easily retrofitted with zero-emission technologies as soon as they are technological ready.