

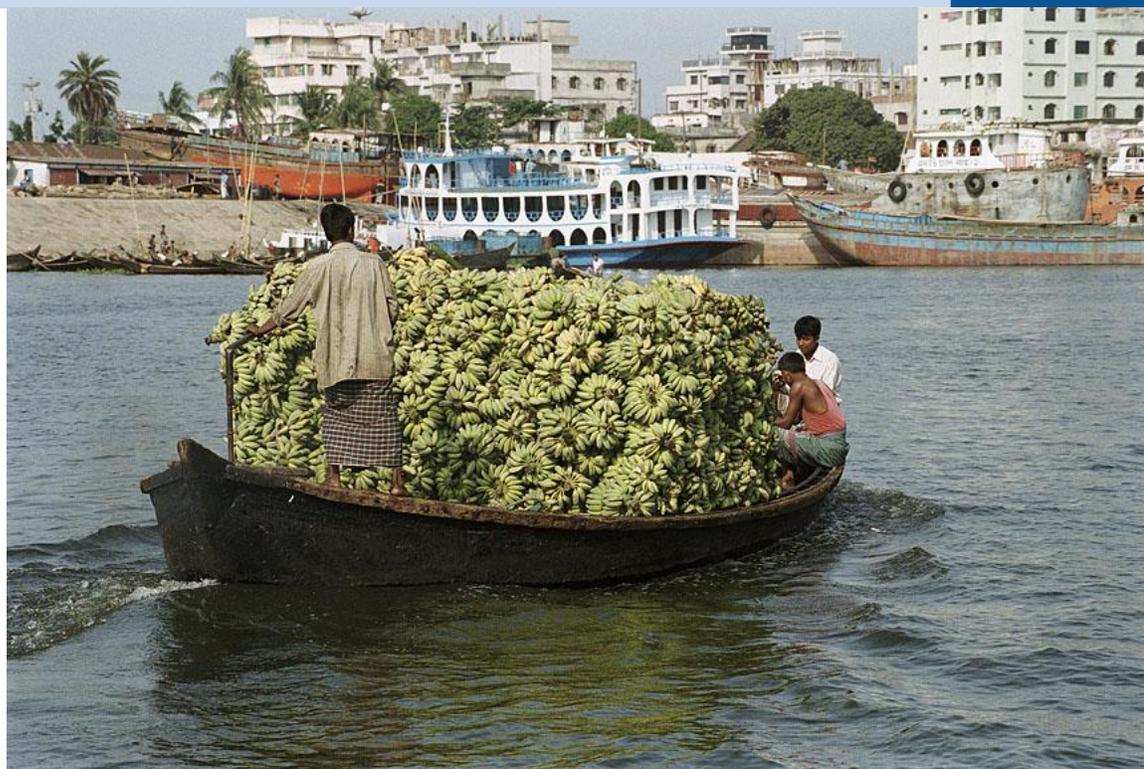


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# ENERGY EFFICIENT INLAND WATER TRANSPORT IN BANGLADESH



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CONSULTING SERVICES FOR THE  
DEVELOPMENT OF MORE ENERGY  
EFFICIENT INLAND WATER  
TRANSPORT



The Transport Research Support program is a joint World Bank/ DFID initiative focusing on emerging issues in the transport sector. Its goal is to generate knowledge in high priority areas of the transport sector and to disseminate to practitioners and decision-makers in developing countries.



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# ACKNOWLEDGEMENTS

The “Consulting services for the Development of more energy efficient inland water transport (IWT)” has been prepared for the World Bank Transport Anchor group (TWITR) in Washington which administers and manages the Transport Research Support Program (TRSP), a financing of **DFID**, Department for International Department of United Kingdom Government.

The task team would like to acknowledge the timely support, help and guidance from Michel Audigé, the Sector Manager, Transport, South Asia Region. The task was lead by Jean-Noel Guillosoou, Lead Transport Economist, Sustainable Department, Transport Unit, South Asia Region and Ishtiaque Ahmed, Transport Specialist of the World Bank Dhaka office, provided useful insight, direction and support on a large number of issues when needed. Special thanks go to Comfort Olatunji who provided administrative, editorial and logistics support during the preparation and finalization of this report.

Quality and peer reviews were done both at the concept stage and final report stage by Messrs. John Allen Rogers, Consultant Environment Department, World Bank, Federico Querio, Climate Change Team, World Bank, Reynaldo Bench, Sr. Port Specialist, World Bank, and Nathaniel P. Adams, Consultant of the World Bank.

The report was prepared by ECORYS Nederland BV, in association with Ecofys (Netherlands) and HB Consultants (Bangladesh). The ECORYS team was led by Mr. Johan Gille, and further consisted of Mr. Dick d’Arnaud and Mr. Jorrit Harmsen. Input from Ecofys was provided by Mr. Rob Winkel and Mr. Sikko Zoer, and from HB Consultants by Dr M. Ismail and Mr. Golam Moula Mollah.

The work done by the consultants and the study recommendations were shared with key stakeholders from various agencies in Bangladesh. This report presents the findings of three activities and the contents are based on literature review, desk study and several interviews held within the Netherlands, and data collection, interviews and site visits in Bangladesh.

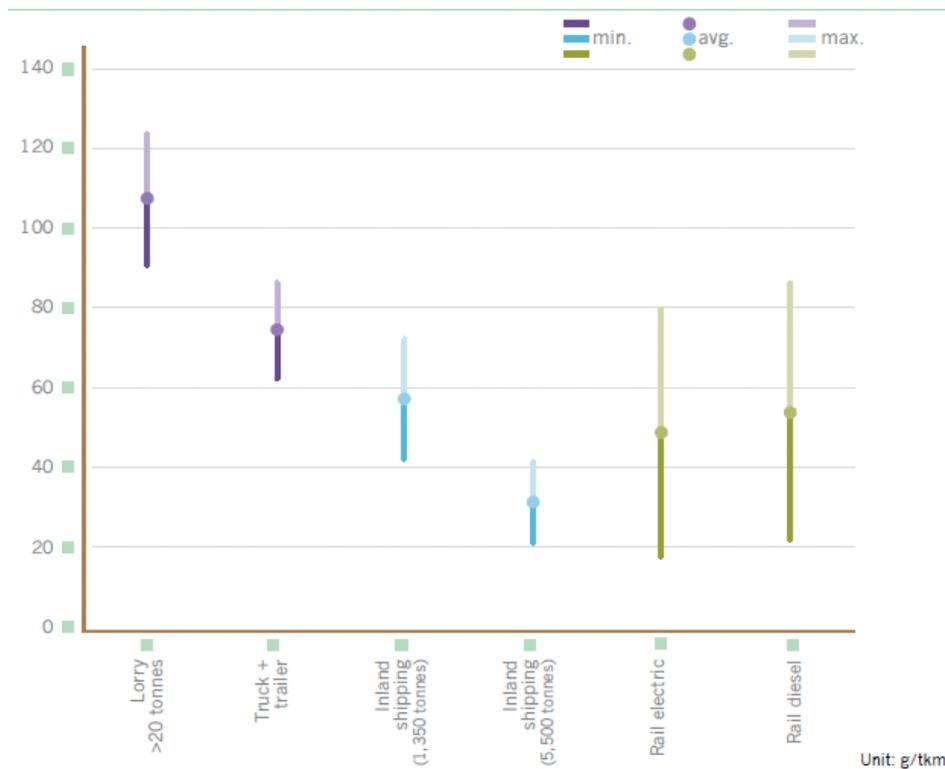


# EXECUTIVE SUMMARY

## 1.1 EXISTING DATA ON ENERGY EFFICIENCY OF INLAND WATER TRANSPORT (IWT)

Inland water transport is considered more energy efficient, emitting less CO<sub>2</sub> per ton-km performed, compared to transport modes like road or rail. Figure S.1 below shows the average emissions of IW transport as ranging from 25 gr CO<sub>2</sub>/ ton-km to 70 gr CO<sub>2</sub>/ ton-km. The variation depends on fleet structure, the age profiles of vessels and engines, and nautical and market conditions.

Figure S.1 CO<sub>2</sub> emissions including well to tank (g per ton-km) and pre- and end-haulage of freight transport in 2010 at long distances (> 150 km) in the Netherlands



Source: CE Delft (2008)

The IW sector is able to ship more tons per km with greater fuel efficiency than other modes due to its inherent economy of scale. This benefits the climate, and makes the sector more cost-efficient than other modes. Various factors explain the variation of energy performance of the different modes:

- Fuel types: Energy sources, including fuel or electricity, vary depending on the mode of transport.

- Costs: Energy is a key contributor to transport costs and the type of energy used by each mode impacts on its financial attractiveness.
- Efficiencies of scale: IW ships can take much larger payloads, thereby reducing fuel consumption and costs per ton.
- Logistical factors: IWT requires pre- and end-haulage. It depends on a limited fairway network and includes empty kilometers, which have to be accounted for.
- Commodities involved: Load capacity cannot always be used fully used when large cargoes (containers) are being shipped.

#### *Improving the energy efficiency of transport*

Many countries could still more fully exploit the potential of IWT. At the same time the modal share of road transport is increasing at the cost of IWT. There are various reasons for this. The advantages of other modes (speed of delivery, flexibility), limitations of infrastructure (water levels, bridge clearances, port access) and underdeveloped intermodal facilities (transshipment from IWT to truck for pre- and end-haulage) are among the main arguments shippers use to avoid IWT. The lower carbon footprint of IWT transport appears to be a less important factor in their cost-benefit calculations, also in the case of policy makers.

#### *Improving the energy performance of IWT itself*

Improved energy efficiency of the IW fleet could have important impacts in developing countries. This could conceivably be larger than in developed countries in terms of the sector's contribution to an improved climate and enhancing its cost-competitive position relative to other modes. The energy efficiency performance of inland vessels in developing countries is assumed to be lower than in developed IWT countries due to the use of older engine technologies and vessel designs. The introduction of new technologies could therefore help to achieve much higher efficiency improvements.

#### *Recommended benchmark methodology*

The International Panel on Climate Change (IPCC) has developed an energy efficiency benchmarking methodology. The 'actual emissions method' applies if:

- The relevance of international, cross-border traffic is limited.
- Fuel consumption data is reliably available.
- The methodology could be used for assessments of both freight and passenger transport.
- It is further important to distinguish sector emissions (exhaust) from fuel chain emissions (well to wheel). The latter also covers fuel extraction, transport, production and distribution, and performance levels may change if these are also taken into account. Considering these aspects in the actual emissions method, requires an adjustment of the emissions factor applied. It is also important to recognize that IWT requires pre- and end-haulage of goods by road which also generates emissions. Figure S.1 gives an overview of all the relevant CO<sub>2</sub> emissions.

## 1.2 TECHNICAL ADVANCES AND IMPROVEMENTS OF IWT EFFICIENCY

There are numerous conventional and technologically advanced options for enhancing IWT energy efficiency.

### *Conventional options for improving energy efficiency*

Conventional options for improving energy efficiency include: optimizing operations, minimizing vessel resistance, improving propulsion systems, and adapting fairways. Each of these has different investment requirements. Optimizing operations falls under the control of the transport operator. It is relatively easy to implement and has low investment requirements. The adaptation of fairways requires decisions and budget allocation on the part of public authorities and lies at the other end of the range of investment options.

### *Technologically advanced options for improving energy efficiency*

A literature review and interviews with innovation institutes revealed four major themes regarding the improvement of energy efficiency:

1. The use of alternative fuels: bio-diesel, Compressed Natural Gas (CNG)/Liquid Natural gas (LNG), dual fuel (combination of diesel and CNG), electricity or hydrogen.
2. Advanced low-resistance ship design.
3. Advanced high-efficiency propulsion systems.
4. New logistical concepts, changing the operational methods of ships, including new vessel design.

In addition to ongoing studies focusing on the improvement of engine or propulsion systems, and hulls and hull hydrodynamics, there are several research projects and promotional programmes that aim at efficiency improvements of conventional technologies on existing ships.

### *Assessment*

An indicative assessment of the options for the improvement of energy efficiency is provided in table s.1. Qualitative scores indicate their relative implementation costs and possible savings, their impact on emissions and consequences for safety and other aspects.

TABLE S.1 ASSESSMENT OF FUEL EFFICIENCY IMPROVEMENT MEANS

| Means                                       | Investment Costs | Cost Savings          | Environment                               | Safety   |
|---|------------------|-----------------------|---|----------|
| Conventional means                          |                  |                       |   |          |
| Optimizing operations                       | Low              | Low                   | Low                                       | None     |
| Minimizing resistance                       | Low to moderate  | Low/ Moderate         | Low                                       | Low      |
| Propulsion systems and steering gear        | Moderate to high | Moderate to high      | Moderate                                  | Low      |
| Adapting fairways                           | Very high        | Potentially very high | Emissions moderate, other aspects varying | Moderate |
| Advanced means                              |                  |                       |   |          |
| Alternative fuels                           | Moderate         | Moderate to high      | Moderate                                  | Low      |
| Advanced low resistance design              | High             | High                  | Moderate                                  | Low      |
| Advanced high efficiency propulsion systems | Moderate to high | High                  | High                                      | Low      |
| New logistical concepts                     | Low to high      | Low to high           | Low to Moderate                           | None     |
|   |                  |                       |   |          |

Source: Own assessment of study team

### 1.3 FEASIBILITY OF A PILOT PROJECT USING CNG IN IWT

A proposed pilot project in Bangladesh foresees equipping a passenger vessel with a retrofitted dual fuel engine system and replaceable CNG tanks. This would require some modification of the vessel. A preliminary feasibility study conducted for this pilot concluded that the pilot was technically and economically feasible.

Mono-fuel engine systems using NG remain an option. However, the countries in which this is used would need to have a secure, long-term supply of NG to reduce investment risks faced by IWT operators. Uncertainty about such supplies in Bangladesh would have to be taken into consideration for the country-wide expansion of the pilot. The pilot will not significantly impact on the national availability of CNG; however scaling up the pilot to a larger segment of the IW fleet could have that impact.

The investment costs of the Bangladesh pilot amount to some USD 43,000, while the socio-economic Cost-Benefit Analysis shows a positive Net Present Value of USD 145,000. From the operators' perspective, the pilot is financially feasible, with an earn-back period of 1.1 years. Costs and benefits may have different levels in other countries as these depend on the fleet in existence, technologies used and landside infrastructure.

The decision to proceed with the pilot should also consider criteria such as safety and maintenance:

- CNG tanks should be installed carefully to avoid impacting negatively on vessel stability.
- CNG tanks should be loaded/unloaded at fixed quay walls, because of the stability needed during these operations. Floating pontoons, such as those used in Bangladesh for the embarkation/disembarkation of passengers, should be avoided.
- Exhaust gases should be carefully monitored. Incorrectly tuned engines could generate emission levels that exceed those of diesel engines.

# PART A: REVIEW OF EXISTING DATA ON ENERGY EFFICIENCY OF INLAND WATER TRANSPORT

# 1 INTRODUCTION

## 1.1 BACKGROUND TO THE STUDY

Transport accounts for a large share of global greenhouse gas (GHG) emissions, up to 23% of global CO<sub>2</sub> emissions, following OECD data. It is also one of the few sectors where emission levels are still increasing (OECD/ITF, 2008). Most modes of transport showed increased CO<sub>2</sub> emission levels between 2000 and 2005. However, such growth was the highest in international aviation and international maritime transport, (See Table 1.1 below).

TABLE 1.1 WORLDWIDE CO<sub>2</sub> EMISSIONS FROM TRANSPORT

| CO <sub>2</sub> emissions (Mt CO <sub>2</sub> ) | 2000   | 2005   | % change |
|---|--------|--------|----------|
| Worldwide CO <sub>2</sub> from fuel combustion  | 21,024 | 27,136 | 29%      |
| Transport                                       | 4,614  | 6,337  | 37%      |
| Passenger Road                                  | 3,307  | 4,648  | 41%      |
| Rail  | 148    | 125    | -16%     |
| Domestic aviation                               | 256    | 314    | 23%      |
| International aviation                          | 292    | 416    | 42%      |
| Domestic navigation                             | 96     | 111    | 16%      |
| International maritime shipping                 | 358    | 543    | 52%      |

Source: IEA (2007)

The above table makes no distinction between passenger and freight transport. Freight accounts for approximately 31% of CO<sub>2</sub> emissions of road transport and 84% of rail transport (IEA/SMP 2004). No information is available on the share of the CO<sub>2</sub> emissions of passenger transport in inland navigation. For the calculations in this study this share was set at nil.<sup>1</sup>

Table 1.2 Compares emissions by various land transport modes and the way these developed between 1990 and 2005. The enormous share of CO<sub>2</sub> emissions resulting from road transport is clear and has increased relative to that of rail or inland shipping.

<sup>1</sup> In the western world the relevance of passenger transport compared to freight is very small, but in countries like Vietnam or Bangladesh this is certainly not the case. In Bangladesh for example IWT accounted in 2005 for about 8.9 billion passenger-kms and 3.0 billion ton-kms. Due to the fact that volumes in Western countries are very high compared to developing countries, we still expect the global average to be rather small.

TABLE 1.2 SHARES IN WORLDWIDE CO<sub>2</sub> EMISSIONS FROM TRANSPORT

| CO <sub>2</sub> emissions (Mt CO <sub>2</sub> ) | 1990  | Share 1990 | 2005  | Share 2005 |
|---|-------|------------|-------|------------|
| Road  | 1,033 | 82%        | 1,451 | 87%        |
| Rail  | 124   | 10%        | 104   | 6%         |
| Domestic navigation                             | 96    | 8%         | 111   | 7%         |
| Total land transport                            | 1,252 | 100%       | 1,667 | 100%       |

Source: own calculations study team based on IEA (2007) and IEA/SMP (2004)

Stabilization of greenhouse gas emissions from transport and achieving the Kyoto Protocol objectives will require policies that foster behavioral change. The pressure on policy makers to tackle the issue of climate change through translating the Kyoto Protocol into tangible action plans, is growing in concert with mounting climate change problems. Implementing the Kyoto Protocol will enhance the sustainability of the transport sector and reduce its contribution to the problem of climate change.

## 1.2 OBJECTIVE AND SCOPE

Inland water transport is more energy efficient than modes like road or rail. The bigger capacity of IWT units means that the sector is able to ship more tons per kilometer per unit of fuel than what is possible with other modes. This benefits the climate and makes the sector relatively cost-efficient. Even so, few countries fully exploit the potential benefits of IWT and in many countries the share of road transport is increasing at the cost of IWT.

There are various possible reasons for this trend. Among the main reasons given by shippers to avoid IWT are advantages of road transport such as speed of delivery and flexibility, limitations imposed by IWT infrastructure (water levels, bridge clearances, port access) and underdeveloped intermodal facilities (transshipment from IWT to truck for pre- and end-haulage). For shippers these arguments are more important than the potential reduction of transport costs and CO<sub>2</sub> emissions.

IWT policies to date have tended to have the alleviation of road congestion as the main underlying objective, and governments have only recently starting looking at the carbon-sensitive policies that are needed to promote it as a way to reduce sector emissions.

For developing countries IWT energy-efficiency improvement harbors substantial potential, in terms of the sector's contribution to an improved climate and enhancing its cost-competitive position relative to other modes. The energy efficiency performance of inland vessels in developing countries is assumed to be lower than in developed IWT countries due to the use of older engine technologies and vessel designs. The introduction of new technologies could therefore help to achieve much higher efficiency improvements.

Policy makers and promotion organizations dedicate less effort to the sector as a result of their limited IWT-related knowledge and capacity. This could be

changed by raising general awareness of the scope for reducing the transport sector's impact on environment and climate.

The objective of part A of this assignment is to deepen knowledge and insights into IWT energy efficiency, as compared to other transport modes, and of methods to further increase the IWT sector energy-efficiency. The scope of this study is limited to CO<sub>2</sub>.

### 1.3 STRUCTURE

Chapter 2 compares the global energy-efficiency of IWT with that of other transport modes. It also discusses the reasons for differences between modes and the implications of each for CO<sub>2</sub> emissions.

Chapter 3 deals with the varying energy-performance of IWT vessels in various regions in the world. Chapter 4 explores several energy efficiency benchmarking methods. The conclusions of Part A are presented in Chapter 5.

## 2 GLOBAL PERFORMANCE: IWT VERSUS OTHER MODES

This chapter describes the energy performance of inland shipping versus that of other land transport modes (par. 2.1). It also discusses factors behind the differences observed (par. 2.2) and possible consequences for overall GHG emissions of the transport sector (par. 2.3).

A comparison of the performance of transport modes requires an assessment of transport sector emissions (exhausts) and emissions along the entire fuel supply chain (also called 'well to wheel'<sup>2</sup>). The latter includes fuel extraction, transport, production and distribution and is further elaborated in chapter 4. Some data sources used for this chapter apply the exhaust approach, while others present the supply chain approach. This is indicated where relevant.

### 2.1 ENERGY EFFICIENCY OF TRANSPORT MODES

#### 2.1.1 ENERGY EFFICIENCY MEASUREMENT

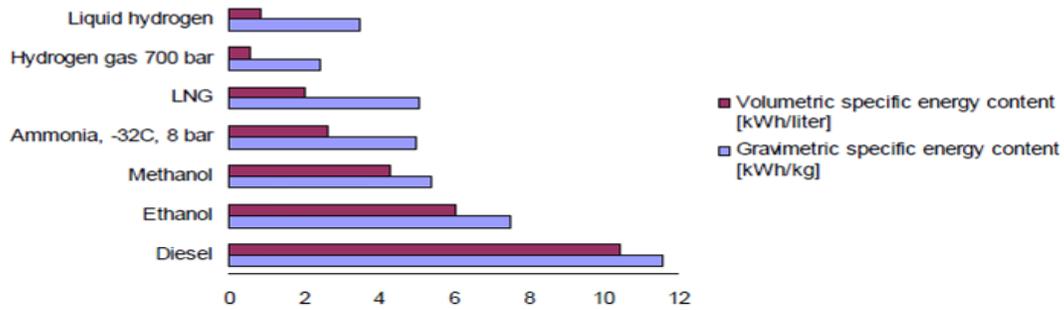
Kilometers driven per liter of fuel, or liters used per 100 km, are common ways of measuring energy efficiency in transport. Measuring energy efficiency in freight transport should also take into consideration the volume or weight of the cargo being transported as this influences fuel consumption. Accordingly fuel consumption per ton-km is frequently used as a measure of freight transport energy efficiency.

However, different modes of transport often use fuel types with different energy contents. One liter of diesel, for example, contains more energy than one liter of LNG and has by far the highest energy content per kilogram or per liter (see the figure below). Shifting from one fuel to the other may therefore involve changes in the size of the storage tanks.

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<sup>2</sup> The entire fuel chain is called 'well-to-wheel'. While the emissions within the transport sector are called exhausts, the emission at the front end of this are called 'well-to-tank'. Furthermore under the 'door-to-door' concept all emission of the entire transport chain are to be accounted for.

Figure 2- Energy content (in kWh), both volumetric and gravimetric, of different fuels



Source: Grimmelius (2010)

Differences in the energy content of different fuels can be accommodated by using energy value (Joules) as one of the measures in one's formula. This means that each fuel type has to be converted into this unit based on standard energy content values (see figure 2.1). Such conversion could also be used in the case of transport modes that do not use carbon-based fuel types, like rail transport where electric power is common. Table 2.1 compares the energy consumption of four modes of transport as measured in Mega-Joules per ton-km. It clearly demonstrates that IWT is more efficient than roads and on par with rail.

TABLE 2.1 ENERGY CONSUMPTION OF VARIOUS MODES OF TRANSPORT

|               | CO <sub>2</sub> emission<br>[g/ton-km] * | Energy consumption<br>[MJ/ton-km] | Fuel Economy<br>(diesel equivalent) [liter/ton-km] |
|---------------|--|-----------------------------------|--|
| Truck         | 97 – 110                                 | 1.13 – 1.28                       | 0.031 – 0.036                                      |
| Rail diesel   | 21 – 86                                  | 0.24 – 1.00                       | 0.007 – 0.028                                      |
| Rail electric | 18 – 80                                  | 0.14 – 0.62                       | 0.004 – 0.017                                      |
| IWT           | 25 - 70                                  | 0.44 – 0.84                       | 0.008 – 0.023                                      |

Source: calculated by study team based on Ecofys data.

**BOX 2.1 METHODOLOGY FOR CALCULATING ENERGY CONSUMPTION OF VARIOUS MODES OF TRANSPORT**

Comparisons of transport mode energy efficiency in different countries reflect variable fuel prices rather than energy efficiency. If transport operators do not pay the full cost of using energy, then the type of fuel/energy source used will depend only on the direct cost to the operators (i.e. the full cost minus the externalities). A comparison of fuel prices is not easy to make. Prices for standard products like Marine Diesel Oil (MDO) are known (currently around USD 720 per ton). However, every country has its own tax regime, which can vary between modes within the same country. In many European countries diesel fuel for road trucks is taxed, but not for IWT. Fuel for the inland shipping sector is not taxed, with a cost per liter of diesel of around USD 0.81 (CBRB index, November 2010). Truck diesel, in comparison, costs about USD 1.70 per liter (European Commission, 20 December 2010).

Furthermore there are taxation differences between countries, causing for example road freight routes to pass Luxembourg because of the low tax levels involved.

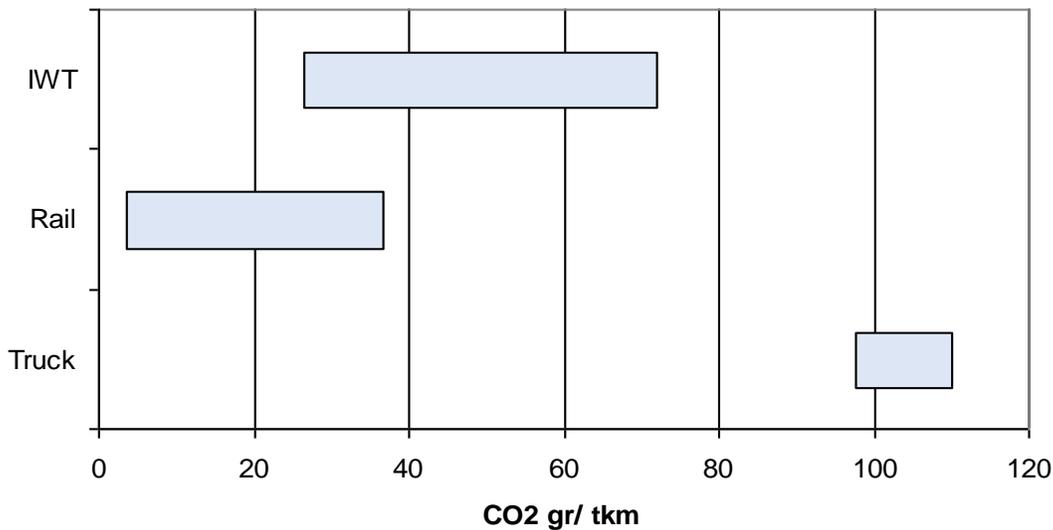
A proper comparison should include all costs and not only what is paid by the operators. Externalities such as the climate impacts of emission levels and impacts on health should also be considered to arrive at a meaningful measure of a transport mode's efficiency. Costs calculated on this basis exceed direct costs by far. For this reason this report will use greenhouse gas emissions as a measure of energy efficiency. The analysis will be limited to CO<sub>2</sub> emissions as much information is available on this topic for each of the different transport modes.

### 2.1.2 CO<sub>2</sub> EMISSIONS AS AN INDICATOR OF ENERGY EFFICIENCY

Figure 2.3 presents the range of CO<sub>2</sub> emissions for three modes and shows that the average CO<sub>2</sub> emissions per ton-km for road transport are much higher than those for the other two modes of transport. It also shows rail transport to be the most energy efficient mode of transport, however, this is because only exhaust emissions are presented. Also, data is based on rail freight transport in Western Europe, which mostly runs on electricity and therefore has relatively low exhaust emission levels. Well-to-tank emissions are needed for more accurate measurements. These vary depending on the source of power generation.

Average emissions of IW transport range from 25 gr CO<sub>2</sub>/ ton-km to 70 gr CO<sub>2</sub>/ ton-km. IWT emissions are much lower than road transport emissions, and are at levels comparable to that of rail transport.

Figure 2.3 Average CO<sub>2</sub> emissions for selected transport modes in different countries (tank to wheel, excluding pre- and end-haulage)



Source: TREMOVE model v2.7b (2009), ECORYS & Consia (2010), Texas Transportation Institute & Center for Ports & Waterways (2009)

<sup>1</sup> Based on calculations for the Netherlands, Germany, France, the United States and Vietnam

**BOX 2.2 METHODOLOGY FOR CALCULATING AVERAGE CO<sub>2</sub> EMISSIONS FOR SELECTED TRANSPORT MODES IN DIFFERENT COUNTRIES**

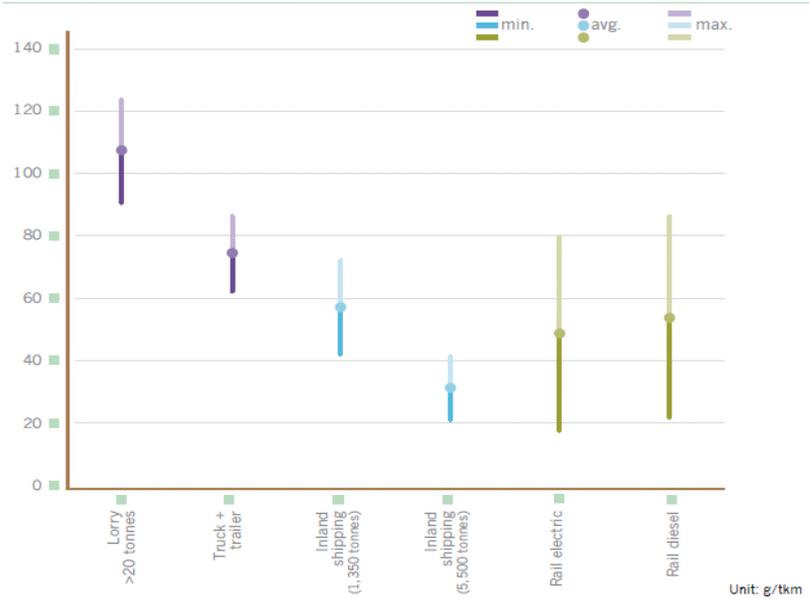
EU data was generated by means of the TREMOVE model (version 2.7b). TREMOVE is a European Commission policy assessment model, which assesses the effects of different transport and environment policies on transport sector emissions. It estimates the transport demand, modal shifts, vehicle stock renewal, the emissions of air pollutants and the welfare level. The model covers passenger and freight transport. The module for freight transport covers road, rail and inland shipping. Based on the vehicle stock and transport demand in each country, the model estimates the total amount of ton-kilometers and total CO<sub>2</sub> emissions for each type of transport.

US data was obtained from a study by Texas Transportation Institute & Center for Ports & Inland Waterways (2009). Its estimates of average CO<sub>2</sub> emissions are based on the average fuel consumption of road, rail and inland shipping, and calculations of the power efficiency of each vehicle type. Data was converted from short ton-miles per gallon to CO<sub>2</sub> per gram per ton-kilometer using conversion factors listed in annex 3.

Data from Vietnam was obtained from a study by ECORYS & Consia (2010). Estimations of the vehicle fleet for road and inland waterway transport were used and average CO<sub>2</sub> emissions were calculated by means of weighted average.

The ranges in figure 2.3 reflect differences in average CO<sub>2</sub> emissions between countries. There are also large variations within modes in individual countries. Figure 2.4 below shows CO<sub>2</sub> emissions for long distance transport in the Netherlands. It shows that, for instance, the CO<sub>2</sub> emissions per ton-km for a large truck-and-trailer combination are significantly lower than those for a 20 ton truck. The lower emissions are explained by the significantly higher capacity of a truck-and-trailer compared to that of a single truck, the increase in capacity offsetting the increase in fuel consumption and CO<sub>2</sub> emissions. The same principle holds for inland shipping.

**FIGURE 2.4** CO<sub>2</sub> EMISSIONS INCLUDING WELL TO TANK (G PER TON-KM) OF FREIGHT TRANSPORT IN 2010 AT LONG DISTANCES (> 150 KM) IN THE NETHERLANDS, INCLUDING PRE- AND END-HAULAGE (WELL TO TANK AND TANK TO EXHAUST)



Source: CE Delft (2008)

**BOX 2.3 METHODOLOGY FOR CALCULATING WELL TO TANK EMISSIONS (G PER TON-KM) OF FREIGHT TRANSPORT**

The figures of fig 2.3 were calculated on the basis of CO<sub>2</sub> emissions for IW vessels in the Netherlands. The underlying study of CE Delft (2008) includes well-to-tank and tank-to-exhaust emissions. Their CO<sub>2</sub> data further include logistical factors such as pre- and end-haulage. Figure 2.3 shows the outcome for a long distance case. The points in the figure are the most likely outcome, but also a wider bandwidth is presented, based on a best and worst case analysis for the different logistical factors

## 2.2 FACTORS OF INFLUENCE ON ENERGY EFFICIENCY

Various factors help to explain differences in energy performance between modes. The following categories are here considered:

- Fuel costs
- Scale factor
- Logistical factors
- Commodities involved

### 2.2.1 FUEL COSTS

Cost is the first criterion considered by entrepreneurs in the transport sector when making decisions about what fuel to use. They take fuel efficiency and the technology used into account indirectly. For example, where a cheap fuel type needs an expensive engine, a more expensive fuel may be the rational choice.

The operating range is another factor for non-carbon fuels like hydrogen or electricity. Due to differences in energy content (see section 2.1), the size of batteries may have to be much larger than diesel fuel tanks to be able to sail the same distances. This has a negative impact on the net payload capacity of the vessel or truck.

Tax policies also have an impact on fuel costs. In European countries, for example, fuel for inland shipping is not taxed, while fuel for road freight is. Price variability therefore complicates comparison.

### 2.2.2 ECONOMIES OF SCALE

IWT, and to a lesser extent rail, can benefit from economies of scale, or, in the case of energy, efficiencies of scale. IW vessels can carry larger volumes of cargo relative to the extra fuel needed, resulting in lower emissions per ton-km compared to road. Also larger vessels or trucks have lower per ton-km emissions than smaller vehicles. Therefore the fleet composition is relevant, which is further explored in chapter 3.

### 2.2.3 LOGISTICAL FACTORS

Figure 2.4 in the previous paragraph presents ranges of average CO<sub>2</sub> emissions for IWT, rail and road. CE Delft (2008) considers the following logistical parameters for this estimate:

- Pre- and end-haulage required for IWT and rail transport;
- The amount of additional kilometers for rail and IWT against road freight because of differences in density of the network.
- Variation in the load factor for all modes of transport.
- Productive kilometers (measured by % non-empty kms)

Most freight cargo starting points and destinations are not located in close proximity of a railway line or a waterway and pre- and end-haulage by road is required. CE Delft (2008) estimates that this leads to an additional 5% of the total distance which takes place by road.

Transport distances increase by approximately 10% when shipping freight by rail or IWT as opposed to using roads. This is because of the lower density of rail networks and inland waterways compared to road networks.

The load factor is the average amount of goods shipped in single loaded trip as a percentage of the total load capacity of the vehicle. For instance, if a truck with load capacity of 30 ton is loaded with 15 ton of goods, the load factor is 50%. See also the next paragraph on commodities involved. Examples of load factors used by CE Delft are presented in Table 2.2 below.

The last parameter is the amount of productive kilometers, or non-empty haulage. If transport routes are unbalanced, with larger volumes going in one direction than in the other, the percentage of empty kms will be rather high. If however vehicles can obtain return cargoes, the percentages become lower. As seen in table 2.2, the productive kms percentage for Dutch inland shipping is relatively high compared to other modes of transport. This is mainly due to: (i) good balance between export of bulk commodities and import of steel products, and (ii) the high percentage of container traffic in inland shipping in the Netherlands (where shipping of empty containers is also considered a loaded trip).

It is believed that the relative performance of IWT versus other modes in terms of load factor and productive kms, varies little across western countries, making the available load capacity the main difference.

TABLE 2.2 LOGISTICAL PARAMETERS FOR THE NETHERLANDS

|                 | Load capacity (ton) | Load factor % | % productive kms |
|-----------------|---------------------|---------------|------------------|
| Truck >20t      | 27                  | 66            | 50               |
| Truck & Trailer | 27                  | 73            | 59               |
| Rail            | 2,500               | 100           | 50               |
| Dry bulk ship   | 1,350               | 66            | 78               |
| Push Barge      | 5,500               | 66            | 78               |

Source: CE Delft (2008)

#### 2.2.4 COMMODITIES INVOLVED

The load factor (as described above) strongly correlates to the type of cargoes that are shipped. Performance is measured in emissions per ton-km, making the amount of cargo in tons and the type and density of cargo important factors. When shipping bulk cargo, the full carrying capacity of the vehicle (truck, vessel, rail wagon) is normally used, even though the full volume may not always be used. The load factor is then 100 percent. Voluminous but light weight cargo, to the contrary, uses only part of the full carrying capacity in tons.

Accordingly countries that ship only heavy bulk goods by IWT will have better energy performance measured in emissions per ton-km than countries shipping mostly light and voluminous goods in this way.

In conclusion, differences in energy performance between transport modes depend on additional generic factors such as:

- Vehicle size (scale factor); and
- Commodities involved (heavy or light density).

### 2.3 IMPACT ON OVERALL TRANSPORT EMISSIONS

Total transport emissions not only depend on the intrinsic energy performance of modes but also – largely – on the share contributed by each mode (the modal split). This varies greatly between countries as shown in the following section.

#### MODAL SPLIT

The table below gives an indication of the worldwide modal split of land transport in 2005. It consolidates data about OECD countries, Eastern Europe, Russia and other former Soviet countries, and China, and indicates that IWT accounts for approximately 14% of total ton-kms traveled.

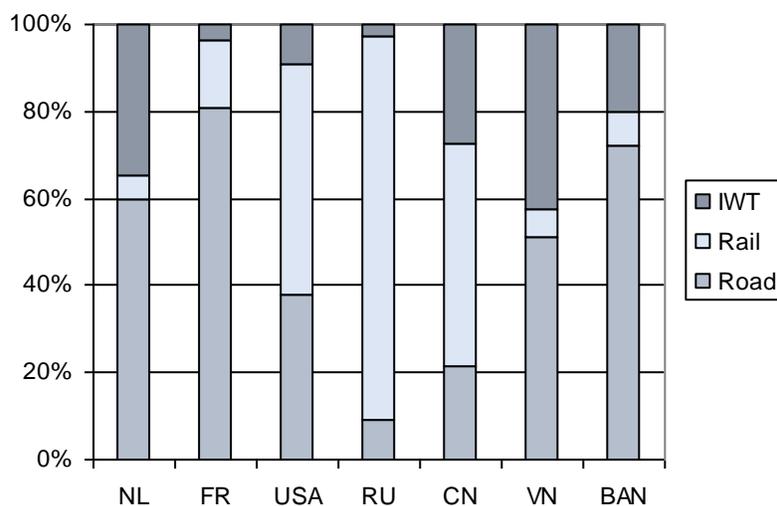
TABLE 2.2 INDICATION OF WORLDWIDE TRANSPORT SIZE AND SHARE IN TON-KM IN 2005<sup>1</sup>

|              | bln ton-km    | Share       |
|--------------|---------------|-------------|
| Road         | 5,706         | 37.5%       |
| Rail         | 7,726         | 50.8%       |
| IWT          | 1,782         | 11.7%       |
| <b>Total</b> | <b>15,213</b> | <b>100%</b> |

Source: OECD (2010) and World Bank (2007)

<sup>1</sup> Based on transport in OECD countries, other Eastern European countries, Russia and other former Soviet countries, and China

figure 2.5 shows the modal split for several countries and the variations between them. Countries with a large land mass, such as the United States, Russia and China, all have a relatively high percentage of rail transport, as high as 88% for Russia. Countries situated in a river delta, such as the Netherlands, Bangladesh and Vietnam, have a relatively small share in rail, and rely more on IWT.

Figure 2.5 Modal split of transport for selected countries (shares in total ton -km)<sup>1</sup>

Source: European Commission (2010), OECD (2010), World Bank (2007), ECORYS & Consia (2010), Ahmed et. al. (2010)

<sup>1</sup> NL, FR, RU, VN = year 2008, USA = year 2007, CN = year 2005, BAN = 2002

The modal split does not reveal any information about the size of the markets concerned. The following table gives an overview of IW transport in 2000, 2005 and 2008, and shows that China has the largest IW freight flows in terms of ton-kilometers. The total volume of freight transported also increased strongly between 2000 and 2005.

IWT is also very large in the United States and Russia, even though its share in the modal split is relatively small in these countries.

TABLE 2.3 IWT FREIGHT GROWTH IN SELECTED COUNTRIES (BILLION TON-KM)

|               | 2000 | 2005  | 2008 |
|---------------|------|-------|------|
| EU27          | 134  | 139   | 145  |
| - Netherlands | 41   | 42    | 45   |
| - Germany     | 66   | 64    | 64   |
| - France      | 9    | 9     | 9    |
| Russia        | 71   | 87    | 64   |
| China         | 712  | 1,112 |      |
| USA           | 526  | 476   | 472  |
| Vietnam       |      |       | 22   |
| Bangladesh    |      | 3     |      |

Source: European Commission (2010), OECD (2010), World Bank (2007), ECORYS & Consia (2010)

The above table indicates that transport mode policies should not only target countries based on their modal shares, but also countries with substantial volumes of transport by these modes.

#### IMPACT OF A SHIFT IN MODAL-SPLIT TOWARDS IWT ON THE TRANSPORT SECTOR CONTRIBUTION TO CLIMATE CHANGE

Previous sections showed that CO<sub>2</sub> emissions per ton-km for inland shipping are much lower than for road transport. This is because of the higher energy efficiency of inland shipping (fuel consumed per ton-km shipped).

A shift in modal split from road to IWT would have a dramatic impact on overall CO<sub>2</sub> emissions. IWT accounts for an estimated 14% of total goods transported, but only 7% of CO<sub>2</sub> emissions. Road transport accounts for around 30 percent of goods transported and contributes 87 percent of total CO<sub>2</sub> emissions. Transferring only 5% of the volume transported by road to IWT, would therefore have a significant impact on global CO<sub>2</sub> emissions. A staggering 62 Mt of CO<sub>2</sub> emissions could be saved in this way.

Policy actions that aim at improving the competitive position of IWT compared to other modes could help to reduce climate change impacts. This could further be combined with measures to increase the energy efficiency of the transport modes concerned. Measures for IWT could aim at increasing the scale of IWT vessels and improving their environmental performance. These trends have already been noted in various developed countries. Part B of this report presents available engine technologies (CNG and other) and other technical options for increasing the fuel efficiency of ships.

### 3 IWT PERFORMANCE IN VARIOUS COUNTRIES

The previous chapter assessed IWT at a global level and compared it with other transport modes. This chapter analyzes IWT energy efficiency and focuses on IWT performance and a comparison between countries. Section 3.1 deals with the energy performance of IWT in various countries where this mode plays an important role. Section 3.2 assesses factors that help to explain the differences observed.

#### 3.1 ENERGY PERFORMANCE

Chapter 2 showed that IWT energy efficiency ranges between about 25 gr CO<sub>2</sub>/ton-km to 70 gr/ton-km, which equals to a fuel consumption of about 0.008-0.023 liters/ton-km if diesel is used. Table 3.1 presents the performance observed in various countries.

TABLE 3.1 EMISSIONS PER TON/KM IN IWT IN VARIOUS COUNTRIES

| Region/ Country | Fuel consumption (liters/ton-km)      |        |
|-----------------|---------------------------------------|--------|
|                 | Average gram CO <sub>2</sub> / ton-km |        |
| EU15            | 32                                    | 0.0102 |
| - Netherlands   | 40                                    | 0.0127 |
| - Germany       | 26                                    | 0.0083 |
| - France        | 33                                    | 0.0105 |
| Vietnam         | 71                                    | 0.0226 |
| United States   | 26                                    | 0.0083 |

Source: own calculations based on Tremove 2.7b (2010), ECORYS & Consia (2010), Texas Transportation Institute & Center for Ports & Waterways (2009). Fuel consumption data have been calculated using the conversion factors as presented in Ch. 2.

The table above uses the data presented in figure 2.3. The methodology used for the different sources is explained in paragraph 2.1.

There is a big difference between average CO<sub>2</sub> emissions in Vietnam and Western countries. The average emission level in Vietnam is about 30 gr/ton-km higher than in the next Western country in line, the Netherlands. The CO<sub>2</sub> emissions of the other countries are all in the same range.

Several factors that may explain the differences observed are analyzed in the next section.

#### 3.2 FACTORS INFLUENCING CO<sub>2</sub> EMISSIONS

The following factors explain differences in IWT energy efficiency between countries:

- Sizes and types of vessels used (fleet breakdown);
- Age of the fleet and of engines;
- Nautical conditions; and
- Market factors.

## SHIP SIZES AND SHIP TYPES

table 3.2 shows that larger vessels are generally more energy efficient per ton-km. For example, the CO<sub>2</sub> emissions per ton-km of a push barge with a load capacity of over 3,000 tons are 33% lower than the emissions of a ship with a capacity of 250 tons. The comparison assumes a load factor of 100 percent and no empty trips. Different load factors and percentage of empty trips would influence the validity of comparisons. However, the conclusion above remains valid for a given load factor and percentage of empty trips.

TABLE 3.2 FUEL CONSUMPTION FOR DIFFERENT SHIP SIZES

| Ship type          | Maximum load weight (ton) | Fuel consumption in g/km | CO <sub>2</sub> emissions in g/km | CO <sub>2</sub> g/ton-km (based on maximum load weight in ton) |
|--------------------|---------------------------|--------------------------|-----------------------------------|--|
| <b>Dry cargo</b>   |                           |                          |                                   |  |
| < 250 t            | 364                       | 973                      | 3,045                             | 8.4  |
| 250 – 400 t        | 364                       | 973                      | 3,045                             | 8.4  |
| 400 – 650 t        | 638                       | 1,360                    | 4,258                             | 6.7  |
| 650 – 1,000 t      | 968                       | 2,030                    | 6,354                             | 6.6  |
| 1,000 – 1,500 t    | 1,350                     | 2,780                    | 8,701                             | 6.4  |
| 1,500 – 3,000 t    | 2,160                     | 5,058                    | 15,833                            | 7.3  |
| > 3,000 t          | 2,160                     | 5,058                    | 15,833                            | 7.3  |
| <b>Tanker</b>      |                           |                          |                                   |  |
| < 250 t            | 364                       | 973                      | 3,045                             | 8.4  |
| 250 – 400 t        | 364                       | 973                      | 3,045                             | 8.4  |
| 400 – 650 t        | 638                       | 1,360                    | 4,258                             | 6.7  |
| 650 – 1,000 t      | 968                       | 2,030                    | 6,354                             | 6.6  |
| 1,000 – 1,500 t    | 1,350                     | 2,780                    | 8,701                             | 6.4  |
| 1,500 – 3,000 t    | 3,000                     | 7,877                    | 24,654                            | 8.2  |
| > 3,000 t          | 3,000                     | 7,877                    | 24,654                            | 8.2  |
| <b>Push barges</b> |                           |                          |                                   |  |
| < 3,000 t          | 4,000                     | 6,618,459                | 20,716                            | 5.2  |
| > 3,000 t          | 7,700                     | 13,685,290               | 42,835                            | 5.6  |

Source: Own calculations based on input data for Tremove 2.7b (2010).

IWT fleet composition is a highly variable factor that should also be considered when comparing IWT energy efficiency in different countries. In the case of Vietnam, for instance, the fleet consists largely of self propelled dry cargo bulk ships, as opposed to the US fleet, up to 77% of which consists of barges operated in push convoys (see table 3.3). The average size of a vessel in the US is therefore much larger than in other countries (see tables 3.4 and 3.5.). The small size of inland vessels in Vietnam explains the high average CO<sub>2</sub> emission of IWT in that country compared to the low emissions in the United States. However, this does not explain why the CO<sub>2</sub> emissions of Dutch ships are higher than those of French or German ones. This may be caused by market factors (see below).

TABLE 3.3 BREAKDOWN OF INLAND SHIPPING FLEET IN 2008 IN TYPE OF VESSEL (BAN = 2007)

|                    | NL           | US            | VN <sup>1</sup> | BAN <sup>2</sup> |
|--------------------|--------------|---------------|-----------------|------------------|
| dry cargo ships    | 58%          | 2%            | 75%             | 12%              |
| Tankers            | 13%          | 0%            | 2%              | 6%               |
| Tugboats           | 10%          | 13%           | 4%              | 10%              |
| Dry bulk barges    | 12%          | 66%           |                 | 16%              |
| tanker barges      | 1%           | 11%           |                 | 6%               |
| Passenger ships    | 5%           | 2%            |                 | 8%               |
| Other              |              | 5%            | 20%             | 41%              |
| <b>Total</b>       | <b>100%</b>  | <b>100%</b>   | <b>100%</b>     | <b>100%</b>      |
| <b>Total ships</b> | <b>5,009</b> | <b>40,301</b> | <b>130,970</b>  | <b>195</b>       |

<sup>1</sup> For VN: category other contains passenger ships

<sup>2</sup> For BAN: BIWTC fleet only, categorization adjusted by study team

Sources: Central Commission for Rhine Shipping (NL) (2009), USACE (US) (2009b), ECORYS & Consia (VN) (2010), BIWTC (2007). Data VN include country boats.

The US data show a predominance of vessels ranging from 1,000 to 2,000 tons, most of which are barges operated in convoys of 9 to 15. This result in combined sizes of over 10,000 tons, resulting in substantially improved efficiency compared to that of the original fleet structure.

In France vessels types are smaller than, for instance, in the Netherlands. In part this is a function of the fairway network, France having much more smaller waterways.

TABLE 3.4 SHARE IN SIZE BASED ON NUMBER OF VESSELS IN 2008 (FR, BAN = 2007)

|                      | NL           | FR           | US <sup>1</sup> | VN            | BAN         |
|----------------------|--------------|--------------|-----------------|---------------|-------------|
| Up to 249 t          | 10%          | 0%           | 1%              | 91%           | 34%         |
| 250 - 399 t          | 7%           | 41%          | 0%              | 3%            | 16%         |
| 400 - 649 t          | 14%          | 23%          | 5%              | 2%            | 13%         |
| 650 – 999 t          | 18%          | 16%          | 8%              | 3%            | 22%         |
| 1,000 – 1,499 t      | 18%          | 8%           | 33%             | 1%            | 14%         |
| 1,500 – 1,999 t      | 9%           | 3%           | 42%             | 0%            | 2%          |
| 2,000 - 2,499 t      | 7%           | 3%           | 1%              | 0%            | 0%          |
| 2,500 – 2,999 t      | 9%           | 6%           | 0%              | 0%            | 0%          |
| 3,000 t and more     | 8%           | 0%           | 9%              | 0%            | 0%          |
| <b>Total</b>         | <b>100%</b>  | <b>100%</b>  | <b>100%</b>     | <b>100%</b>   | <b>100%</b> |
| <b>Total vessels</b> | <b>4,499</b> | <b>1,369</b> | <b>31,238</b>   | <b>95,126</b> | <b>102</b>  |

<sup>1</sup> Excluding self propelled vessels (894 vessels) and tugboats (5,424 vessels) for which no capacity data was available

Sources: Central Commission for the Navigation of the Rhine (NL + FR) (2008 & 2009), USACE (US) (2009b), ECORYS & Consia (VN) (2010), BIWWC (BAN) (2007). Data VN include country boats.

TABLE 3.5 SHARE IN TOTAL CAPACITY IN 2008 ('000 TONS) (FR, BAN = 2007)

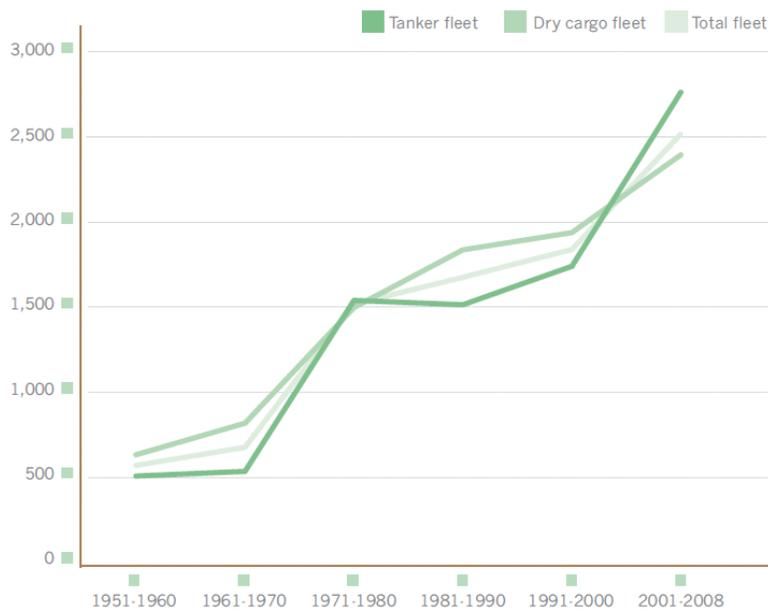
|                        | NL           | FR            | US <sup>1</sup> | VN           | BAN         |
|------------------------|--------------|---------------|-----------------|--------------|-------------|
| Up to 249 t            | 1%           | 0%            | 0%              | 30%          | 7%          |
| 250 - 399 t            | 2%           | 0%            | 0%              | 12%          | 11%         |
| 400 - 649 t            | 6%           | 1%            | 1%              | 14%          | 12%         |
| 650 - 999 t            | 11%          | 4%            | 4%              | 24%          | 35%         |
| 1,000 - 1,499 t        | 17%          | 28%           | 28%             | 20%          | 29%         |
| 1,500 - 1,999 t        | 12%          | 39%           | 39%             | 0%           | 6%          |
| 2,000 - 2,499 t        | 11%          | 1%            | 1%              | 0%           | 0%          |
| 2,500 - 2,999 t        | 19%          | 1%            | 1%              | 0%           | 0%          |
| 3,000 t and more       | 22%          | 25%           | 25%             | 0%           | 0%          |
| <b>Total</b>           | <b>100%</b>  | <b>100%</b>   | <b>100%</b>     | <b>100%</b>  | <b>100%</b> |
| <b>Total '000 tons</b> | <b>5,924</b> | <b>58,218</b> | <b>58,218</b>   | <b>7,801</b> | <b>53</b>   |

<sup>1</sup> Excluding self propelled vessels and tugboats for which no capacity data was available

Sources: Central Commission for the Navigation of the Rhine (NL + FR) (2008 & 2009), USACE (US) (2009b), ECORYS & Consia (VN) (2010), BIWTC (BAN) (2007).

Historical analysis of the Western European shipping fleet shows that there has been a gradual increase in size since the 1950s. This path could also be followed by developing countries. Ship size in Vietnam, for instance, is increasing rapidly, a trend that is expected to continue (ECORYS & Consia, 2010).

Figure 3.1 Average increase in tonnage in the West European fleet



Source: BVB (2009)

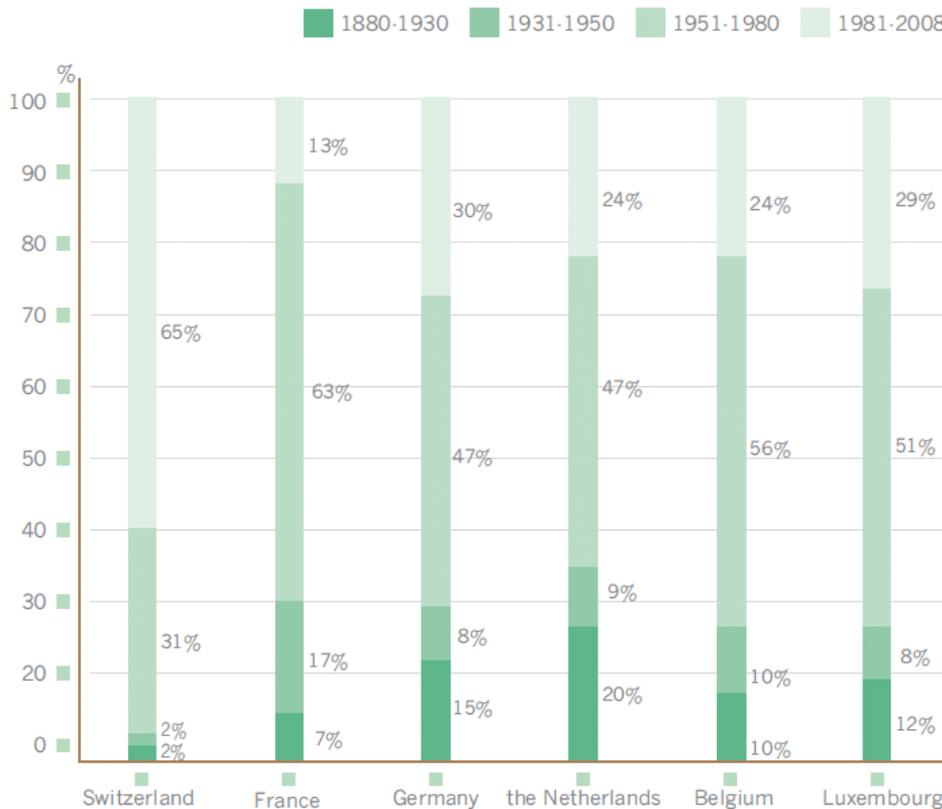
AGE OF FLEET AND ENGINES

Newer vessels generally have lower CO<sub>2</sub> emission per ton-km than older ones, largely due to continuing technological improvements. This relates to the design of the vessel and the engine technologies used (see also part B of this report for more details on these factors).

New technologies however penetrate slowly as ships tend to be in operation for a long period of time, which increases the return on investment. BVB (2009) states that well-maintained ships could have a life span of over 50 years. Accordingly only 24% of all vessels in the Netherlands are less than 20-year old. This renewal rate is much lower than in the case of road transport. About 70% of all truck and trailer combinations in the Netherlands is less than 5 years old (ECORYS 2009).

In Bangladesh, age data of only the BIWTC fleet could be obtained (BIWTC, 2007). This indicated that most ships were built in the 1960s and 70s, with self-propelled barges and a number of ferries built mainly in the 1980s. This suggests a similar age structure as in European countries (Figure 3.2).

Figure 3.2 Dates of construction of the inland shipping fleet in Western Europe

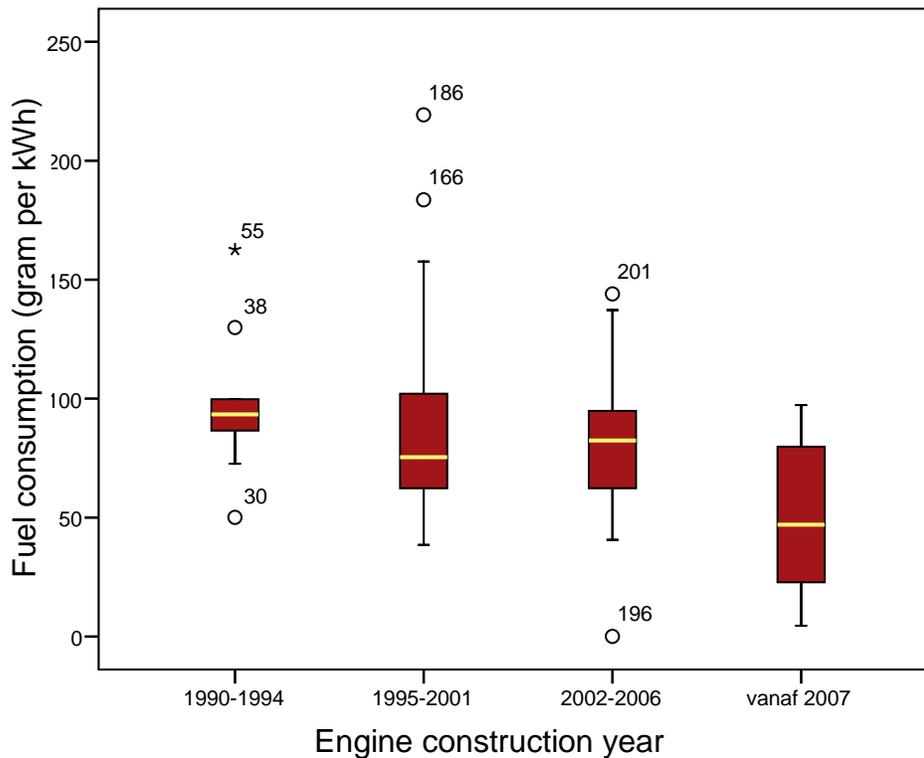


Source: BVB (2009)

The hull may be used for more than 50 years, though engines could be modernized for improved performance. Some older vessels may therefore have an energy performance similar to that of younger vessels.

An Ecorys survey conducted among shipping operators in the Netherlands confirms the relation between engine age and fuel consumption (see Figure 3.3 below). Fuel consumption is expressed in grams per kWh of engine output. This measure differs from the grams per ton-km shipped. The study shows that these two indicators correlate well.

Figure 3.3 Fuel consumption by engine age (in gram per kWh)



Source: ECORYS (2008)

#### NAUTICAL CONDITIONS

Nautical conditions in a country also contribute to variations in energy performance. Sailing upstream rivers against a strong flow of water uses more fuel than sailing downstream or in quiet canals. This could be an advantage in countries with dense canal networks.

Water levels are also relevant. Most rivers depend on rain or melting snow for their water supply, both of which may vary in the course of a year with

pronounced low or high water periods. Fuel consumption may increase during low water periods because of lower load factors and reduced keel clearance (see part B on this matter). Flow velocity may increase during the high water season, resulting in higher fuel consumption when traveling upstream, and lower consumption the other way around.

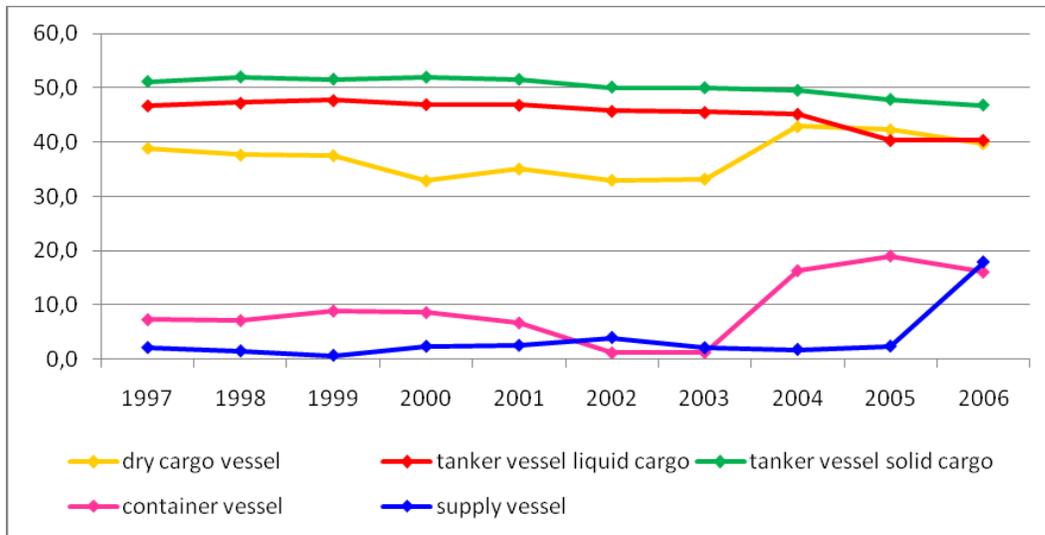
MARKET FACTORS

Market structure, finally, could contribute to varying energy-efficiency performances across countries. Load factor and empty kilometers are especially relevant in this regard. Data about the market structure in the Netherlands was presented in Table 2.1 of chapter 2. Similar country-wide data sets could not be found for other countries.

Studies in the Netherlands (ECORYS, 2008) indicate that larger sized vessels tend to have a lower share of empty trips than smaller ones, leading to better overall efficiency. This is because it is easier to find return consignments for larger ships than for smaller ones, which are dependent on the availability of smaller consignments.

The share of empty trips also tends to be lower for vessels that are operated continuously (24 hours/day, 7 days/week), as opposed to semi-continuous or daily operations (ECORYS, 2008). Beelen (2010) confirms this for Belgium where vessel types vary substantially (see figure 3.4 below).

Figure 3.4 Evolution of share of empty trips by vessel type (1997-2006)



## 4 BENCHMARK METHODOLOGY

This chapter describes methods available to measure the energy efficiency of different transport modes. Section 4.1 deals with general methods for all transport modes. In section 4.2 a method specific to the IWT sector is described.

### 4.1 ACTUAL EMISSIONS METHOD

The energy efficiency of (freight) transport modes, expressed in *Kilograms of CO<sub>2</sub> emission per ton-kilometer*, is calculated by means of the following formula:

(1.)

$$\text{kg CO}_2 / \text{ton} \cdot \text{km} = \frac{\text{consumed fuel} \times \text{CO}_2 \text{ emission factor}}{\text{payload} \times \text{distance travelled}}$$

Energy consumption in *Megajoules per ton-kilometer* (i.e. an alternative method to measure energy efficiency) is calculated by means of the following formula:

$$(2.) \quad \text{MJ} / \text{ton} \cdot \text{km} = \frac{\text{consumed fuel} \times \text{energy density}}{\text{payload} \times \text{distance travelled}}$$

Table 4.1 describes the parameters used in the formulas (1.) and (2.).

Table 4.1 Parameters for measurement of energy efficiency and consumption

| Variable                        | Description  | Unit       |
|---------------------------------|--|------------|
| Consumed fuel                   | Overall fuel consumption of investigated vehicle(s)/vessel(s) per unit of time (e.g. year, month)            | liters     |
| CO <sub>2</sub> emission factor | CO <sub>2</sub> emission per combusted unit of fuel  | kg / liter |
| Energy density                  | Energy content (Lower Heating Value) per combusted unit of fuel  | MJ / liter |
| Payload                         | Total amount of freight transported by investigated vehicle(s)/vessel(s) per unit of time (e.g. year, month) | tons       |
| Distance traveled               | Average distance traveled by the total amount of transported freight   | kilometer  |

The formulas (1.) and (2.) can be used to calculate the energy efficiency of any transport (sub) sector in a specific geographical area. They could also be used to determine the energy efficiency of any one specific vehicle/vessel or a vehicle/vessel class.

The formulas for IWT are based on the commonly used method for measuring the carbon footprint of transport sectors. This is in line with the IPCC protocol, which states that the calculation of greenhouse gas emissions of inland waterway transport should be based on the fuel supplied to vessels which have their points of departure and arrival within the region or country being analyzed.

#### 4.2 'DUTCH METHODOLOGY'

Using the 'actual emissions method' for international transport poses a problem for the allocation of emissions, as all exhaust emissions should be allocated to the country where they are emitted. This does not necessarily have to be the same country in which the fuel was bunkered. An alternative measurement method was used to determine IWT emissions in Western Europe to overcome this problem.

This method was applied to Dutch inland shipping, where it is referred to as the 'Dutch methodology' (Klein *et al.*, 2009; Denier van der Gon, H., Hulskotte, J., 2010). It aims at measuring:

##### EMISSIONS FROM VESSEL PROPULSION ENGINES PER VESSEL CLASS

The 'Dutch methodology' considers all emissions on the basis of energy consumption per vessel class. The power demand (kW) for all vessel types is calculated for various inland waterway types and rivers, and a distinction is made between loaded and empty ships. An average speed is calculated on the basis of the vessel class and the maximum speed allowed on the route concerned. (Klein *et al.*, 2009)

Depending on the route followed, IWT fuel bunkered in one country can result in emissions in several other countries. However, CO<sub>2</sub> emissions resulting from international transport are not included in IPCC calculations. This is covered by the 'Dutch methodology', which is used to calculate tailpipe emissions from national and international IWT in Dutch territory.

In contrast to the actual emissions method, the 'Dutch methodology' uses data on 'traffic intensities' (i.e. exact data on the combination of vessel class and a particular inland waterway) to determine IWT emissions. In 2003, when the method was developed, such data was not readily available, a situation that was expected to change. However, by 2010 such data remained unavailable. Accordingly indirect data was, and still is, used to make a rough estimation of IWT emissions. Emission data produced by means of the 'Dutch methodology' should therefore be considered provisional (Denier van der Gon, H., Hulskotte, J., 2010).

Formula (3.) uses the Dutch methodology to calculate IWT emissions per vessel class:

(3)

$$\text{Emission} = \text{vessel passages} \times \text{power demand} \times \text{time} \times \text{emission factor}$$

Vessel passages are the number of vessels passing a distinct inland waterway it route. The general calculation is tailored to the available data.

Formula (4.) is used to calculate the emission (e) in kilograms of substance (s) in one direction (d) for a specific vessel class (v,c), with or without cargo (b), on a specific route (r) on Dutch inland waterways (Klein *et al.*, 2009):

$$(3.) \quad E_{v,c,b,r,s,d} = N_{v,c,b,r,d} \cdot P_{v,b,r} \cdot \frac{L_r}{(V_{v,r,d} + V_r)} \cdot EF_{v,s}$$

Formula (5.) can be derived from (4.) to calculate CO<sub>2</sub> emissions per ton-km payload transported in a specific vessel class (v,c), over a specific route (r), in one direction (d), with a cargo:

$$(4.) \quad \frac{E_{v,c,r,d}}{Pl_{v,c,r,d}} = \frac{N_{v,c,r,d} \cdot P_{v,r}}{(V_{v,r,d} + V_r) \cdot Pl_{v,c,r,d}} \cdot EF_v$$

The energy efficiency of the investigated transport mode in formula (5.) is expressed in the same unit as in formula (1.):

$$\frac{kgCO_2}{ton \cdot km} \quad \text{Kilograms } CO_2 \text{ emission per ton-kilometer}$$

Table 4.2 provides an overview of the variables and indices used in formulas (4.) and (5.).

TABLE 4.2: VARIABLES FORMULA (4.) [KLEIN ET AL., 2009]

|                   | Description   | Unit             |
|-------------------|---|------------------|
| $E_{v,c,b,r,s,d}$ | Emission from propulsion engines per vessel class   | kg               |
| $N_{v,c,b,r,d}$   | Number of vessels of this class on the route and with this cargo situation sailing in this direction        | -                |
| $P_{v,b,r}$       | Average engine power of this vessel class on this route   | kW               |
| $L_r$             | Length of the route   | kilometer        |
| $V_{r,s,d}$       | Average speed of the vessel in this class on this route   | Kilometer / hour |
| $V_r$             | Rate of flow of the water on this route (either positive or negative)                                       | Kilometer / hour |
| $EF_{v,s}$        | Average emission factor of the engines of this vessel class   | kg / kWh         |
| $Pl_{v,c,r,d}$    | Total payload transported by the number of vessels $N$ of this class on the route sailing in this direction | tons             |
| Indices           | Description   |                  |
| $V$               | Vessel class  |                  |
| $C$               | Aggregated cargo capacity class   |                  |
| $B$               | Cargo situation (loaded or unloaded)  |                  |
| $R$               | Route   |                  |
| $S$               | (Emitted) substance (e.g. CO <sub>2</sub> )   |                  |
| $D$               | Direction of travel   |                  |

### 4.3 PRACTICALITIES OF VARIOUS METHODS

The 'actual emissions method' (method 1) and 'Dutch methodology' (method 2) could theoretically be applied to all IWT systems to calculate energy efficiency. However, a number of practicalities should be considered when choosing between these.

- *Data availability*

The two methods have very different data requirements. Method 1 (actual emissions method) requires only crude information about fuel consumption and freight. Method 2, as applied in the Netherlands, relies on an extensive IWT database. Similar data may be obtainable in other developed countries. Most developing countries, to the contrary, do not have as clearly defined vessel classes and routes or have less developed traffic registration systems. Calculating IWT emissions would therefore first entail setting up a database to cover all vessel activity (in vessel kilometers), data on loaded and empty trips, vessel classes and the average power and speed per vessel class. Moreover, a distribution overview of fleet age would have to be conducted to update

figures on power and speed correctly over time. Finally, such a database would have to cover all shipping movements over one year in the country investigated.

- *Emission factors: fuel chain versus transport exhaust only*

Both methods require an emission factor to calculate the CO<sub>2</sub> emission per functional unit. It is also necessary to decide whether to consider the entire fuel supply chain or only the final energy conversion of the fuel (transport exhaust). CO<sub>2</sub> emissions from final fuel to energy conversions (through combustion) depend almost exclusively on the carbon content of the fuel. The data of most common fuels is generally fairly available and accurate. Assessing emissions along the entire fuel supply chain, means taking into consideration also emissions resulting from fuel extraction, transport, production and distribution. All these processes consume energy, thereby reducing overall chain-efficiency and increasing the CO<sub>2</sub> emissions per combusted unit of fuel. However, such inefficiencies vary significantly between fuel types and between countries (e.g. fuel produced locally or imported). It is therefore recommended that energy-efficiency assessments of IWT systems using different primary energy sources also assess the efficiency of the respective fuel supply chains.

- *Ease of calculation*

The emissions of an entire sector can be calculated fairly easily using method 1, whereas method 2 requires a series of calculations per vessel class, route, direction and cargo situation. Moreover, a simple derivative like formula (5.) will hold only for (partially) loaded vessels. Assessing empty vessels will result in a division by zero, which means that the cargo flows have to be analyzed independently of the loaded vessels.

- *Reliability*

Method 1 is based on actual emissions derived from actual fuel consumption, whereas method 2 is based on average energy consumption per vessel class - itself an average derived from the distribution of new and older vessels/engines within a class. A wider range of assumptions are therefore at play in method 2, thereby reducing its reliability relative to method 1.

- *International transport*

IWT fuel bunkered in one country can lead to emissions in other countries, depending on the vessel route. Method 2 makes it possible to allocate emissions from international transport to specific countries or regions by calculating emissions along specified routes and by dividing trajectories in separate routes. This is not possible with method 1 and is one of the main arguments in favor of method 2. Nonetheless, if inland shipping is mainly domestic, there is no need for such divisions and method 1 suffices.

- *Auxiliary systems*

Auxiliary systems on vessels, apart from the main propulsion engine, also consume energy. Such emissions are automatically included in method 1 as CO<sub>2</sub> emission is calculated on the basis of fuel consumption, rather than the engine used. In method 2, CO<sub>2</sub> emissions are calculated using emission factors and power demand. Power demand does not typically include auxiliary systems and associated emissions. A separate analysis is therefore needed,

making use of average auxiliary emissions per vessel class. An alternative would be to include auxiliary systems into the power demand used for the calculations.

- *Other emissions*

The two methods differ substantially in respect of their treatment of other exhaust gas emissions. Method 1 uses the energy content and emission factor of fuels, which are useful only when calculating the energy efficiency and CO<sub>2</sub> emission resulting from the combustion of fuels. Method 2 can also be used to determine the emissions of other substances (such as NOX, CO, PM<sub>10</sub>, etc.) resulting from fuel combustion. This was one of the reasons behind the development of the 'Dutch methodology'. The only requirement is that the average emission factor in kilograms per kilowatt-hour engine power is available for the relevant vessel class. Method 2 thereby provides a framework for calculating the overall impact of vessel movements on climate change and air quality.

- *Passenger transport*

Both methods are designed for assessing freight transport only. The environmental performance of passenger transport can be assessed using a similar method, but where per ton-km figures are replaced with per passenger-km figures. This will be useful in countries with high passenger IWT volumes like Bangladesh. Similar to what is done for freight transport, the method allows for comparison over time and between countries.

- *Comparison between countries*

Method 1 can be used to compare country performance, based on IPCC recommendations, provided the data is gathered in a similar way and using the same definitions across the board. The Eurostat guiding principles ensure that this is the case within Europe. Such certainty about the completeness and correctness of data does not exist in other regions of the world. Despite this the method can generate results that are reliable enough for comparison between countries

#### 4.4 RECOMMENDED APPROACH

The 'actual emissions method' allows for a rapid analysis of the IWT sector in countries or regions where information is not readily available. The calculation is simple and straightforward and allows for a transparent assessment of the situation with actual emission figures. It also depends less on third parties to provide information and the method is recommended when comparing the environmental impact of IWT to that of other transport modes.

The 'Dutch methodology' is an advanced approach which requires an extensive database with detailed information per vessel class, route, direction and cargo situation. It has clear value for IWT in the Netherlands and other internationally oriented, highly codified countries, but less so in the rest of the world.

## PART B: REVIEW OF TECHNOLOGICAL ADVANCES AND IMPROVEMENT TO INCREASE ENERGY EFFICIENCY OF IWT

## 5 INTRODUCTION

Fuel efficiency has been an issue in the Western world going back to the first oil crisis in the seventies. Barge operators – horrified by fuel price increase – were desperately looking for a way to reduce costs, which in some cases amounted to as much as 70% of the total transport costs. Considerable fuel savings were achieved through a joint effort from research institutes, ship builders and designers, and barge operators. The primary objective of the barge operators at that time was cost reduction. The reduction of carbon emissions auxiliary output was considered less important at the time, though this has obviously changed in light of improved knowledge and awareness of the impacts of GHG and the limits of fossil fuel resources.

The following four aspects are generally considered when assessing the efficiency of IWT operations:

1. Optimization of the IWT operations;
2. Minimizing the resistance of hulls and of barge convoys;
3. Efficiency of propulsion methods and steering systems; and
4. Adapting fairways to accommodate optimum ship size and shape.

This review will first focus on **conventional means**, all of which have not necessarily been implemented in all developing countries. Conventional means could be implemented at fairly short notice and the required awareness could be achieved through education, training, seminars and symposium.

This review also considers **advanced means**, technologies and approaches that are in still in their development or pilot phases, including the following:

1. Alternative fuels;
2. Advanced, low-resistance ship design;
3. Advanced, high-efficiency propulsion systems; and
4. New logistical concepts.

A distinction is made between newly built vessels and those with retrofitted technologies, or improvements of older systems. The latter may be cheaper and are often used to modernize existing fleets, especially if they could still be used for a long period of time. The often significant environmental performance achieved in this way may still be below that achieved when the same technology is installed in newly built vessels.

## 6 FUEL SAVINGS BY CONVENTIONAL MEANS

This section will consider the following conventional technologies and concepts:

1. Optimization of IWT operations;
2. Minimizing the resistance of the hull and barge convoys;
3. Efficiency of propulsion methods and steering systems; and
4. Adapting fairways in view of optimum ship size and shape.

The order of these items reflects the size of the investments required. Optimizing operations, at the one extreme, requires little investment and still achieves significant efficiency improvements. The adaptation of fairways, at the other extreme, requires significant investments.

### 6.1 OPTIMIZATION OF IWT OPERATIONS

#### VOYAGE PLANNING

Voyage planning can help to maximize benefits from tides and currents, especially where narrow tidal passages must be negotiated. Relevant items include reducing the speed or adjusting the departure for just-in-time arrival for loading and unloading. This requires the cooperation of port managers who, more often than not, focus entirely on minimizing demurrage, which exists only for seagoing vessels.

Also the cooperation of the crew is needed, who may not be overly concerned about operational efficiency. Rewards could be used to motivate them, but carefully so as not to receive unintended effects. In the Netherlands this is achieved through the promotion program 'VoortVarend Besparen' (proactive saving). A highly successful fuel competition motivated crew to sail as efficiently as they could. No direct reward was at stake, but the honor of being recognized as the most efficient among peers served as the motivation. The program also helped shipping companies to achieve substantial benefits as a result of the fuel saved.

#### BARGE CONVOY FORMATION

Push-barges are the most fuel- and cost-efficient mode for point-to-point transportation of commodities. This applies to traditional cargo such as coal, grain, fertilizer and fuels, but also to containers and even cars. Optimization can be achieved through the formation of barge convoys instead of using single cargo vessels. Push-barge systems are less common in developing countries because of the high investment costs and the scattered pattern of origins and destinations of most freight transport.

Barge formations require a large fleet and therefore a high investment costs. It also requires a high level of organization at the headquarters and at the ports. Barge formations thereby become viable only in the case of large and capital

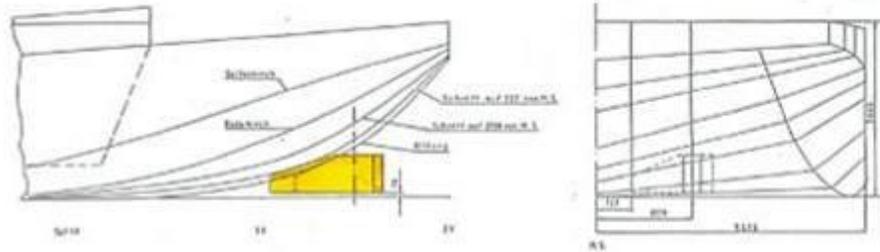
intensive companies serving dense transport corridors. Self-propelled barges are more flexible in scattered freight flow situations, and can render a dedicated service to one shipper. An intermediate solution requiring minimal up-front investment is the use of self-propelled vessels that are converted for pushing up front (tandem formation).

It is not necessary to substantially increase the propulsion power of an existing self-propelled vessel to push an extra barge. This is because the improved length to beam ratio (L/B) creates an enormous hydraulic advantage, translating into much lower specific power (the power required per cubic meter of water displacement) to reach the same speed. The benefit is such that a slight reduction in speed might even be acceptable. Substantial energy savings can be achieved by adding a barge to the self-propelled vessel.

Some operators using this system equipped their extra barge with a bow steering unit for improved maneuverability or for shifting the barge temporarily to another quay or jetty. Such a unit comes in useful when extra power is needed against strong current or lateral winds, or for emergency maneuvers.

Other operators equip their dumb barges with a passive bow rudder, hand or mechanically operated, for additional maneuverability. The technical design of such a system is shown in the following figure.

Figure 6.1 Dumb barge with passive rudders for bow steering



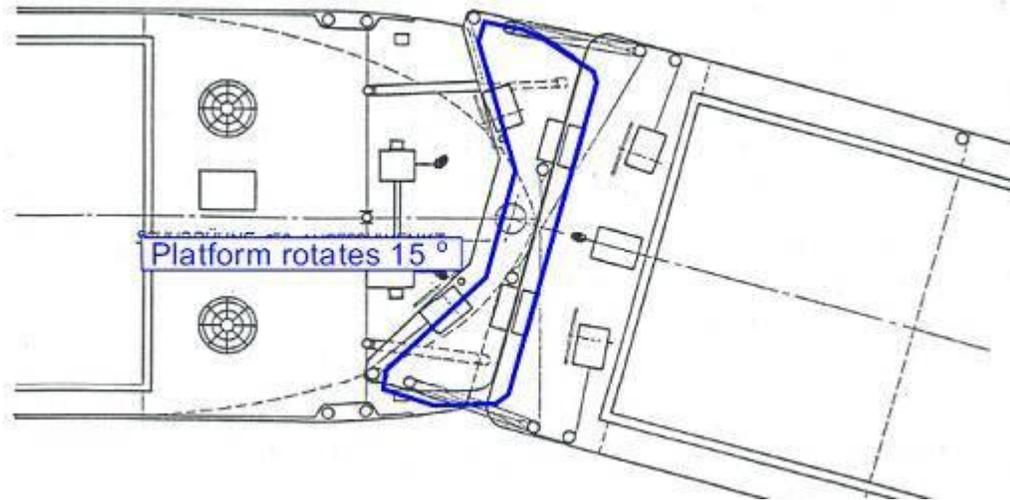
Source: own drawing study team based on lectures of Dick d'Arnaud for ESCAP in Bangkok (1989), Jakarta (1990), The Netherlands (1991 and 1993) and others.

It is possible to use a so-called Articulated Barge System (ABS, see figure 6.2) with a self-propelled vessel plus dumb barge system. This provides a significant advantage when sailing through bends and the drift angle is reduced to almost zero. This means that:

- the convoy is capable of negotiating narrow or tightly curved bends instead of breaking up the combination;
- more room is left for oncoming traffic, which no longer has to wait for passage to be completed;
- resistance, and therefore the power needed and fuel consumption, is reduced considerably.

Figure 6.2 shows an ABS consisting of a platform on the pushing vessel, housing bollards and coupling winches, which pivots up to 15 degrees by means of remote controlled hydraulic cylinders. The front barge then acts as a giant rudder.

Figure 6.2 Barge pushing sp vessel using its Articulated Barge System when sailing through a bend



Source: own drawing study team

## 6.2 MINIMIZING THE HULL RESISTANCE

Hull shape could significantly influence overall IWT efficiency, especially in the case of shallow water navigation (which is nearly always the case for IWT).

The stern section must be adapted to house an efficient propulsion system. The shape of the bow-section could be equally important to reduce the hull resistance factor and thereby the power needed to move the vessel. Traditionally vessels in developing countries were built with a fine bow and swept stern, following the well-known practice for sailing vessels and which is ideal for sailing with light winds (see the figure below for an example of this). The most important characteristic of this bow shape is its low resistance, which leads to acceptable speed levels using little power and fuel. However, the carrying capacity of such ships is relatively low.

Figure 6.3 Example of an inland freight vessel with a traditional bow



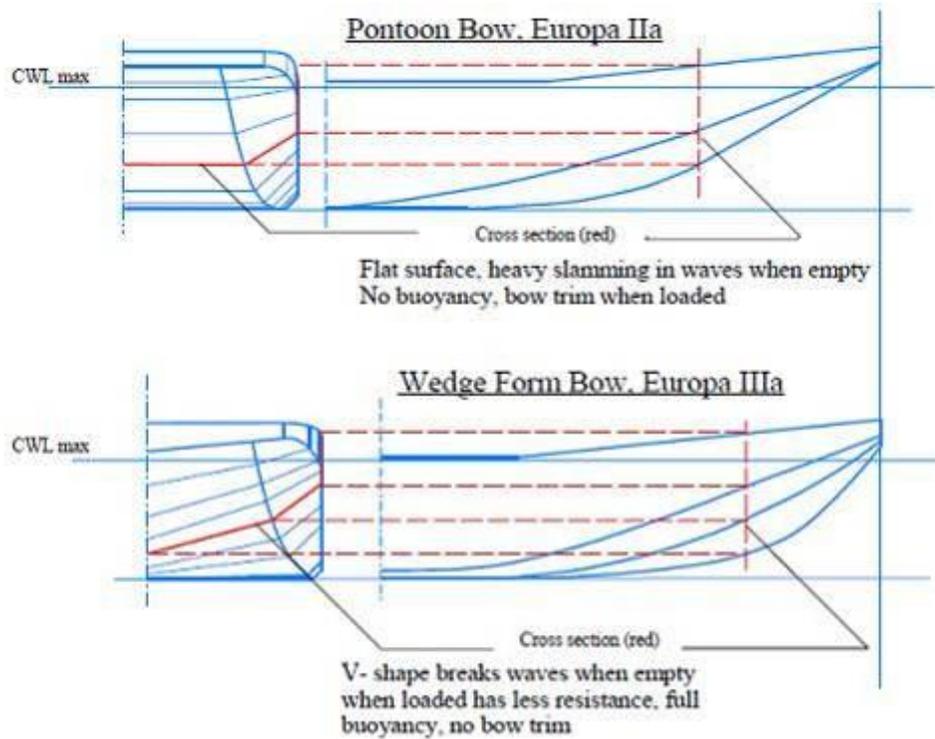
*Source: own photo taken during field mission Bangladesh*

The hulls of the mechanically propelled vessels (and in particular push barges) introduced in Western countries were built in such a way as to maximize cargo carrying capacity, resulting in a full bow and stern and high resistance. This did not matter at the time, because of the low fuel prices.

Since then bow shapes have developed to combine easy construction and maintenance of payload capacity, with low resistance and a reduction of the power needed for propulsion. This design can be used for barges and self-propelled vessels with a box-like hull.

Figure 6.4 compares the initial shape of Europe IIa type (and also USA) barges to the more efficient Europe IIIa shape. Europe IIa consists of a flat bow, slanting under 20 degrees (which was originally even 30 degrees for the smaller type E I). The enlarged type IIIa features a spoon-type stem and wedge-shaped side plates. This shape not only reduces slamming, but also cuts through the water better while increasing bow displacement.

Figure 6.4 Bow shape development of European barges

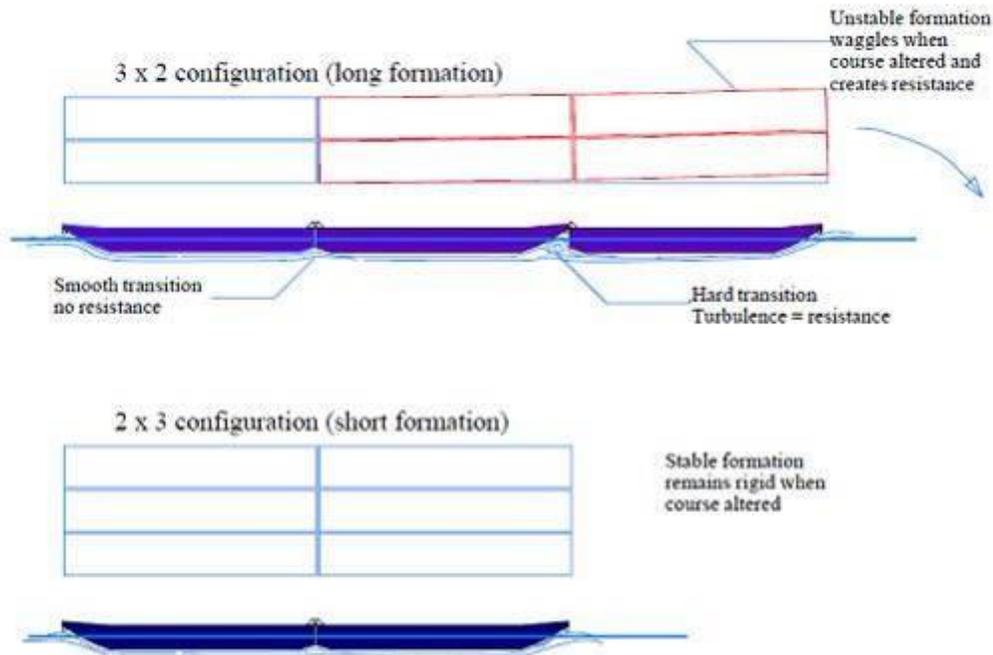


Source: own drawing study team, based on MARIN, VBD and WL research

More efficient convoy and barge formations can similarly reduce water resistance and save energy. A longer and narrower convoy faces less resistance than a short and wide combination. However the advantage of the first may be nullified if the long combination is not rigidly lashed together, because its wagging course would raise the fuel need.

A six barge combination is more efficient in a combination of three wide and two long than of two wide and three long, because in the first combination the stern sections are fully integrated. Therefore they are more rigid than the long formation, because in the long formation the bow of the rear two barges meets the front ones.

Figure 6.5 Barge convoy stability



Source: Own drawing study team

Several research projects aimed at improving hull design. CREATING is the best known project in Europe and resulted in "The Cleanest Ship", a highly efficient gas tanker that currently sails between Rotterdam and Antwerp (Schweighofer & Blaauw, 2009). The European Commission has launched a call for projects to further investigate the modernization of inland vessels under the on-going 7<sup>th</sup> Framework Program. Hull improvement is one of the components of this initiative.

Improving IWT efficiency is also a way to promote the modal shift and, indirectly, to reduce overall CO<sub>2</sub> emissions. The Innovative Barge Trains for Effective Transport on Inland Shallow Waters (INBAT) is a recent project with these objectives and aimed at improving sailing efficiency in shallow water (INBAT, 2005), making use of a combination of lightweight construction and new material applications, an innovative barge train concept and improved propulsive systems.

The project helped to design vessels capable of sailing in water depths of 1m. The changes made will also reduce construction costs and improve payloads. It enhances the viability of operations on smaller or seasonally non-navigable inland waterways. The project further does not directly reduce CO<sub>2</sub> emissions

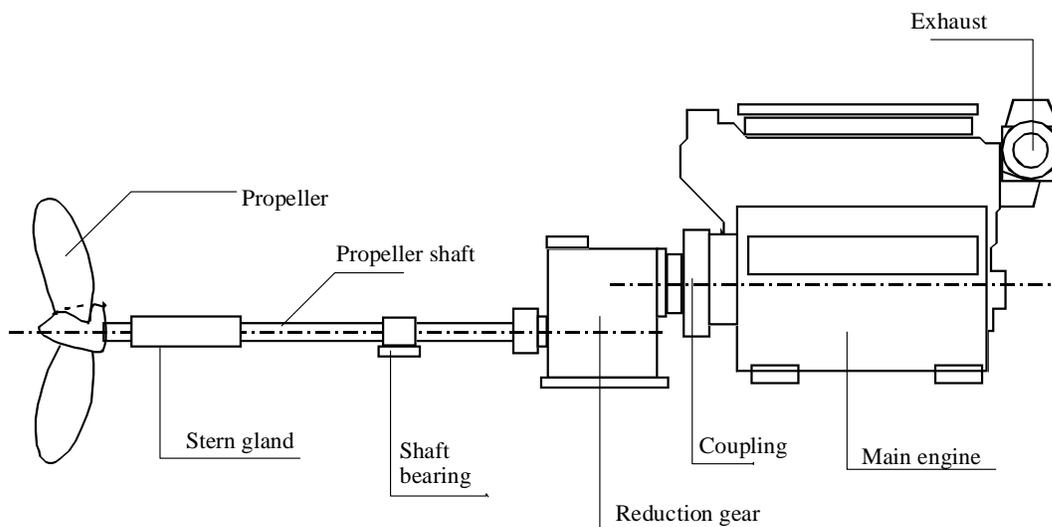
by IWT vessels, but achieves an indirect impact by promoting the modal shift to IWT.

### 6.3 PROPULSION METHOD AND STEERING SYSTEM EFFICIENCY

This section looks at several ways of improving efficiency through reconfiguration of the propeller and stern section, the steering efficiency, and the use of power and of the helm. The main objective is to increase the percentage of fuel energy available as power to the engine propeller.

The figure below contains a schematic presentation of propulsion systems in ships.

Figure 6.6 Schematic display of a propulsion plant

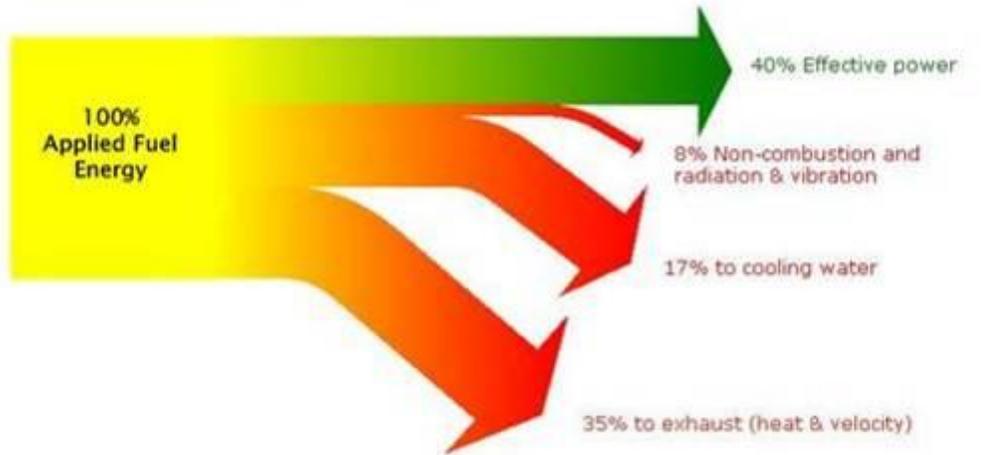


Source: own drawing study team

Figure 6.7 below shows that only 40% of the potential energy in diesel oil will be converted into power on the engine-propeller shaft.

Older engines, which are common in waterborne transport, could have an even worse energy balance, a fact that makes engine replacement an attractive option.

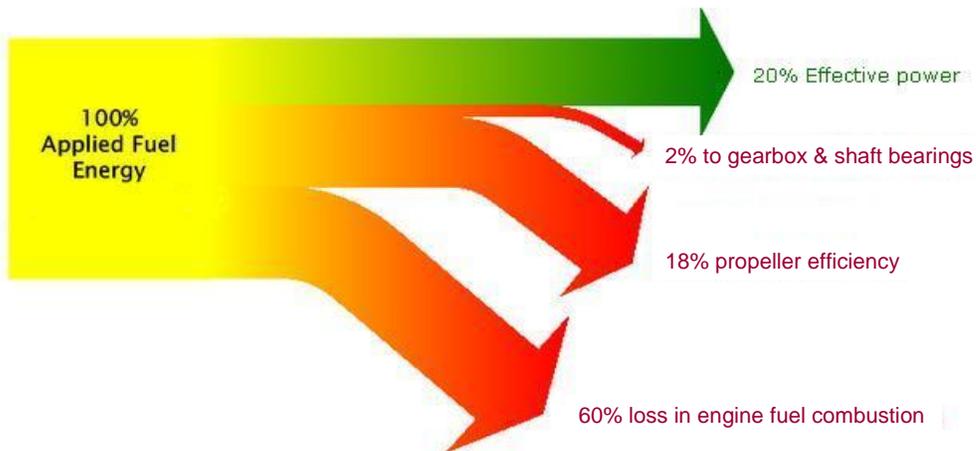
Figure 6.7 Energy balance of a diesel engine



Source: own drawing study team. Figures based on standard diesel engine technology (Prof. Dr. Heuser, VBD)

A properly designed engine uses only about half of effective power delivered to the engine propeller shaft for propulsion, translating into only 20% of the original fuel energy potential. The efficiency of a badly designed engine could be even worse than what is shown in figure 6.8 below.

Figure 6.8 Energy balance of the propulsion plant



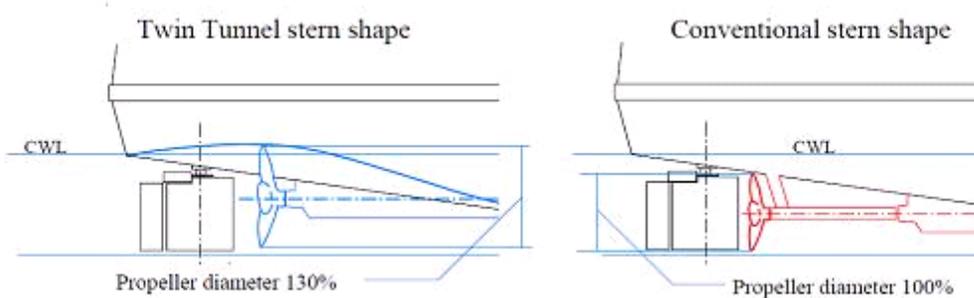
Source: own drawing study team. Figures based on standard diesel engine technology (Prof. Dr. Heuser, VBD) and own trials Dick d'Arnaud

The installation of a gear box, with a high reduction ratio, and a propeller designed specifically for the engine concerned, and the speed and draught of the vessel, count among the main ways improving propulsion efficiency. Such changes may require substantial modification of the ship's stern as described below. The installation of such gear boxes achieved fuel savings of some 30 percent on country boats in Bangladesh.

### 6.3.1 IMPROVING THE PROPELLER AND STERN SECTION

The installation of maximum size propellers for optimal efficiency requires the construction of a tunnel rising above water level on the stern section of the vessels concerned. This makes it possible to house the propeller, though one thereby reduces displacement, affecting trim and load capacity. The efficiency gains, however, compensate for these disadvantages.

Figure 6.9 Propeller size with and without tunnel



Source: own drawing study team based on TU Delft colleges (Dick d'Arnaud)

When it is not possible to increase the propeller size in this way sufficiently, then a twin propeller plant could be installed, the efficiency of which is notably better than that of a single, small diameter propeller. This might be the only way in which to achieve good propeller immersion in shallow waters where ships sometimes have to sail only partially loaded.

### 6.3.2 IMPROVING STEERING EFFICIENCY

Ineffective use of the rudder installation may cause steering with large rudder angles, which induces extra resistance (brake effect).

High rudders cannot be used with IWT vessels due to their limited draught. Accordingly their rudder blades generally have a low aspect ratio (height to length) and thereby reduced efficiency. Blade lengths have to be increased to increase rudder area and thereby efficiency.

More efficient systems rely on multiple rudder blades with a high aspect ratio. Two rudder blades are most commonly used (see figure 6.10 below).

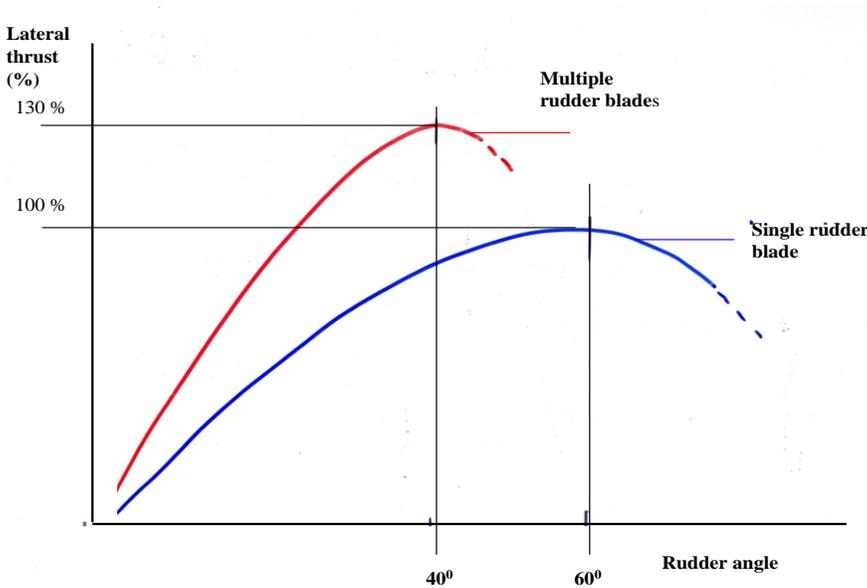
Figure 6.10 Example of a multiple rudder system on an inland vessel



Source: own photo study team taken in the Netherlands

The lateral thrust of a multiple rudder system peaks at a rudder angle of about 40 degrees as opposed to the 60 degrees needed by a single rudder system for substantially less thrust.

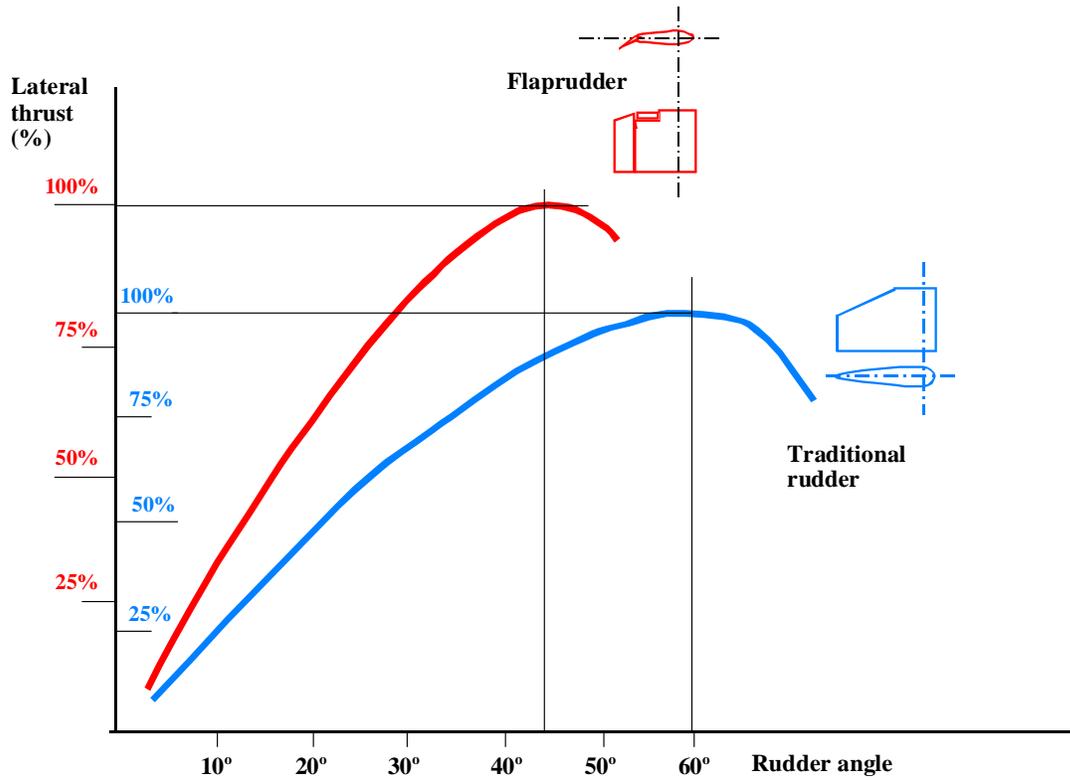
Figure 6.11 Lateral thrust of multiple rudder-vs single rudder



Source: Own drawing study team based on VBD systematic tests 1970 and onward

Energy efficiency improvements can also be achieved by means of a flap rudder. The flap doubles the angle of the main blade, by which it increases lateral thrust at lower angles to a level comparable with that of the multiple rudder system.

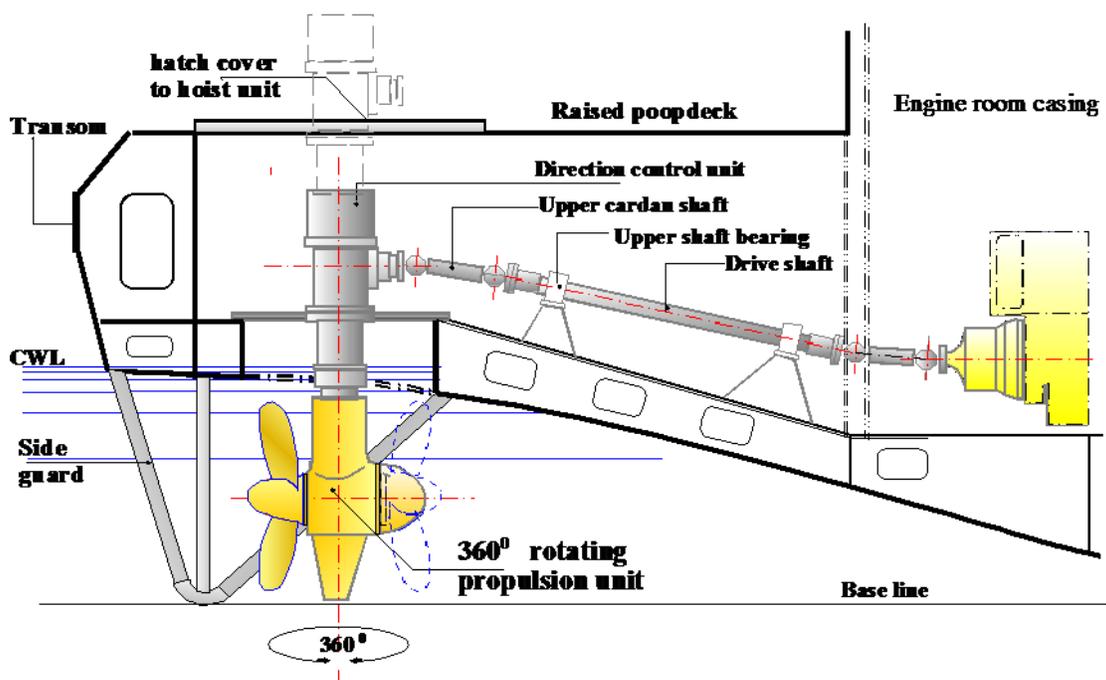
Figure 6.12 Lateral thrust of flap-rudder vs traditional rudder



Source: Own drawing study team based on VBD systematic tests 1970 and onward

A rudder propeller (azimuth thruster) combines efficient propulsion with effective steering and backing. It consists of a propeller assembly capable of 360° rotation as in figure 6.13 below and can direct full thrust in any direction far more effectively than what can be achieved with the most advanced rudder systems. The freely suspended propeller pod in the tunneled stern may however hit the bottom when the stern sweeps over a sandbank and therefore side guards are often added for protection.

Figure 6.13 Arrangement of a rudder propeller system with side guards



Source: Own drawing study team based on MARIN and VBD

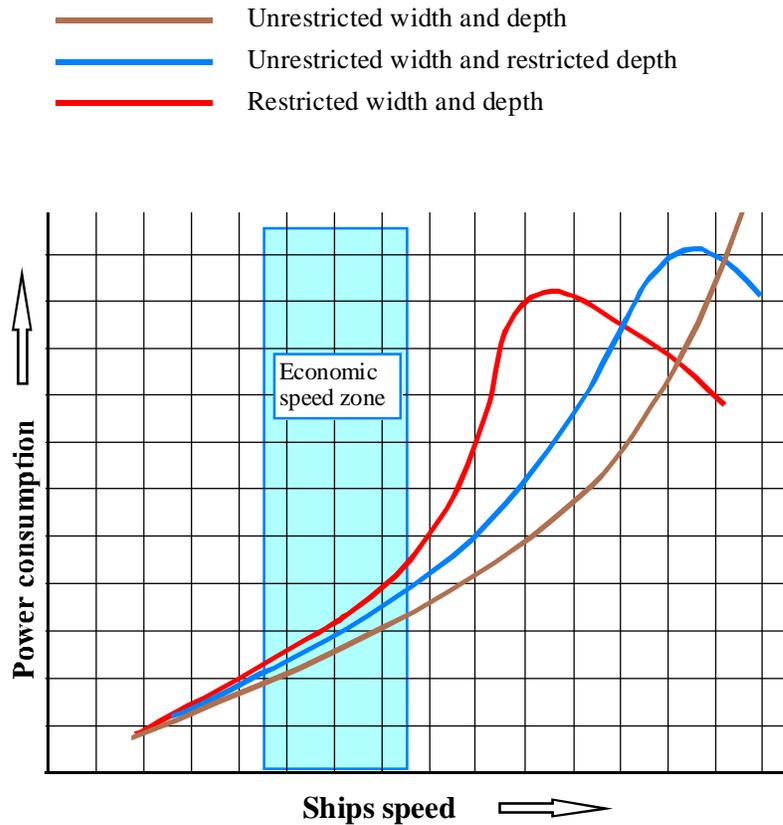
### 6.3.3 USE OF POWER AND HELM

#### POWER

One can significantly reduce fuel consumption with little loss in sailing time by sailing at reduced speeds. The power needed to increase the speed of a vessel sailing under most favorable conditions (i.e. in deep water) builds up to the third power of the velocity increment. This could increase to the fourth or higher power in restricted waters until one reaches 'critical speed', the point after which additional power is not converted into speed<sup>3</sup> as shown in figure 6.14 below.

<sup>3</sup> The critical speed is the speed range whereby speed increase in a fairway restricted in depth and or width is only possible with unproportional high power installed.

Figure 6.14 Power versus ship speed in deep, shallow and restricted waters



Source: Compilation of early test results by Delft Hydraulic Lab and MARIN (1960 - 1970) based on the theoretical approach of Schijff et al, and field test results by Dick d'Arnaud

The brown line indicates the power demand for speed in deep water and represents a third power curve. This curve rises more steeply to about the fourth power (blue curve) when the water is shallow and wide. The power demand curve rises so steeply in shallow and narrow water that it becomes practically impossible to reach the critical speed (red curve). All situations have an economic speed zone in which reasonable speed overlaps with economic fuel consumption.

Simple technical applications like a so-called 'Tempomaat' (speed regulator) or a fuel meter, could significantly affect energy efficiency. A slight decrease in speed could substantially reduce fuel consumption and reduce operating costs. This benefit is not directly observable by ship owners in day-to-day operations who may accordingly be reluctant to invest in such an application.

Tempomaat is a software application that uses GIS to calculate the most economical sail plan, taking into account fairway characteristics, traffic, etc. The Dutch government subsidizes acquisition of this software in the Netherlands. It can reduce fuel use by some 7%<sup>4</sup>.

<sup>4</sup> Source: Interview with Mr. Khalid Tachi of the Dutch Expertise and Innovation Centre Inland Shipping (EICB)

A fuel meter is a very simple tool that can be used to save fuel. It shows how much extra fuel is used if speed is increased and shippers can get a concrete sense of how much they would save by slowing down a bit.

#### HELM

Steering quality has an impact on sailing efficiency and depends on the experience and sensitivity of the helmsman, who has to anticipate the movement of the vessel taking account of the current, wind, water depth and other traffic. Too much helm is given quite often, as a result of which vessels overshoot their intended course. This happens especially with larger vessels or combinations, on shallow and/or narrow waters with other traffic. The combination of (one-sided) bottom drag and suction from other vessels can turn accurate steering into a rather difficult affair.

Compensating for this often results in further overshoots and something of a zig-zag course. Every rudder movement induces some resistance. Overcompensation thereby reduces speed and increases fuel consumption.

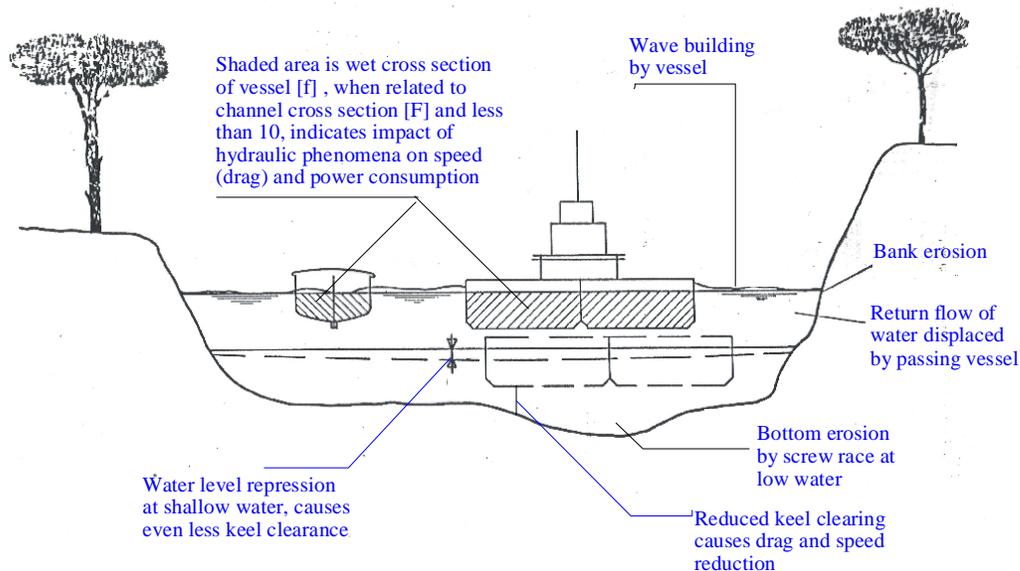
Electric or hydraulically controlled rudder systems reduce over-steering. However, automatic steering equipment represents the best solution. It makes use of a gyro-compass and rate-of-turn selection (zero rate-of-turn = a straight course) and can result in substantial fuel savings.

Increased awareness of steering errors would on its own help to improve efficiency and could be achieved through training and instruction.

## 6.4 ADAPTATION OF THE WATERWAY

The characteristics of fairways have an enormous impact on operational efficiency. Time is saved by straightening rivers, though this may have unwanted impacts on erosion, sedimentation rates and the balance between hydraulic and morphologic regimes. Attention should rather be paid to improving shallow and narrow stretches, with the objective of eliminating suction, or bottom drag, phenomena like squat (settling deeper in the water), and repression (a drop of the water level). Side effects of these improvements include the prevention of bank and river bed erosion, factors that could deteriorate vessel passage (Figure 6.15).

Figure 6.15 Hydraulic effects in width and/or depth restricted fairways



Source: Own drawing study team

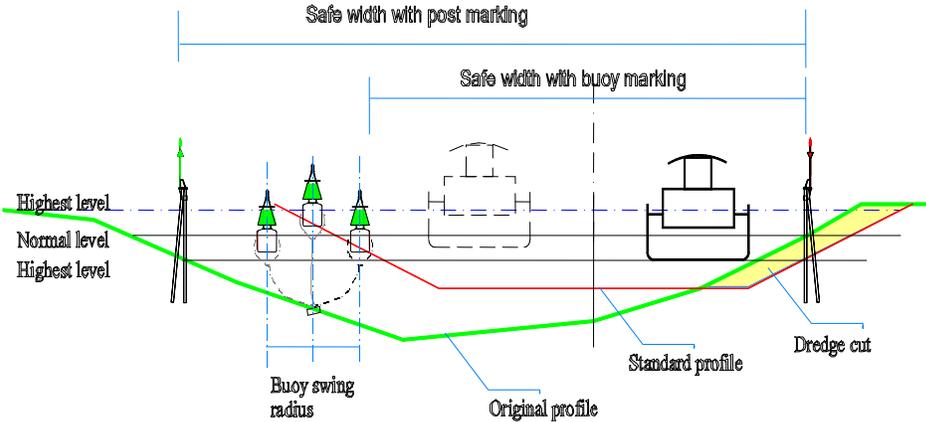
The intensity of these hydraulic effects can be described by means of the following parameters:

- The ratio  $(H/d)$  of water depth  $(H)$  over draft  $(d)$ : this should not be less than 1.4, although a ratio of 1.2 may be permitted in places, provided the vessel proceeds dead slow (minimal speed at which vessel can still be steered);
- Keel clearance  $(H - d)$ : this should be more than 0.5 m for unrestricted speed;
- Blockage coefficient  $(F/f)$ , which is the ratio between the wet cross section of the waterway  $(F)$  and the wet cross section of the vessel  $(f)$ . When the ratio is less than 10, speed must be reduced to avoid unwanted effects like erosion and squat (the effect of deeper sinking of the vessels stern, in relation to the speed);
- The ratio power  $(HP)$  to displacement  $(\Delta)$ , also called specific power: When this is high, then a vessel is able to reach a high speed in unrestricted waters. When a high specific power ratio is applied in restricted waters, it will generate unwanted and energy-wasting hydraulic phenomena. There are examples where the speed remains low, regardless of the power applied. This could happen when sailing in narrow canals (high blockage coefficient) with low keel clearance.

After waterway improvements have been implemented, vessel pilots have to be shown the cleared profile, so as to facilitate movements of vessels and maximize the use of the improved waterways. Signaling options also have an influence on the navigable width available. For instance (Figure 6.16), a section of a tidal canal was straightened by excavating part of the bank. This enlarged

the available width (green shaded), which was then indicated by means of lighted beacons to permit night navigation. Fixed beacons were preferred to buoys. This was because variable water levels introduce a big margin of error and limit the available width that is safely available. This would even become more serious if the buoy were laid in the standard minimum profile (outline in red).

Figure 6.16 Indication of navigable width by fixed posts vs buoys



Source: own drawing study team, based on Rijkswaterstaat tests 1970s-1980s

# 7 FUEL SAVINGS USING ADVANCED MEANS

This section describes four advanced ways of improving fuel efficiency:

1. The use of alternative fuels
2. Advanced low resistance ship design
3. Advanced high efficiency propulsion systems
4. New logistical concepts

Exhaust gas after-treatment technologies constitute a possible fifth category. These are already commonly used to remove particulates, nitrogen oxides or hydrocarbons from exhaust gas. After-treatment technologies that reduce CO<sub>2</sub> emissions on mobile applications are a recent development that has not yet been applied to IWT engines. (See Ecospec website & Ecospec CSNO<sub>x</sub> product brochure for further reading.)

## 7.1 THE USE OF ALTERNATIVE FUELS

### PETRO-DIESEL

The name petro-diesel (or gasoil) is increasingly used to distinguish this fuel type from other liquid fuels like biodiesel and biomass. Petro-diesel is distilled from petroleum and available in various grades of purity, chemical composition (sulfur content) and contamination. All of these factors have a direct impact on combustion efficiency and harmful emissions.

### PETRO-DIESEL TYPE EN 590

EN 590 is a type of diesel fuel with a sulfur content of only 0.2% in weight. The main advantage of this type of diesel is its low SO<sub>2</sub> content, which translates into a reduced impact on air quality. EN 590 diesel fuel has a higher price per liter, but also an energetic value that is higher than that of “normal” gas oils. Fuel consumption can accordingly be reduced by 3% to 7%. Using EN 590 diesel fuel is economically feasible in Western Europe under current economic conditions. The inland tanker vessel MS Victoria (the ‘Cleanest Ship’ developed under the CREATING project mentioned before) uses this type of fuel.

TABLE 7.1 COMPARISON OF PRICE PER MEGA JOULE BETWEEN GAS OIL AND EN 590

|                        | Energetic value<br>MJ/L | Price<br>USDct/L | Price per MJ<br>USDct/MJ |
|------------------------|-------------------------|------------------|--------------------------|
| Gas oil (petro diesel) | 36.55                   | 42               | 1.138                    |
| EN 590                 | 38.02                   | 44               | 1.163                    |

Source: Visser (2009)

## BIO-DIESEL

This liquid fuel is obtained from vegetable oils or fats and can be used in pure form or mixed with petro-diesel. Pure or mixed, this fuel substantially reduces harmful emissions, especially if upstream emissions are included.<sup>5</sup>

The main disadvantage of this type of fuel is that engines have to be converted to burn a pure or high percentage bio-diesel fuel mix. In the EU, bio-diesel is therefore blended at a low percentage with regular gasoil. Other countries, such as the United States, use bio-fuels largely as an alternative fuel.

## CNG AND LNG

Compressed Natural Gas (CNG) is Natural Gas stored under a pressure of up to 250 bar. It is then released to be burned as fuel under low (atmospheric) pressure. It is the most common alternative to petrol, principally because of its wide availability and low carbon and other emissions. Use in diesel engines requires conversion to gas combustion with spark ignition.

Liquefied Natural Gas (LNG) is gas stored in liquid form at minus 164 degrees Celsius under atmospheric pressure. An advantage of LNG is that more gas can be stored in liquid than in gas form. Main disadvantages are the high costs of LNG tanks and insufficiently dense distribution systems in some countries.

LNG is currently used on a small scale in maritime shipping. Some LNG-tankers use the boil off of loaded LNG as fuel. LNG is also used on ferries and coastal vessels. Norway is a major innovator in this regard and 16 of their ships currently run on NG stored on board as LNG. These include car/passenger ferries, passenger ferries, supply vessels, coast guard vessels, and small coastal LNG tankers (NGV, 2009). Another five such vessels are currently under construction.

This fuel type is currently also used for inland shipping in Amsterdam (canal cruise boats) and Australia (freight vessels).

## DUAL FUEL (CNG/LNG + DIESEL)

This system uses Natural Gas, either from CNG or LNG, blended with diesel. The latter is needed for ignition. Contrary to vaporized diesel fuel, NG does not spontaneously combust when injected into a cylinder under high pressure.

An NG and petro-diesel dual fuel pilot project for inland shipping is currently being implemented in the Netherlands. It is a combined project of the company Deen Shipping, diesel-engine specialist PON Power and naval design firm International Naval Engineering Consultants (INEC). The project is co-financed by the Dutch Ministry of Transport. In this newly designed fuel system, NG will serve as main fuel with petro-diesel as an ignition fuel. The NG will be stored aboard as CNG or possibly as LNG in tanks placed as a container

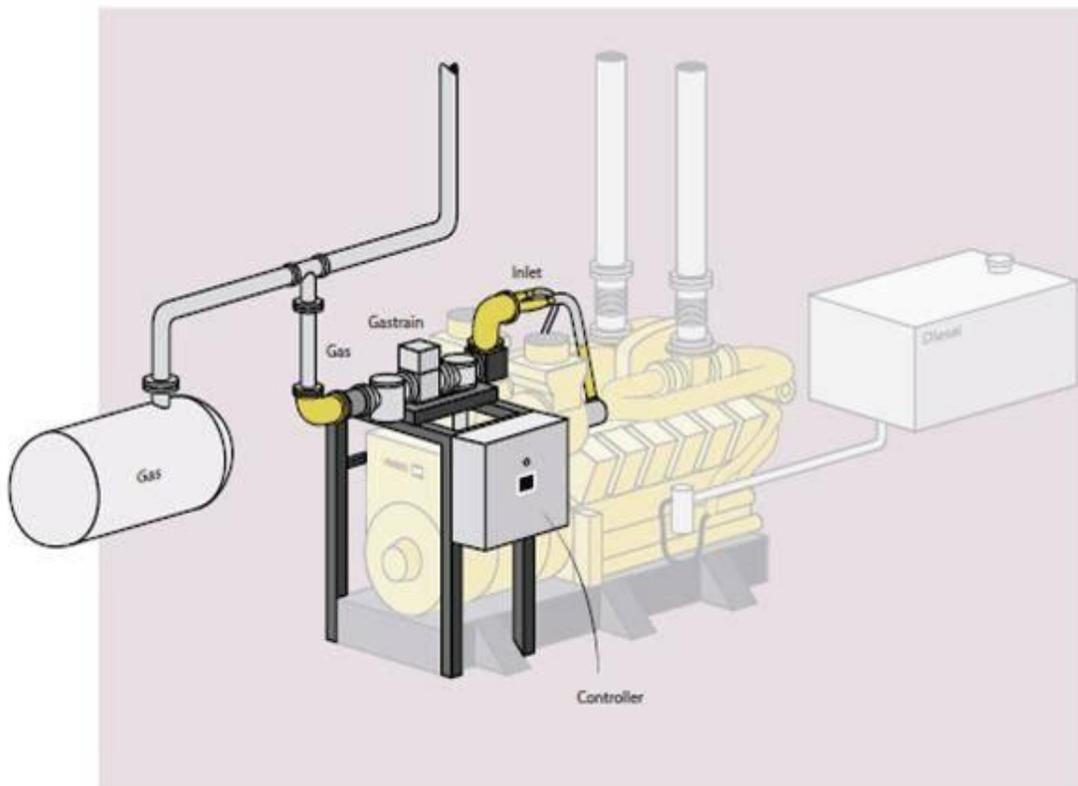
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<sup>5</sup> Upstream refers to emissions associated with the production, processing and transport of fuels to the place of consumption, or well-to-tank emissions.

on the deck. In the future the NG will be stored as LNG in tanks incorporated into the ship's structure. The main advantage of this system is the lower CO<sub>2</sub> emissions due to the low CO<sub>2</sub> per m<sup>3</sup> fuel. According to PON Power, the system could save 30% CO<sub>2</sub> emissions (interview with PON 2010).

Figure 7.1 below shows such a system with four main external components (the NG and petro-diesel buffer tanks, the mixing unit (gas train), the electronic control box, and the engine).

Figure 7.1 Schematic display of a gas-diesel mixing and control unit for dual fuel usage



Source: PON Power (2010)

Already in 1986 an initiative was taken to use CNG in inland shipping in Bangladesh. Petro Bangla set up a World Bank funded project called 'Second Natural Gas Development'. This included pilots for the use of CNG in railways and in IWT. Rupantarito Prakritik Gas Company acted as the implementation agency with consultants from New Zealand preparing the conversion.

The project proposed conversion of one BIWTC inland vessel to CNG, which was to serve as a ferry between Aricha and Doulodia. However, they struggled

to fuel the ship effectively from a floating storage tank, leading to long downtimes for the ship concerned and the project was stopped in 1993.<sup>6</sup>

## HYDROGEN

Hydrogen is the last innovative fuel type discussed. It makes use of fuel cells, which generate electricity to power electric systems including propulsion. Fuel cells use hydrogenic gas as fuel and oxygen as oxidant.

The use of hydrogen fuel was piloted on a canal cruise boat in Amsterdam, a project that was initiated by a private cruise company. Safety was the main issue here as hydrogenic gas has to be stored in tanks at 500 bar pressure. Transferring fuel stored at such pressures is forbidden in many places including Amsterdam, which forbids the refueling of hydrogenic gas tanks in the city.<sup>7</sup>

## 7.2 ADVANCED LOW RESISTANCE SHIP DESIGN

Inland vessels could benefit from research on advanced design for seagoing vessels, which generally have much larger R&D budgets at their disposal. Hull design is often a relevant component within R&D projects, though no specific improvements are currently being implemented on inland vessels.

## 7.3 ADVANCED HIGH-EFFICIENCY PROPULSION SYSTEMS

### DIESEL ELECTRIC PROPULSION

Advanced high-efficiency is achieved by propelling an All Electric Ship (AES), otherwise known as a diesel-electric ship, with multiple diesel-powered electric generators. The use of such a system has several benefits.

First, the proper use of multiple systems ensures that the engines generate the optimum amount of power needed for specific circumstances. Ship engines in general are considered to be operating efficiently if at least 70% of their power is delivered. However, in the course of a trip the total power output needed at any one point in time may vary substantially (e.g. when traveling upstream or downstream). Average power delivery therefore is not optimal. With a larger number of smaller engines at one's disposal means that power can be added or subtracted by turning extra engines on or off. The amount of power used is therefore more appropriate to the circumstances, saving fuel and reducing CO<sub>2</sub> emissions.

Second, a diesel-electric system makes it possible to use road truck engines, instead of shipping engine, which has several benefits. The market for road truck engines is much larger than that of specialized shipping engines. There is much more R&D funding in the sector, resulting in much more innovation. In Europe for instance, truck emissions have declined massively over the last 10 years, mainly because of innovative engine design. Also, the initial investment costs of road transport engines are much lower than for ship engines, while the depreciation is much faster. Engines can therefore be replaced more quickly,

<sup>6</sup> Source: Information obtained from Rupantarito Prakritic Gas Company

<sup>7</sup> Interview with Henk Blaauw of MARIN

giving ship owners access to the latest fuel efficiency innovations.<sup>8</sup> Under these conditions fuel savings over the lifetime of a ship could be significant.<sup>9</sup>

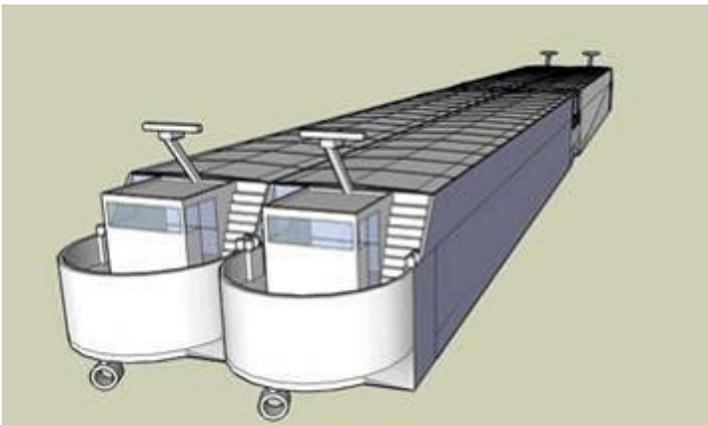
## 7.4 NEW LOGISTICAL CONCEPTS

### Q-BARGE

Q-Barge is a Dutch new shipping concept developed especially for small inland waterways. It consists of a small motorized unit (mini pushboat), which is coupled to a maximum of four small barges, two long and two wide (double tandem unit). The weight of the vessel is minimized by using light weight material, while load capacity is maximized by smart design of the steering cabin and excluding the skipper's accommodation space. The maximum load capacity amounts to 590t.

Introduction of the Q-barge will be combined with another new operational concept: the "trajectory skipper". The skipper will be hired by a ship owner and will operate a vessel to a specific location. At this location s/he will commence on a return trip with another vessel or by (a rented) car. The main advantage of this operational concept is that shipping becomes a more regular job.

Figure 7.2 Artist impression of a Q-barge truck with four barges



Source: <http://www.researchsmallbarges.nl/>

### WATER TRUCK

The "Water Truck" is a combined Dutch-Belgian initiative within the EU-funded Interreg program, which aims to increase the usage of IWT in smaller inland waterways. Main innovations in this concept are:

- Exclusion of skipper accommodation space from the ship;
- Disconnection of loading/unloading and sailing.

<sup>8</sup> As an example; it is common for Dutch truck operators to replace their trucks every four year

<sup>9</sup> Interview with Mr. Khalid Tachi of the Dutch Expertise and Innovation Centre Inland Shipping (EICB)

The first part of the concept is similar to the Q-barge concept. The push-vessel consists of a steering hut and motor, and has place for a small car allowing staff to travel back home on the same day.

Figure 7.3 Conceptual design of a mini-pushboat for the water truck system



Source: EICB (2010)

The second part of the concept is largely operational. Barges are operated mainly in so-called barge trains. The barges are disconnected at the destination where final mooring takes place on an individual basis. Using this system, economies of scale are achieved while providing the operator with enough flexibility.

Figure 7.4 Artist impression of the Water Truck system in operation



Source: EICB (2010)

## TOTAL SHIP OVERHAUL

A combination of measures is being investigated under the EU-funded research project INBISHIP. This aims at economically and environmentally friendlier river ship operation and investigates measures such as flexible propulsion power control; increased stowage space; additional maneuverability for improved safety; forward relocation of crew accommodation away from the vibrations and noise of the machinery concentrated aft; and forward relocation of the wheelhouse for improved visibility.

The last measure has received negative responses from skippers who are used to being at the back of the ship, with the cargo holds and ship's aft clearly visible in front of them (Hekkenberg, 2010). Implementation of this measure will therefore be influenced by cultural rather than technical issues.

## E-NAVIGATION

Finally, the efficiency of operations can also be improved by introducing IT systems into what has been quite a traditional sector. Many operations contribute to better estimates of the sailing speed needed, lock and bridge planning and thereby better fuel consumption. This includes the tracking and tracing of ships, which has not been common until quite recently except for container trade, the use of water level information for schedule calculations and the integration thereof into terminal planning and ship scheduling.

The term e-navigation covers a variety of aspects, one of which is RIS (River Information Services) under the auspices of which a major reorganization of traffic management on European waterways is currently unfolding. It is based on permitting the exchange of information between international traffic management agencies, vessel operators and fairway management, and between skippers and terminals. With IT developments ongoing in other sectors, the opportunities for the IWT sector will likely expand as well.

## 7.5 CONCLUSION ON ADVANCED MEANS

Advanced means to increase the fuel efficiency of inland navigation can be implemented in various areas at operational and technical level, and in the design of ships. The cost of implementing such technologies is higher when compared to conventional means and probably only justified when building new vessels. In some cases the outcomes are uncertain, such as when new logistical concepts are being investigated. IT systems, however, can be applied to all vessels, old or new.

## 8 CONCLUSIONS

### CONVENTIONAL MEANS OF INCREASING ENERGY EFFICIENCY

Four conventional ways of increasing IWT energy efficiency were presented in chapter 6. The main differences between these were their investment requirements and the parties responsible for implementing the measures. Vessel operators can implement operational optimization measures fairly easily, in addition to which the investment needs are low. Fairway adaptations, however, are more complex and require public funding.

### ADVANCED MEANS FOR INCREASING ENERGY EFFICIENCY

A range of technological innovations are available on the market or under research. The literature study and interviews with research institutes conducted for this study highlight three major themes for energy-efficiency innovation: operations, means of propulsion and fuel type usage. Ongoing research projects and promotional programs aim at increasing the use of available advanced technologies on existing ships, while investigating possible improvements of hull/hydrodynamics and engine/propulsion systems.

### ASSESSMENT

No quantitative assessment of the costs and benefits of the measures under discussion were made in the previous sections. An indicative assessment can however be given using qualitative scores for cost of implementation, possible financial savings, the impact on emissions and consequences for safety and other aspects. This assessment is presented in the following table.

TABLE 8.1 ASSESSMENT OF FUEL EFFICIENCY IMPROVEMENT MEANS

| Means                                       | Costs            | Savings               | Environment                               | Safety   |
|---|------------------|-----------------------|---|----------|
| <b>Conventional means</b>                   |                  |                       |   |          |
| Optimizing operations                       | Low              | Low                   | Low                                       | none     |
| Minimizing resistance                       | Low to moderate  | Low/ Moderate         | Low                                       | Low      |
| Propulsion systems and steering gear        | Moderate to high | Moderate to high      | Moderate                                  | Low      |
| Adapting fairways                           | Very high        | Potentially very high | Emissions moderate, other aspects varying | Moderate |
| <b>Advanced means</b>                       |                  |                       |   |          |
| Alternative fuels                           | Moderate         | Moderate to high      | Moderate                                  | Low      |
| Advanced low resistance design              | High             | High                  | Moderate                                  | Low      |
| Advanced high efficiency propulsion systems | Moderate to high | High                  | High                                      | Low      |
| New logistical concepts                     | Low to high      | Low to high           | Low to Moderate                           | None     |

Source: own assessment of study team

These measures can be implemented at the initiative of vessel operators or public authorities. Operators will make decisions based on the financial return of an investment. Policy decisions can be taken at government level to provide the operators with the needed investment incentives. Such policy decisions may comprise fiscal incentives, research funding or improving river transport infrastructure.

## PART C: FEASIBILITY OF A PILOT PROJECT TO CONVERT VESSEL ENGINES TO CNG

## 9 INTRODUCTION

Propulsion technologies using Compressed Natural Gas (CNG) can help to reduce engine emissions in the transport sector. CNG has been highly effective in reducing GHG emissions in urban transport. The technology is also used on several fjord ferries in Norway and on some offshore vessels. Research to use CNG for inland shipping is underway in the Netherlands.

Given the promising results elsewhere, the World Bank considers CNG an interesting option for a pilot project which aims at converting IWT vessel engines to CNG. This section reviews the feasibility of such project using Bangladesh as a case study.

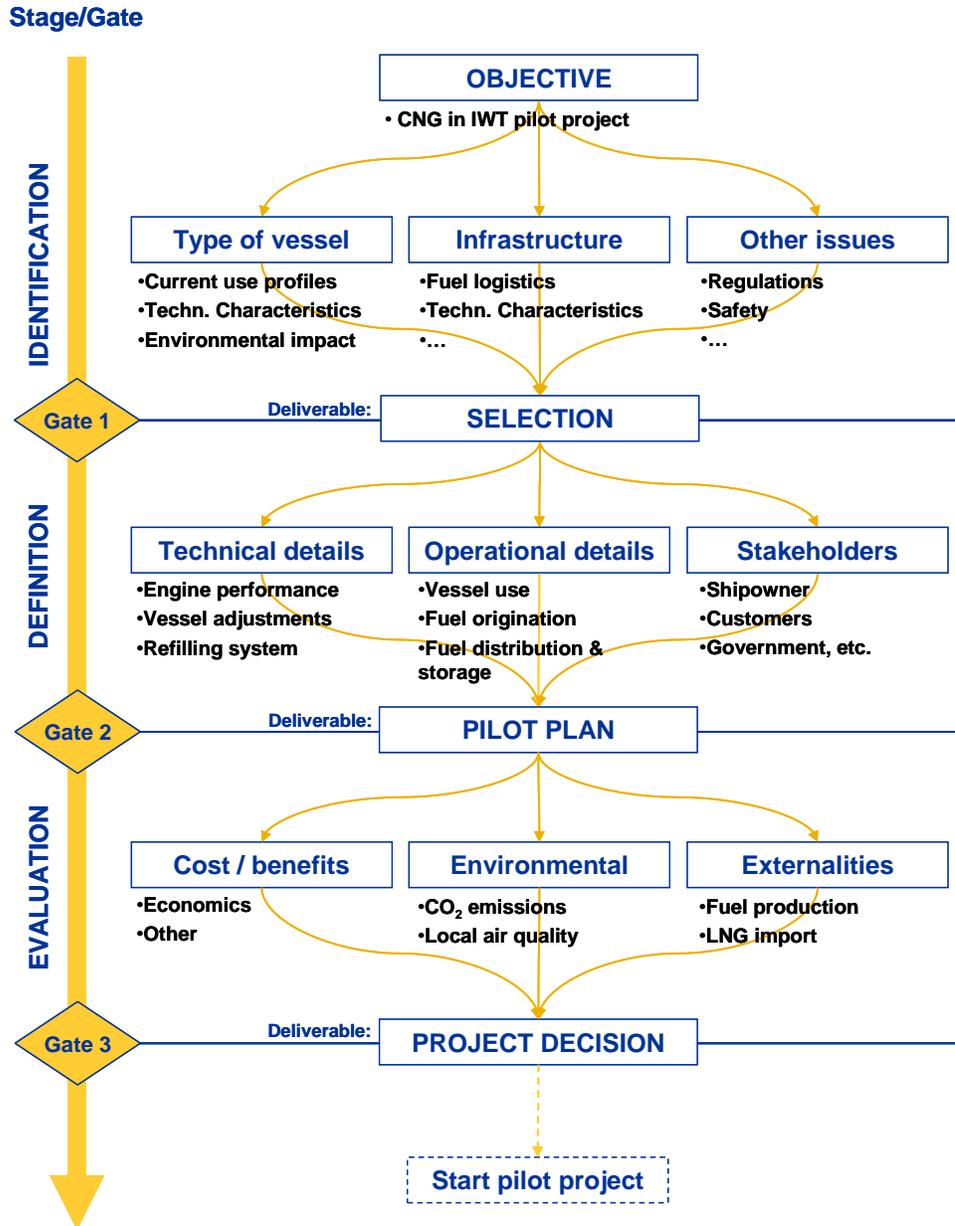
CNG is used extensively in Bangladesh by cars, buses and three wheelers. Conversion of three wheelers to CNG has had a dramatic impact on air quality in Bangladesh. It is not yet used in inland water transport, though a pilot was planned in the 90s. Bangladesh has its own gas reserves which makes the fuel attractive when compared with imported diesel fuel.

Chapter 10 presents the methodology used to evaluate the pilot. Chapter 11 discusses the experience and lessons in using CNG as a fuel type for shipping. Chapter 12 evaluates the feasibility of the pilot project using a Stage-Gate review process.

# 10 FEASIBILITY METHODOLOGY

The methodology used to assess the feasibility of the proposed pilot project is based on the so-called Stage-Gate review process as described in figure 10.1.

Figure 10.1 Stage/Gate methodology for assessing the feasibility of converting IWT engines to CNG



Source: study team

The Stage/Gate approach consists of three stages, each ending in a gate.

#### IDENTIFICATION STAGE

During this stage, data is gathered on:

- types of vessels and their technological characteristics (age of vessel, engine type, vessel design, how they are currently used operationally);
- supporting infrastructure (e.g. the current supply of fuel, locations of storage, frequency of fuelling, loading/unloading sites and equipment and other port facilities);
- waterways (routes on which vessels are operated, sailing distances, water depth and navigability); and
- other aspects (safety regulations, traffic density, environmental restrictions, etc.).

Based on these elements a selection is made of vessel types that appear the most promising with regard to the implementation of the pilot (gate 1).

#### DEFINITION STAGE

During this stage the parameters of the pilot are worked out. This covers

- technical details such as the engine performance, system adjustment requirements in the vessel and on shore, and fuel filling systems. One issue, for example, is whether fuel storage can be arranged in independent tanks (for example in containers) or as built-in systems;
- operational details such as the normal operational parameters of the ship (routes, main distances sailed, cargo loads, etc.), and the flexibility of these processes with respect to activities like the loading/unloading of fuel tanks; and
- stakeholders to be involved in the pilot (ship owner/operator, shippers, regulatory authorities, etc.).

The result of this stage is a plan (gate 2), describing the steps for pilot implementation.

#### EVALUATION STAGE

During this stage the feasibility of using CNG is assessed, based on the plan designed during the previous stage. The evaluation covers

- economic aspects (cost of the investment, operational costs compared to the base case situation);
- environmental aspects (benefits of reduced CO<sub>2</sub> emissions and local air quality); and
- estimates of relevant externalities (for example the availability of fuel and the pressure on other sectors also using gas).

Quantitative estimates were made for each of these components. The valuation is based on data available in Bangladesh or, if not available, extrapolated from European figures, e.g. on emission impacts.

The result of this stage is a (preliminary) project recommendation (gate 3).

# 11 THE USE OF CNG FOR INLAND WATER TRANSPORT

Various fuel options including CNG were discussed in Part B. This chapter reviews CNG experience in the IWT sector and constraints that have to be taken into account in evaluating a pilot.

## 11.1 INTRODUCTION

Natural gas combustion is the cleanest of all fossil fuels, as natural gas consists mainly of methane with low percentages of hydrocarbons like ethane, propane and butane. It produces the lowest carbon dioxide emissions of all hydrocarbon fuels; exhaust gas is also virtually free of particulate matter and does not contain sulphur, thereby eliminating all SO<sub>x</sub> emissions. Natural gas therefore has environmental benefits and also represents an economically viable alternative to diesel fuel. However, realizing this depends on operational specifics.

Due to the gaseous nature of the fuel, it has to be stored in a compressed gaseous (CNG) or in a liquefied state (LNG). Compressed Natural Gas (CNG) is natural gas pressurized up to 200-250 bar, while Liquefied Natural Gas (LNG) is natural gas converted to liquid form by cooling it to a very low temperature. Compression or liquefaction of natural gas is needed to obtain an acceptable energy-density per unit-volume for transportation.

CNG is commonly used as a fuel in passenger cars in Bangladesh. Most cars previously ran on petrol, but a switch to CNG vehicles took place because NG in Bangladesh is roughly nine times cheaper than petrol. This study investigates the feasibility of a CNG pilot project for IWT. There are obvious reasons for this:

- the use of NG instead of conventional fuels reduces CO<sub>2</sub> emissions;
- CNG is readily available for passenger cars at filling stations all over the country;
- there is sufficient knowledge on industry standards and CNG technology; and
- Bangladesh possesses extensive natural gas reserves.

Worldwide LNG is receiving more attention than CNG as a fuel for heavy-duty road transport, inland navigation and offshore vessels. The energy content of LNG per unit of mass or volume is significantly higher than the energy content of CNG, making it easier and cheaper to transport and store. Another driver for the growing interest in LNG as a transport fuel are technological advances made with liquefaction, which has led to lower LNG prices.

## 11.2 CNG EXPERIENCE IN SHIPPING

Natural gas has been used as a marine fuel since the early 1980s. However, until now CNG has not really been used as a fuel for inland vessels. Examples include tourist boats in Russia, the USA (Zbaraza 2004) and Amsterdam in the

Netherlands (Ecofys 2009). Research and conceptual engineering on CNG propulsion systems in inland shipping is continuing, but has not yet been implemented.

There are currently 11 CNG canal boats in operation in Amsterdam (see figure 11.1). These vessels consume minimal amounts of fuel, because of their low average speed of 5 km/h.

Figure 11.1 Example of a mono-fuel CNG canal boat in Amsterdam



Source: Amsterdam Canal Company website

CNG is used as a fuel for (seagoing) freight vessels and passenger ferries in Canada and Norway. The bulk of these vessels is not propelled with mono-fuel NG engines, but with dual-fuel systems. These engines can run on either diesel fuel or a mixture of diesel and natural gas. Normally dual-fuel engines use primarily natural gas, with the diesel fuel acting as a 'liquid spark plug'. The share of natural gas in dual fuel systems can be up to 90% with modern engines. If natural gas is (temporarily) unavailable, the engine can also run on pure diesel fuel. This is important as gas distribution systems are often not as omnipresent and reliable as diesel distribution systems.

The M.V. *Accolade II*, still in operation in Adelaide, Australia since the early 1980s, is the oldest (non-LNG carrier) natural-gas powered marine vessel. The *Accolade* is a limestone carrier of over 100 meters in length, propelled by two 6-cylinder Fuji dual-fuel engines that generate 1,650 BHP each on NG.

The most striking example of dual-fuel technology in the marine sector is the successful operation of two car ferries in Canada, the M.V. "*Klatawa*" & "*Kulleet*" over a period of 15 years. The two ferries each had a capacity of 26 cars and 146 passengers, and ran on the Fraser River close to Vancouver until a bridge was built.

The M.V. *Klatawa* was built in 1982. Its two deck-mounted Caterpillar engines were converted to dual-fuel operation in 1985. Eight CNG cylinders were mounted on the main deck in two compartments, one for each engine. Putting the gas storage, piping and the engines on the main deck, meant that there was no gas below the main deck, the main safety feature of the ship.

Calculations made after 4 years of operation showed an 8-year payback period, while engine maintenance costs were reduced due to the increased lifespan of the engines. In consequence the MV *Kulleet* was also converted to natural gas in 1988. The experience gained with the *Klatawa* reduced the investment costs and payback for the *Kulleet* was calculated to about 5 years.

Exhaust emissions were not the focus of the project and therefore no figures were reported.

Figure 11.2 M.V. Klatawa in operation



Source: Wayne Weber

There are other examples of river vessels using natural gas as fuel<sup>10</sup>. However, these have not been properly assessed.

The fact that mono-fuel NG engines have not been used in inland navigation applications, other than tourist or canal boats, indicates that dual-fuel technology is worth serious consideration for any CNG pilot project with marine or inland navigation applications.

### 11.3 FUEL STORAGE

The lack of space for CNG fuel tanks on existing diesel vessels often acts as a barrier to conversion. Natural gas has to be stored in a compressed gaseous state (CNG) or in a liquefied state (LNG) so as to obtain an acceptable energy-density per unit-volume. CNG tanks take up roughly 4.5 times as much space as diesel tanks, while LNG tanks use roughly twice as much as diesel for the same amount of energy.

<sup>10</sup> See for instance: <http://www.brettandwolffllc.com/ngmvessels.html>

Compressed Natural Gas (CNG) is stored in pressurized cylinders, available in various sizes from 60 liters to roughly 2,000 liters or more. Multiple cylinders can be combined into a tank unit for the desired storage capacity. figure 11.3 and figure 11.4 show examples of CNG storage units. These are large, bulky CNG cylinder units. Cylinders can also be mounted individually in the vessel's hull or on deck. Most CNG cylinders are used at a pressure of 200 bar.

Figure 11.3 40ft CNG cylinder unit, with four cylinders



Source: study team

Figure 11.4 Multiple CNG cylinder unit



Source: study team

Liquefied Natural Gas (LNG) is natural gas converted to liquid form by reducing its temperature to  $-162^{\circ}\text{C}$ , and can be stored in cryogenic tanks. LNG has clear advantages over CNG in terms of energy-content per unit-volume. However, LNG cryogenic tanks have about 1.5 times the weight of ordinary diesel fuel tanks for the same energy content. CNG has 4.5 times as much weight for the same energy content. Around 75% of the weight of the CNG storage assembly consists of the high pressure tanks.

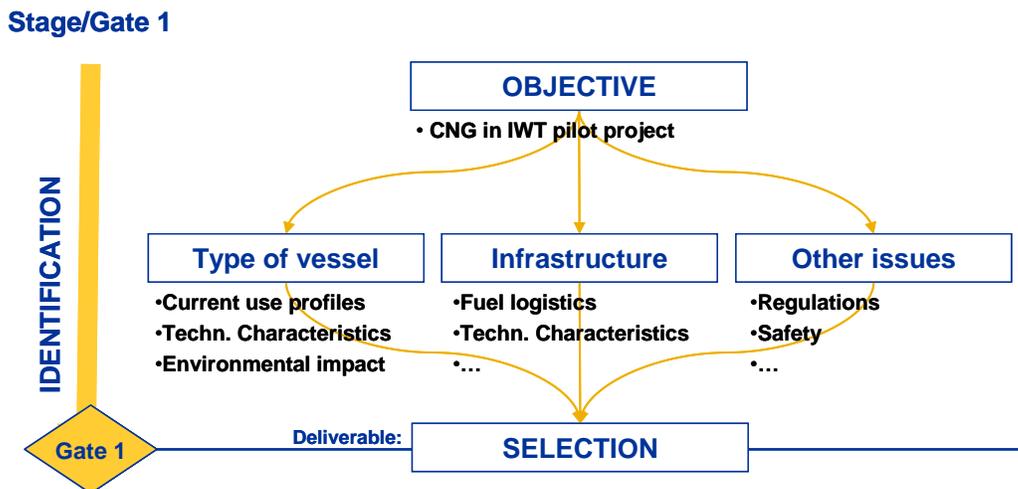
## 12 EVALUATION

This section assesses the feasibility of an IWT pilot project in Bangladesh in which a vessel will be equipped to use NG as its primary fuel source. The results of this evaluation are relevant in Bangladesh and elsewhere. The relevant analytical stages are discussed below.

### 12.1 STAGE/GATE 1 ANALYSIS: IDENTIFICATION

Key parameters that constrain and define the options for using CNG in the IWT sector include the following: infrastructure (river, gas), type of equipment and safety. Figure 12.1 summarizes the steps to be taken during stage 1.

Figure 12.1 Stage/gate evaluation methodology: identification stage



Source: study team

#### INFRASTRUCTURE

The existing infrastructure scanned included current fuel logistics, relevant technical details and some aspects of waterways and ports.

#### OVERALL SUPPLY OF CNG

The existence of a network for CNG distribution is one of the main infrastructure issues that could affect pilot project design. CNG is commonly used as a transport fuel in motor vehicles in Bangladesh. NG is also used for various domestic and industrial purposes, as a result of which the country has a well-developed natural gas infrastructure.

Despite the generally good availability of CNG, remote areas often fall outside the national distribution network. In such cases CNG may be delivered by tank

transporters or delivered in bottles. CNG pilot projects should accordingly be set up in the vicinity of areas with denser populations and good infrastructure so as to avoid the need to invest in infrastructure.

#### INFRASTRUCTURE FOR REFUELING IWT

It seems technically feasible to develop large, dedicated and fast-filling onshore CNG facilities (alternatively floating stations on pontoons) in several places in Bangladesh. The start-up costs, however, are significant. Investments have to be made into large compressor stations, piping, buffer tanks, and perhaps pontoons with moorings and land bridges. Especially in the case of a single pilot project it will be difficult to recoup such high investment costs through fuels savings.

A smaller, low-key refueling facility located near one of the passenger terminals constitutes a good possible alternative. However, in Bangladesh these terminals are floating pontoons and not regular docks. Pontoons are better able to cope with the water level differences between the dry season and the monsoon and are more practical along the largely natural banks of the rivers in Bangladesh. They can also easily be shifted should the location used silt up. Unfortunately pontoons cannot easily accommodate the suggested low-key refueling facilities. It would also be expensive to build a dedicated floating CNG refueling facility.

Using existing CNG refueling infrastructure for road transport, in combination with a mobile CNG tank unit, remains the cheapest option for a pilot project. Such tank units could be loaded once a day at least at existing CNG road filling stations. CNG tank vessels are an alternative, especially if the project were to be scaled up.

#### BOX 12.1 CNG BUNKER VESSELS

A so-called CNG bunker (or feeder) vessel currently exists only in concept (the same holds for LNG feeder vessels). The concept is suited for local CNG distribution to areas without a dense pipeline network.

Early adopters of CNG technology may want to bunker fuel at different locations, requiring multiple CNG filling stations. This typically requires high investments that are difficult to recuperate in the course of a pilot project. A CNG bunker vessel represents a flexible alternative as it does away with the need for extensive infrastructure development. New CNG users could also easily be added to CNG delivery routes.

## TYPE OF VESSEL

The type of vessel used in the CNG pilot project should meet the following criteria:

- Fit with operations: the vessel should sail on set routes and return to the same ports/docks on a regular basis. This will make it possible to make use of existing refueling facilities or to set up such facilities where needed. In the case of vessels that travel on random routes this would not be viable.
- Fit with technical characteristics: the vessel should have enough space for additional fuel tanks. The engine room should have the space for a more complex fuel system and should be sufficiently modern to allow for state-of-the-art CNG conversion technologies.
- Environmental impact: converting the vessel should have a large positive environmental impact in itself. If not, it should be possible to scale the pilot up to similar vessels, thereby to achieve significant environmental benefits.

A number of vessel categories of interest to the pilot project were identified on the basis of interviews with local experts and stakeholders in inland waterway transport in Bangladesh. These are:

- Large BIWTC-operated river-crossing ferries for cars, road transport and passenger buses, most notably on the roads to and from Dhaka across the Padma River<sup>11</sup>;
- Smaller private-sector operated passenger vessels, operated on the routes Dhaka/Narajanganj – Chandpur.

Inland cargo vessels were also considered, but deemed unfit for a pilot project because they generally do not sail on fixed routes. Focusing on these would become possible only once CNG-use has been established in the passenger sector and is a longer-term option. Two top candidate vessel categories are discussed below.

## LARGE BIWTC FERRIES

BIWTC considered converting the propulsion engines of some of their major ferries into NG engines some time ago. Unfortunately the plan lacked sufficient financial support. In the process ferries were considered as likely candidates for a NG pilot project. The Ro-Ro ferry operations fitted the required profile for CNG application well. The vessels are used on short routes and regularly return to the same locations. Moreover, large amounts of fuel are consumed because of the high engine power and full continuous operation of these vessels. These characteristics guarantee a large positive environmental impact and opportunities to recuperate investments in CNG technology. There is ample room in the engine room to install additional equipment for dual fuel operations.

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<sup>11</sup> However, ferries will have to be used on other routes once the Padma bridge is built, with the project expected to start in 2011.

The lack of room for CNG storage, other than on the car deck, constitutes the main constraint. A possible solution is to put a 40ft CNG tank container on the car deck among the transported vehicles. This would hamper the Ro-Ro operations, unless the CNG tanks could be mounted individually on the sides, where they would constrict the outer lanes in places. Engine age and inadequate maintenance as a result of a lack of spares could result in sub-optimal performance.

The main prerequisite for the installation of NG engines in these ferries would be an adequate supply of CNG near the waterfront of the ferry terminal. Building such a fuel facility would be expensive and is examined in further below.

Two ferry locations were investigated: (a) the Padma River crossing of the N7 National road, between Paturia and Daulatdia Ghat, which has a route length of some 10 km; and (b) the Padma River crossing of the N5 National road from Dhakam between Maowa and Char Janajat, which has a route length of up to 16 km, depending on the season.

Figure 12.2 Path of Ferry crossing at Maowa during dry season (about 16 km)



Source: Google Earth, own compilation study team

Figure 12.3 Path of Ferry crossing at Paturia (about 6 km)



Source: Google Earth, own compilation study team

Figure 12.4 BIWTC ferry at Paturia



Source: photo study team

### Small passenger vessel

Small privately operated passenger vessels are particularly suitable for a CNG pilot project. Vessels sail almost daily from Dhaka or Narajanganj to Chandpur and back. A one-way trip from Narajanganj to Chandpur takes 6 hours, which means that the vessels are en route for roughly 12 hours per day. The remaining idle hours are more than enough for daily refueling.

Limited space in the engine compartments may pose a constraint to conversions to dual-fuel systems, though this also reduces safety risks. The main issue, however, is to find room for the CNG storage tanks. Passenger accommodation occupies most of the superstructure, making the top deck the most obvious location for the tanks. The additional weight would certainly reduce vessel stability, which cannot be permitted. Aft of the main deck house on a somewhat extended main deck thereby becomes the best location.

Figure 12.5 Private operator passenger vessel routes.



Source: Google Earth, own compilation study team

The direct environmental impact of CNG application in these passenger vessels is much lower than what it would be in the case of ferries. The potential for scalability, however, is substantial and many similar vessels could benefit from the lessons learned in a pilot project.

BIWTA/BIWTC are interested in the execution of a pilot project. They are keen to reduce the operating costs of publicly-owned ferries in the public interest;

also to reduce the emission of harmful gases. The motivation of interested private sector passenger vessel operators is purely financial.

#### OTHER ISSUES

Two issues needing more attention were identified in the course of the mission to Bangladesh, namely:

- Safety requirements;
- Shortage of supply in the national NG distribution network.

#### Safety

Currently there are little or no regulatory barriers for the use of CNG in IWT. In the course of discussions with the BIWTC safety officer it was decided to further assess the following safety aspects:

- No CNG storage cylinders or tanks should be located below the main deck of a vessel where ventilation may be insufficient, even taking into account that natural gas is lighter than air.
- CNG storage could be placed in an open space on the main deck with sufficient natural ventilation. Care should be taken that escaping gas does not enter any pockets or spaces of the deck above.
- The safest option would be to place CNG cylinders on an open deck outside the passenger area, or which is properly separated from the passenger space (e.g. by means of a fence).
- When placing CNG tanks or other heavy items on vessels, the stability of the vessel must always be checked.
- When filling CNG in tanks or cylinders that are mounted on a vessel, the fill connection must be on the main deck level to allow for easy connection of the fill hose.
- Filling should not be allowed when there are passengers on board.
- When filling, the crew should stay away from the tanks or cylinders.
- No smoking should be allowed on the vessel, on the passenger terminal or in the direct vicinity of the vessel while filling.

In the case of ferries there should be no vehicles on the car deck and no passengers in the superstructure. The same rules apply when using a CNG tank transport vessel and for private sector operated passenger vessels. In the case of the latter the tanks have to be exchanged at a private jetty during the idle hours, during which time there are normally no passengers around. A verification system should nonetheless be in place to ensure that no (early) passengers are on board and that no unauthorized personnel are in the vicinity of the vessel.

None of these regulations are show-stoppers for either of the vessels identified as candidates for a pilot project.

### Shortage of natural gas supply

The current shortage of NG in Bangladesh poses an additional barrier to CNG-use in IWT or any other high-consumption applications. The pressure in the national gas grid regularly drops to very low levels due to high demand and there is simply not enough gas in the grid during peak hours. Increasing demand by expanding CNG-use to IWT would aggravate this problem.

This is one of the reasons why vessel operators are currently unwilling to switch to mono-fuel NG propulsion systems as refueling problems could put their incomes at risk. Dual-fuel engines could bypass this obstacle, as vehicles could fall back on diesel fuel in the event of CNG shortages. Vessels can also easily be restored to their original condition by removing the CNG tanks and piping and conversion would not, therefore, reduce the residual value of the engine or vessel should CNG become unavailable...

NG shortages may pose a risk to the proposed pilot project at the moment, but it does not mean that the use of NG in IWT has to be reconsidered altogether. Most stakeholders interviewed in Bangladesh expected the government to address the shortage issue in the future, though uncertainty remains.

#### RESULT: GATE 1

The BIWTC ferries appear to be the logical choice for a pilot project. Ferries consume large amounts of diesel fuel and continuously sail the same routes. However, there are some barriers. There is little room for mobile CNG tank units and Ro-Ro operations would be severely hampered if available space is used for storage. Other CNG storage solutions require a dedicated CNG refueling facility, which in turn requires investments that exceed the capacity of a single pilot project. Also, replacing ferry engines and converting them to dual-fuel operation will be expensive. Finally due to their continuous operations there is little time for refueling.

Small private sector operated passenger vessels seem to be a more viable option, even though they consume less fuel and follow longer routes. From an operational perspective the vessels sailing daily from Narajanganj to Chandpur and back would be very suitable for a CNG pilot project. The main issue here is to find a suitable and safe location for the CNG tanks needed to complete a roundtrip without refueling. However, this challenge is not insurmountable and is further assessed during stage 2. There is enough time between return trips refueling.

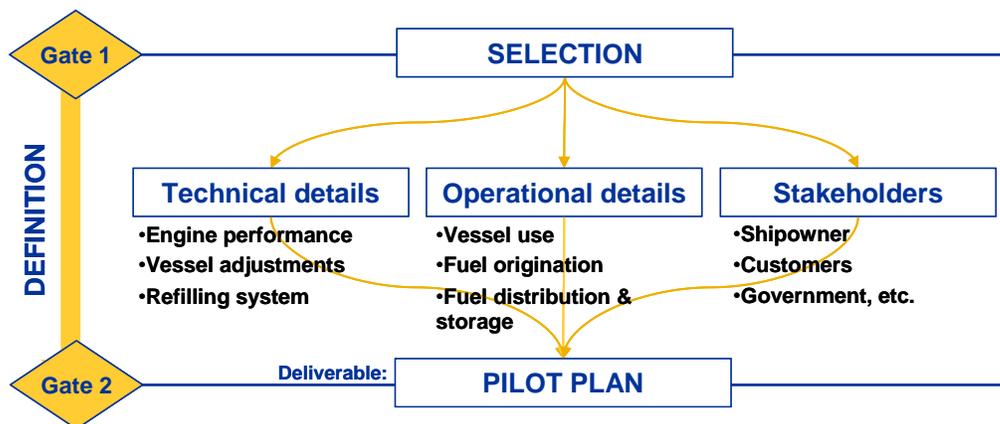
Small private sector operated vessels represent the best choice for the pilot project, in large part because of its smaller scale and lower investment needs. Yet, NG supply problems in Bangladesh hamper any pilot project of this nature, as it reduces the willingness of operators to switch over from diesel fuel. Dual-fuel systems present a solution for this problem as vessel operators retain diesel as a fall-back option, thereby increasing the attractiveness of the pilot project from their perspective. Small private sector operated vessels are therefore selected for the stage/gate 2 analysis.

## 12.2 STAGE/GATE 2 ANALYSIS: DEFINITION

This section examines the details of the technical and operational aspects of the pilot, based on the options chosen at the end of stage-gate 1. Figure 12.6 summarizes the steps taken during stage 2.

Figure 12.6 Stage/gate evaluation methodology: definition stage

### Stage/Gate 2



Source: study team

### OPERATIONAL DETAILS

The selected passenger vessels are scheduled to sail from Narajanganj to Chandpur and back every day. A one-way trip is roughly 60 kilometers and takes some 6 hours. The following operational specifications are relevant:

- Distance one-way trip: 60 km
- Distance round trip: 120 km
- Average groundspeed: 10 km/h
- Average travel time round trip: 12 hours
- Available time for refueling: 6 – 8 hours/day
- Average number of sailing days per year: 330 days
- Refueling: once daily

Refueling will be done through existing CNG infrastructure for road transport. One or more mobile CNG tank units could be used. The mobile CNG tank units could be unloaded from the vessel when empty and transported to a nearby CNG filling station for refueling. Working pressure, fuel composition and the origin of the fuel are therefore identical to that in the road transport sector.

A truck with a mounted crane is the most cost-effective option for the unloading, transporting, and reloading of the CNG tank unit. The truck driver

has to lift the empty CNG tanks from the vessel and load them onto his truck for refueling at a nearby filling station. It is not necessary to offload the CNG units from the truck at the station and it will take roughly 30 minutes to fill them. The full CNG tank units have to be transported back and reloaded onto the vessel. The tanks could be transported by local companies, meaning that no additional investments are required in the pilot phase.

Pontoons like the ones used as passenger terminals in Bangladesh cannot be used for the loading and offloading of mobile CNG tank units from and onto a vessel. A fixed dock is needed for this operation and there are a number of suitable private factory docks in the vicinity of Narajanganj. Factory owners confirmed that the docks could be used for unloading and reloading CNG tanks for 2 – 3 hours a day.

Finally, the operational details of these passenger vessels make possible a flexible schedule, allowing for refueling during 'off-peak' hours.

#### TECHNICAL DETAILS

The passenger vessels vary in size, displacement and engine power. The technical details of the MV Trina (M-10467) will be used as the point of departure for this assessment. The MV Trina has the following specifications:

- Length: 26.5 m
- Beam: 6.25 m
- Draught: 1.35 m
- Engine power: 165 bhp
- Fuel type: Petro-diesel
- Specific fuel consumption: 180 g/bhph
- Fuel consumption per hour: 30 kg/h at full power

The vessel's current diesel engine will be converted to dual-fuel operation. Dual-fuel conversion of diesel engines is a proven technology. Nonetheless, the substitution of diesel fuel by CNG in retrofitted dual-fuel systems is typically less efficient than what can be achieved with OEM dual-fuel engines. A 50 percent CNG-to-diesel substitution rate in day-to-day operation is therefore assumed for this pilot project.

Engine performance is not affected by the dual-fuel conversion. Also fuel consumption in units of energy remains the same. The service life of dual-fuel retrofit systems varies, though the experience of Canadian ferries described above proves that 15 years is feasible.

The energy consumption of a vessel doing a typical round trip at full power is calculated as follows:

- Total travel time round trip: 12 hours
- Fuel consumption at full power: +/- 30 kg/h
- Total fuel consumption round trip: 355 kg diesel (425 liter diesel)
- Total energy consumption round trip: 15.3 GigaJoules (GJ)

With 50 percent diesel fuel substitution, the 7.7 GJ per round trip needs to be produced from NG instead of diesel. This translates into roughly 185 kilograms or 230 m<sup>3</sup> of NG and a tank capacity of 0.92 m<sup>3</sup> is needed to store this.

CNG storage should ideally consist of two CNG tank units, each consisting of two 250 liter CNG cylinders mounted on a support frame. Assuming the use of Type 3 composite CNG cylinders, the four cylinders have the following specifications:

|                           |                     |
|---------------------------|---------------------|
| – NG-equivalent Capacity: | 65.8 m <sup>3</sup> |
| – CNG-equivalent Volume:  | 250 liter           |
| – Tare weight:            | 91 kg               |
| – Gross weight:           | 144 kg              |
| – Diameter:               | 404 mm              |
| – Length:                 | 2.800 mm            |
| – Service life:           | 15 years            |

## STAKEHOLDERS

Private vessel operators and BIWTA, the inland waterways authority, are the main stakeholders of the proposed pilot project. BIWTA provides general support and maintains a regulatory framework that is beneficial for the development of CNG as an IWT fuel. The BIWTA also has to approve any CNG pilot project in IWT.

The field mission in Bangladesh encountered strong support among private vessel operators for a CNG pilot project with a passenger vessel on short (< 100km) routes (like the selected route between Narajanganj and Chandpur). The subject was not new to them and they consider CNG as a good way of reducing operating costs. The possible reduction of exhaust emissions was less important to them. Dual fuel technology is preferred to mono-fuel CNG operation, because of the retention of conventional diesel as an option.

Local stakeholders did not consider the reduction of passenger capacity in vessels to accommodate CNG tanks as a problem as the resulting cost savings were expected to cover this loss. However, the operators of passenger vessels appeared unwilling or unable to finance (part of) such a CNG pilot project themselves. An initial pilot project could demonstrate the viability of the required investments and influence attitudes toward the investments needed.

## RESULT: GATE 2

During stage 2 the vessel refueling options were reviewed and a design for the storage of CNG was proposed. The widespread use of mobile pontoons for public transport poses a constraint in Bangladesh and necessitates the use of private fixed docks for refueling (This characteristic does not necessarily feature in other countries). Vessels could therefore be refueled from local CNG stations using mobile tanks transported by and loaded and unloaded from trucks. A 50 percent CNG-to-diesel substitution rate is assumed for diesel

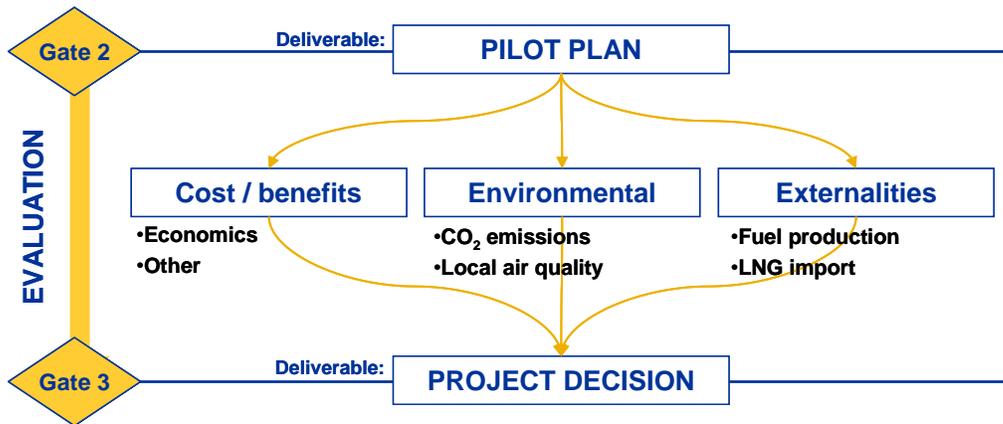
engines already in operation, which is slightly less efficient than brand new dual-fuel OEM engines. Four 250 liter Type 3 composite CNG cylinders can be used for storage.

### 12.3 STAGE/GATE 3 ANALYSIS: EVALUATION

This section evaluates costs and benefits of a pilot to convert river vessel engines to dual fuel (CNG + diesel). It also assesses the impacts on emissions and comments on externalities which may influence the feasibility and scalability of the pilot project. Figure 12.7 summarizes the steps in the third stage.

Figure 12.7 Stage/gate evaluation methodology: evaluation stage

#### Stage/Gate 3



Source: study team

#### COST/BENEFITS

The costs and benefits of the pilot project are analyzed from a broad economic welfare perspective. This means that direct costs and benefits and all other possible positive and negative effects on the economy of the pilot country are taken into account.

The economic cost benefit analysis (CBA) differs from a financial CBA in the following respect:

- All duties paid and grants received in relation to the project are excluded from the analysis;
- All prices are corrected for market distortions (such as taxes); and
- If possible, the external effects of the project are internalized by including monetized costs and benefits.

The period of analysis is equal to the economic lifetime of the project and the residual value is included as revenue (in fact as a negative investment) at the end of the period of analysis. The economic internal rate of return (EIRR) can be calculated from the flow of costs and benefits generated. If the ratio is above a certain predefined limit (the capital opportunity costs), the project is feasible from an economic point of view. Other indicators of feasibility, such as net present value (NPV) and benefit cost ratio (B/C-ratio), were also calculated.

### Assumptions

The following assumptions were made to set up this CBA:

- a discount rate of 12% was used (BRAC 2008)<sup>12</sup>;
- the assumed lifetime of the project is 15 years, with no residual value after ending of the project;
- the investment period is 3 months.

### Economic costs

The economic costs of the project consist of:

- the investment costs of the project;
- the annual maintenance costs of the project, indicated as a fixed percentage of the investment costs;
- the annual operational costs of the project.

### Investment costs

The table below provides an estimate of the total investment costs for the pilot project. Included are the costs of a CNG conversion kit, lightweight CNG tanks, local engineering of engine conversion and (most notably) the mobile tank unit (design & construction), and further miscellaneous material costs (piping, nozzles, etc). The costs were estimated based on telephone interviews with possible suppliers.

TABLE 12.1 INVESTMENT COSTS FOR CNG DUAL FUEL SYSTEM (IN USD)

|                    | Economic Price in USD |               |
|--------------------|-----------------------|---------------|
|                    | Market Price in USD   |               |
| CNG conversion kit | 10,000                | 10,000        |
| CNG tanks          | 16,000                | 16,000        |
| Engineering        | 13,000                | 12,000        |
| Other              | 4,000                 | 4,000         |
| <b>Total</b>       | <b>43,000</b>         | <b>42,000</b> |

Source: Telephone interviews suppliers

<sup>12</sup> Literature on cost-benefit analyses for Bangladesh gives rates between 10% and 15%. See for instance Alam (2009) and BRAC (2008).

The CBA assumes that the materials are imported from abroad and possible taxes were taken into account in the calculation. Local engineering costs were corrected for a 10% labor tax.

#### *Maintenance costs*

In principle the use of a dual-fuel system reduces maintenance costs as NG fuels combust more cleanly. Reduced carbon deposits on piston rings, injectors, etc. mean that engine overhaul could be postponed. Lubricating oil does not become dirty as quickly, thereby extending the intervals between oil changes.

The maintenance costs included in this assessment are relatively high at a 5% of total investment costs or USD 2,150 per annum. This was done to finance the following main activities:

- recurrent replacement of fuel filters (every 1 – 3 years);
- recurrent safety checks on injection nozzles, tanks and piping;
- monitoring of emissions and related engine tuning to control emissions;
- risk premium for daily (off)loading of CNG tank units.

Repairs could become relatively expensive, especially when imported spare parts are needed (Type 3 CNG tanks, filters). It is assumed that maintenance will be sourced locally and maintenance costs have been corrected for VAT (4.5%). Maintenance costs without taxes thereby amount to USD 2,050 per annum.

In reality little maintenance is carried out in the IWT sector in Bangladesh. When something breaks down it is repaired, apart from which little money is invested into maintenance. This is acceptable for diesel engines, but for safety reasons it is assumed that vessel operators will maintain the dual-fuel engines.

#### *Logistics costs*

Refueling a dual-fuel boat will involve higher logistical costs than only using petro-diesel (see stage 1). These costs include the following components:

- hiring a heavy duty truck with mounted crane and driver, for refueling the CNG tanks (2 hours/sailing day);
- additional vessel movements for loading and offloading of CNG tank units (2 hours/sailing day);
- docking at a privately owned dock, for loading and offloading of CNG tank units (1 hour/sailing day).

The extra personnel costs (vessel & truck operators) amount to some USD 2,000 per annum, based on annual personnel costs of USD 1,750 per FTE. An additional USD 2,000 per annum is spent on equipment costs (truck & docks), leading to a total logistical cost of USD 4,000 per annum.

### Economic benefits

The economic benefits of the pilot can be assessed by comparing the expected costs and benefits with what the situation would be without implementation of the pilot. The following economic benefits were calculated:

- Reduction in fuel costs to the ship operator.
- External benefits of the project, i.e. externalities like environmental benefits or changes in safety. Input for these benefits result from the environmental analysis and the description of the externalities (see below).

#### Fuel benefits

The main economic benefit is the reduction of fuel costs to the operator. Table 12.2 below presents the cost difference between petro-diesel and CNG based on market prices in Bangladesh (cost per MJ of diesel is double that of CNG).

TABLE 12.2 PRICE DIFFERENCE BETWEEN PETRO-DIESEL AND CNG

| Fuel type    | Marketprice in USD per native unit | Marketprice in USD/MJ |
|--------------|------------------------------------|-----------------------|
| Petro-diesel | 0.63 USD/L                         | 0.012 USD/MJ          |
| CNG          | 0.23 USD/M <sup>3</sup>            | 0.006 USD/MJ          |

Source: Field mission Bangladesh

The price difference between diesel and CNG means that large savings could be achieved by switching to dual fuel. The table below estimates cost reductions that could be achieved by passenger vessels sailing between Narajanganj and Chandpur. A total amount of USD 28,500 could be saved per year, based on a daily roundtrip and 330 sailing days per year. This is almost one third of the total fuel costs per year.

TABLE 12.3 FUEL COST SAVINGS FOR PILOT PROJECT WHEN USING CNG (IN USD IN MARKET PRICES) <sup>1</sup>

|                     | Per trip  | Per day   | Per year      |
|---------------------|-----------|-----------|---------------|
| Petro-diesel        | 134       | 268       | 88,500        |
| Dual fuel (50% CNG) | 91        | 182       | 60,000        |
| <b>Saving</b>       | <b>43</b> | <b>86</b> | <b>28,500</b> |

Source: study team

<sup>1</sup> Based on the assumptions listed in stage 2

The taxation on CNG is much higher than on diesel in Bangladesh. The diesel price includes only 4.5% VAT compared to 32.7% tax on CNG. Excluding taxes increases the cost difference to USD 29,500 (see table 12.2 and 12.3 below).

TABLE 12.4 ECONOMIC PRICE DIFFERENCE BETWEEN PETRO-DIESEL AND CNG

| Fuel type    | Economic price in USD per native unit | Economic price in USD/MJ |
|--------------|---------------------------------------|--------------------------|
| Petro-diesel | 0.60 USD/L                            | 0.012 USD/MJ             |
| CNG          | 0.15 USD/M <sup>3</sup>               | 0.004 USD/MJ             |

Source: Field mission Bangladesh

TABLE 12.5 FUEL COST SAVINGS FOR PILOT PROJECT WHEN USING CNG (IN USD IN ECONOMIC PRICES) <sup>1</sup>

|                     | Per trip | Per day | Per year |
|---------------------|----------|---------|----------|
| Petro-diesel        | 128      | 256     | 84.5     |
| Dual fuel (50% CNG) | 83       | 166     | 55       |
| <b>Saving</b>       | 45       | 90      | 29.5     |

Source: study team

<sup>1</sup> Based on the assumptions listed in stage 2

#### External benefits

The reduction of CO<sub>2</sub> emissions and reducing emissions of sulphur and other particles constitute the key positive externalities of the project. CO<sub>2</sub> emissions will be reduced by some 55 tons. Such savings are monetized using unit values based on the "Handbook on estimation of external costs" issued by the European commission (see table 12.4). The handbook gives three different scenarios for valuation of CO<sub>2</sub>. This CBA uses the central values. The total environmental benefits of the pilot project thereby increase from around USD 2,000 in 2011 to 3,500 in 2026.

TABLE 12.6 VALUATION OF CO<sub>2</sub> PER TON IN THREE DIFFERENT SCENARIO'S (USD PER TON)

| Year of application | Lower value | Central value | Upper value |
|---------------------|-------------|---------------|-------------|
| 2010                | 9           | 33            | 59          |
| 2020                | 22          | 52            | 91          |
| 2030                | 29          | 72            | 130         |
| 2040                | 29          | 91            | 176         |
| 2050                | 26          | 111           | 234         |

Source: CE Delft ea (2008), IMPACT – Handbook on estimation of external costs in the transport sector

### Result of the economic CBA

The table below contains the results of the economic CBA. The CNG pilot has a very positive effect on the economy of Bangladesh. The NPV of the project is USD 201,000. This results in a benefit-cost ratio of 4.6 and an eIRR of 165%. The payback period (period after which cumulative costs and benefits reach positive level) is 0.7 years.

TABLE 12.7 RESULTS OF COST-BENEFIT ANALYSIS (IN '000 USD) (DISCOUNT RATE 12%)

|                                 | Effects in 2020 | NPV 2011-2026 |
|---------------------------------|-----------------|---------------|
| <b>Costs</b>                    |                 |               |
| Investment costs                | 0               | -42           |
| Maintenance costs               | 2               | 14            |
| Logistical costs                | -4              | -28           |
| <i>Total costs</i>              | -2              | -56           |
| <b>Benefits</b>                 |                 |               |
| Fuel cost saving                | 32              | 239           |
| Environmental benefits          | 3               | 18            |
| <i>Total benefits</i>           | 34              | 258           |
| <b>Balance Benefits - Costs</b> | 33              | 201           |
| <b>B/C-ratio</b>                |                 | <b>4,6</b>    |
| <b>EIRR</b>                     |                 | <b>165%</b>   |

Source: study team

### Sensitivity analyses

Sensitivity analyses were conducted for different scenarios to test the impact of variations in major assumptions. The following assumptions were tested:

- Doubling of investment costs;
- Tripling of logistical costs;
- Investment period of one year (instead of 3 months);
- 200 sailing days per year (instead of 330);
- Gas price of USD 0.50 per m<sup>3</sup> (instead of 0.23);
- Only 20% use of CNG (instead of 50%);
- Lower value for environmental benefits (low case scenario);
- Lifespan of 10 years (instead of 15).

The results of the sensitivity analyses are presented in the following table. The outcome is sensitive to the level of the fuel prices and fuel mix percentages. However, the CBA remains positive even under extreme conditions. Other important sensitivities include the number of sailing days and the investment costs.

TABLE 12.8 OUTCOME OF VARIOUS SENSITIVITY ANALYSES

| Scenario                                 | NPV in USD '000 | B/C-ratio | EIRR | Payback period in years |
|--|-----------------|-----------|------|-------------------------|
| Base case                                | 201             | 4,6       | 165% | 0,7                     |
| Doubling of investment costs             | 160             | 2,6       | 52%  | 2,3                     |
| Tripling of logistical costs             | 144             | 2,3       | 98%  | 1,2                     |
| Investment period of one year            | 179             | 4,4       | 77%  | 1,5                     |
| 200 sailing days per year                | 100             | 2,8       | 64%  | 1,8                     |
| Gas price of USD 0.50 per m <sup>3</sup> | 107             | 2,9       | 68%  | 1,7                     |
| Only 20% use of CNG in dual fuel         | 47              | 1,8       | 34%  | 3,8                     |
| Lower value for environmental benefits   | 190             | 4,4       | 150% | 0,7                     |
| Lifespan of 10 years                     | 162             | 4,0       | 165% | 0,7                     |

Source: study team

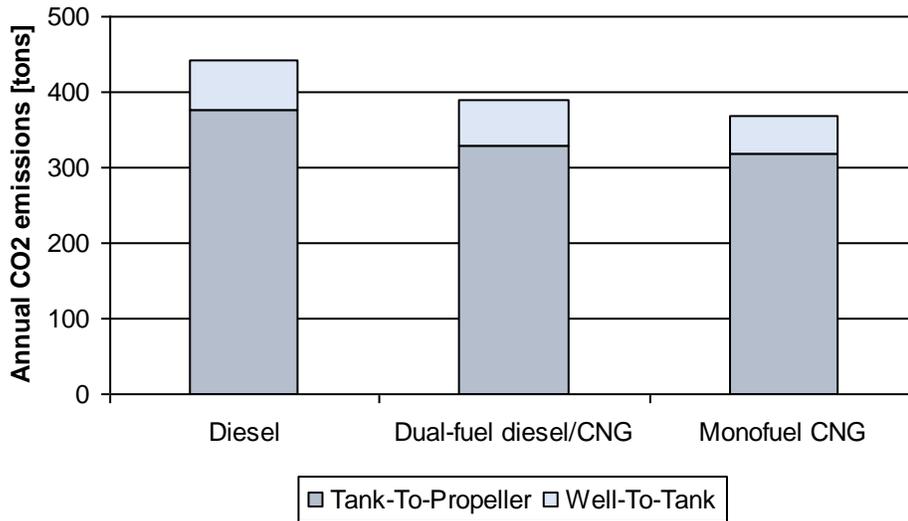
## ENVIRONMENTAL

CNG fuel has clear environmental benefits over most other fossil fuels, especially if NG is the only fuel used. NG engines emit fairly low quantities of particulates, NO<sub>x</sub>, SO<sub>x</sub>, and CO<sub>2</sub>, in comparison with other fuels. These benefits are reduced when using dual-fuel engines running on a mixture of NG and diesel.

### CO<sub>2</sub> emissions

The annual CO<sub>2</sub> emissions of the pilot vessel were calculated using the IPCC method (see Part A). Three options were analyzed: regular diesel operation, dual-fuel diesel-CNG operation (50/50) and mono-fuel CNG operation. First, a comparison with Tank-To-Propeller (TTP) emissions was made in each case. Second, Well-To-Tank (WTT) emissions were included in the comparison to reflect the impact of the fuel production and distribution chain on total CO<sub>2</sub> emissions. The diesel and CNG production chains generate similar amounts of CO<sub>2</sub> emission per unit of energy.

Figure 12.8 Comparison of annual tank-to-propeller CO<sub>2</sub> emissions per propulsion type (tons)



Source: Study team

Switching to dual-fuel operation with a 50/50 fuel mixture will achieve a 10% decrease in CO<sub>2</sub> emissions (Figure 12.8). Switching to mono-fuel CNG operation reduces CO<sub>2</sub> emissions by 12%. Lower CO<sub>2</sub> emissions are expected for mono-fuel CNG operation, but the emission reduction is to a large part offset by the lower efficiency of NG engines.

Dual-fuel combines the advantages of diesel engines (high efficiency) and NG engines (clean fuel). The annual CO<sub>2</sub> emissions of a dual-fuel engine could end up being lower than that of a mono-fuel CNG operation, if the share of NG in the dual-fuel mixture is increased.

TABLE 12.9 OVERVIEW OF CO<sub>2</sub> EMISSIONS PER FUEL TYPE

| Propulsion type      | Tank-To-Propeller | Well-To-Tank | Well-To-Propeller | Reduction % |
|----------------------|-------------------|--------------|-------------------|-------------|
| Diesel               | 375               | 68           | 443               | -           |
| Dual-fuel diesel/CNG | 329               | 70           | 399               | 10%         |
| Mono-fuel CNG        | 317               | 71           | 388               | 12%         |

Source: Study team

Dual-fuel technology requires careful maintenance and engine tuning. When NG is not combusted completely (due to engine wear or engine tuning), unburned hydrocarbons and methane are emitted through the exhaust. This leads to a significant increase in greenhouse gas emissions, even though CO<sub>2</sub> emissions will remain relatively low. Methane has 21 times the greenhouse impact of CO<sub>2</sub> on the atmosphere. It is easy to measure methane concentrations in exhaust gases on a regular basis, and high concentrations of the gas would help to indicate when maintenance or tuning is needed. These

issues are especially relevant in the case of retrofitted systems and old engines. Accordingly the budget for the operational phase of the pilot includes sufficient money for monitoring and tuning (see above).

### Local air quality

As NG is a clean fuel it is possible to reduce the emission of particulates, NO<sub>x</sub> and SO<sub>x</sub> significantly by switching to dual-fuel operation. However, NG combustion in a dual-fuel engine could still, and unpredictably so, generate high levels of these emissions, thereby impacting negatively on local air quality. Meticulous engine tuning and (typically) a lot of laboratory testing help to avoid this. The use of retrofit dual-fuel systems increases this risk. It is therefore recommended to include some sort of emission monitoring program in a dual-fuel pilot project.

### SCALABILITY

No significant externalities were identified that could hinder the upscaling of the CNG pilot. This is due largely to the small scale of the proposed pilot, involving only one dual-fuel CNG passenger vessel. The annual NG consumption of the vessel roughly equals that of 15 ordinary delivery vans. It therefore cannot have a significant impact on national or local NG distribution, though customers using the existing CNG stations may have to wait longer when river vessel tanks are refilled.

Consuming large amounts of NG in IWT could aggravate current supply shortages experienced during peak hours. Among the main reasons for selecting this pilot was its potential for scalability and the significant potential for positive environmental impacts. The full potential for CNG in IWT in Bangladesh is currently unknown. It is however obvious that a large number of inland water vessels would qualify for the use of this technology; also that expanding use to all these vessels would significantly decrease the emission of greenhouse gases and other harmful substances. However this would obviously **aggravate current shortages experienced, particularly at peak hours** and have a negative impact on practically the whole of Bangladesh.

The acceleration of LNG imports in Bangladesh sea-harbors could constitute a possible positive impact. This could compensate for shortages brought about by NG use in IWT and could help to improve the supply situation as a whole.

### FINANCIAL FEASIBILITY

The financial feasibility of the project from the perspective of the operator is also important. In assessing this account is taken only of such elements that are relevant to the operator, e.g. investments, operating costs and financial savings. The method used is the same as the one presented above, but without non-financial components like the environment. All costs and benefits include taxes and the results are presented in below table. The financial IRR amounts to 90%, and the payback period is 1.3 years.

TABLE 12.10 FINANCIAL EVALUATION (IN '000 USD) (DISCOUNT RATE 12%)

|                                 | Effects in 2020 | NPV 2011-2026 |
|---------------------------------|-----------------|---------------|
| <b>Costs</b>                    |                 |               |
| Investment costs                | 0               | -43           |
| Maintenance costs               | -2              | -15           |
| Logistical costs                | -4              | -31           |
| <b>Total costs</b>              | <b>-6</b>       | <b>-88</b>    |
| <b>Benefits</b>                 |                 |               |
| Fuel cost saving                | 28              | 215           |
| <b>Total benefits</b>           | <b>28</b>       | <b>215</b>    |
| <b>Balance Benefits - Costs</b> | <b>22</b>       | <b>127</b>    |
| <b>B/C-ratio</b>                |                 | <b>2.4</b>    |
| <b>FIRR</b>                     |                 | <b>90%</b>    |

Source: study team

The results of the sensitivity analyses, which were similar to those done for the economic analysis, are presented in the table below.

TABLE 12.11 OUTCOME OF VARIOUS SENSITIVITY ANALYSES ON THE FINANCIAL ANALYSIS

| Scenario                                 | NPV in USD '000 | B/C-ratio | FIRR | Payback period in years |
|--|-----------------|-----------|------|-------------------------|
| Base case                                | 127             | 2.4       | 90%  | 1.3                     |
| Doubling of investment costs             | 69              | 1.5       | 29%  | 4.6                     |
| Tripling of logistical costs             | 66              | 1.4       | 46%  | 2.7                     |
| Investment period of one year            | 109             | 2.3       | 52%  | 2.3                     |
| 200 sailing days per year                | 42              | 1.5       | 33%  | 3.9                     |
| CNG price of USD 0.50 per m <sup>3</sup> | -13             | 0.9       | 5%   | N/A                     |
| Only 20% use of CNG in dual fuel         | -2              | 1         | 11%  | N/A                     |
| Lifespan of 10 years                     | 101             | 2.2       | 90%  | 1.3                     |

Source: study team

The results correspond with the CBA sensitivity analysis. The gas price and the fuel mix used have the greatest influence on outcomes. CNG supply problems may further contribute toward a smaller percentage of CNG in the fuel mix. Other important factors include the investment costs and the number of sailing. Higher investment costs result in a longer payback period, which could affect the commercial interests of operators in a market that is highly competitive and uncertain. Confirmation of the viability of the project would

require a more precise evaluation of these factors. However, it is clear that they constitute risks that could influence the decisions of private operators to shift from diesel to CNG.

### RESULT: GATE 3

The pilot is economically feasible and the economic internal rate of return of 165% fully justifies the pilot. This is due to the fairly low investment costs, substantial benefits arising from using cheaper CNG, and the environmental benefits. Sensitivity analyses confirm the robustness of the rate of return.

The pilot is also financially feasible from an operator perspective. The pilot would significantly reduce the operators' fuel costs, making possible an earn-back period of about 1.3 years. Factors such as an increase in CNG price or reduced CNG availability, represent risks for the operator and reduce the financial return on investment.

Emissions from a dual diesel-CNG operation are generally lower than those from a conventional diesel operation. However, when NG is incompletely combusted, the engine could emit high levels of unburned hydrocarbons and methane. This is considered a risk especially in the case of retrofitted systems and old engines. Avoiding this will require a focus on engine maintenance and tuning. In the course of the project, vessel emissions should be monitored for particulates, NO<sub>x</sub> and SO<sub>x</sub> so as to evaluate the actual impact of the conversion.

Scaling the pilot up to cover a large part of the IWT fleet will impact on the overall demand of CNG in the country concerned. This could influence market prices and act as a constraint in the case of limited supplies, as is the case in Bangladesh at the moment. Due to its small size the pilot itself will have no effect on NG supplies. However, such impacts could be felt should the project be scaled up to the rest of the IWT fleet, especially during peak hours. Longer term solutions such as importing LNG via Bangladesh seaports are being investigated.

## ANNEX 1. LIST OF WORKSHOP PARTICIPANTS

Participants of the workshop held Sunday 5 September 2010 in Dhaka, Bangladesh.

| <b>Name</b>                 | <b>Position</b>            | <b>Organisation</b> |
|-----------------------------|----------------------------|---------------------|
| Ms. Jesmin Aga Begum        | Chief planning manager     | BIWTC               |
| Tanvir Haider               | Junior marine officer      | BIWTC               |
| Quazis Sarwar Imtiaz Hashmi | Director (Planning)        | DOE                 |
| Krantakan A. Hannan         | Chief, marine Construction | BIWTC               |
| Mr Fazhul Hoque             | DC PL manager              | BIWTC               |
| Ishtiaque Ahmed             | Transport specialist       | World Bank          |
| Dr. M.R.H. Whandeka         | Advisor                    | Spectra Group       |
| Md Abdul Basher             | Joint director (ports)     | BIWTA               |
| A Razzaque                  | JF Director (exp)          | BIWTA               |
| Md Manzour Quadir           | Sr Deputy Director         | BIWTA               |
| Md Zabizul Alam Khan        | Sr DDCP                    | BIWTA               |
| Khandaker Rasel Hosan       | DD (Planning)              | BIWTA               |
| Md Zahangir Ham             | A.E. (MME)                 | BIWTA               |
| Eng Md Shafiqul Islam       | Deputy Manager (CNG)       | RPGCL               |
| Eng Md Kabir Hossai         | AE (MEE)                   | BIWTA               |
| Parvez Ali Anwar Khan       | IWT Consultant             | Independent         |
| Eng A.I.M. Nuzullah         | DGM                        | RGPC, Petrobangla   |
| Md Mojilwe Rahman Sanker    | D. chief engineering       | BIWTA               |
| Md. Sharif Islam            | Deputy secretary           | Min of Shipping     |
| Mahmud Hassan Salam         | Director (planning)        | BIWTA               |
| Md. Alangir Khan            | Director                   | Dept of Shipping    |
| Md Syreful Hasim            | Joint Chief                | Min of Shipping     |
| Md. Sajjadul Islam          | Deputy Chief               | Min of Shipping     |
| Umme Hasima                 | Assistant Chief            | Min of Shipping     |
| Md Amirul Islam             | Assistant Chief            | Min of Shipping     |
| M.A. Fawily Khan            | Programme officer          | World Bank          |
| Mohammed Sharia Khafers     | Senior executive           | HB Consultants      |
| Hasan Hafijun Rahman        | Executive                  | HB Consultants      |
| Fawzia Shireen Sultana      | Executive                  | HB Consultants      |
| Shireen Lutfunessa          | General Director           | HB Consultants      |
| Golam Molla Moulah          | Expert                     | HB Consultants      |
| Dr. Ismail                  | Expert                     | HB Consultants      |
| Dick d'Arnaud               | Key expert                 | ECORYS              |
| Floor Smakman               | Moderator                  | ECORYS              |

## ANNEX 2: LIST OF INTERVIEWS

### Bangladesh field mission:

- Dhaka Port
  - Mr Mo. Shahidalla -deputy Director of Terminal
- BIWTC
  - Mr. Osman Amin, Director Technical
  - Mrs Jesmin Ara Begum, Chief Planning Manager
  - Mr. Mosharof Hossain GM (Commercial)
  - Capt Sawkat Sarder, GM (Marine)
- BIWTA
  - Mr Feroza Ahmed Member (Engineering)
  - Mahmud Hasan Salim Sr Dep Director (Planning)
- Department of Shipping
  - Mr. Md. Alamgir Khan, Director
- Titas Gas
  - Mr Abdul Aziz Khan, Managing Director
- Private Operators Association
  - Mr Al Haj Md Badiuzzaman Badal Senior Vice Chairman BIW Passengers Carrier Association
  - + additional experts
- World Bank Dhaka
  - Mr Ishtiaque Ahmed Transport Specialist
- Paturia Ferry Terminal
  - Mr M A Matin, DGM
  - Mr. Enamul Haque, Mechanical Engineer
  - Mr Abdus Satter
- Site visit Narayangonj Port
- Ministry of Shipping
  - Mr. Sajjadul Islam

### Netherlands/Germany:

- EICB
  - Mr. Khalid Tachi, advisor innovation
- MARIN
  - Henk G. Blaauw - Sr Project Manager Ships
- PON Power
  - Mr. Rob Paulussen, Account Manager Shipping
  - Mr. Gerhard Groot Enzerink, technical solutions
- VDB Duisburg
- DST
  - Dipl Ing Mr. Zoellner

## ANNEX 3: CONVERSION FACTORS

|           |            |            |
|-----------|------------|------------|
| Short ton | 0.90718474 | Metric ton |
| mile      | 1.609344   | km         |
| Gallon    | 3.7854118  | Liter      |
| Short ton | 2000       | lbs        |
| lbs       | 453.59237  | gr         |

## ANNEX 4: OVERVIEW OF IWT R&D PROJECTS

This annex gives an overview of ongoing research on IWT innovation. The annex aims to give an overview of the broadness of different ongoing programs. There are programs that focus mainly on technology, while others mainly aim to improve operations. Besides an overview of research programs, the annex also describes some individual projects which could lead to notable results.

### PLATINA

In 2006 the European Commission initiated an action plan called NIADES to enhance the use of inland navigation as part of intermodal freight solutions. The objective was to create a sustainable, competitive and environmentally friendly Europe-wide transport network.

The action plan was embraced by the inland navigation sector who collaborated with the Commission to create a multi-disciplinary knowledge network, PLATINA, so as to speed up progress toward NIADES goals. The project is financed within the Seventh Framework Programme of the European Commission.

PLATINA consists of 22 partners from nine different countries. The core consortium consists of Via Donau (Austria) as coordinator, Voies navigables de France (France), Bundesverband der Deutschen Binnenschifffahrt (Germany), Promotie Binnenvaart Vlaanderen (Belgium) and the Rijkswaterstaat Centre for Transport and Navigation (The Netherlands).

Five work packages within the PLATINA deal with specific policy areas:

- Markets;
- Fleet;
- Jobs & skills;
- Image;
- Infrastructure.

Work package two, fleet, specifically deals with IWT innovation. The objective of the work package is to 'improve logistics efficiency, environmental and safety performance of IWT'. Tasks are to support European IWT innovation and set up an IWT innovation database.

The first task within the work package is to identify new innovations in Europe, to provide assistance during the "incubation period" of an innovation, and to speed up promotion and dissemination of the technology. The second part of

the programme focuses on registering innovations on a database and to make them available to the public through a web based tool.<sup>13</sup>

## CREATING

CREATING was a research programme of the European Commission carried out under the Sixth Framework Programme for research, technological development and demonstration activities. Main focus of the programme was to stimulate waterborne transport through improved integration of shipping into existing transport chains.

CREATING has a logistical and a technological focus. The aim of the technological focus is to promote state of the art ship designs for improved economic, safety and environmental performance. Ships have to fulfil the highest requirements regarding:

- Ship hydrodynamics: decreasing the hull resistance of the ship and optimizing both propulsion and maneuverability
- Engines: to be as efficient and clean as possible
- Safety: reducing the risks involved in transport

The CREATING Team comprised 27 partners from 9 countries and deals with the Rhine and Danube basin, the North-South connection from the Netherlands to France, and the East-West canals in Germany and Poland. The team includes research institutes, shipyards and relevant branch organizations (viz. shippers, inland navigation) and maintains strong relations with the authorities. CREATING started in July 2004 and ended after a period of three years.

Among the mechanisms used to improve the environmental performance of inland navigation were cruise control systems, low sulphur fuel, selective catalytic reduction and particulate matter filters. These systems were implemented in the pilot project "The Cleanest Ship". Today this ship is still in service and operated between Rotterdam and Antwerp.

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<sup>13</sup> The tool is still in progress, but will be made available on <http://www.naiades.info>

Figure 12.9 The Cleanest Ship, M/S Victoria



Photo ECORYS

## Program “VoortVarend besparen”

The program “VoortVarend Besparen”, or Energetic Saving, is an initiative of the Dutch Ministry of Transport.<sup>14</sup> Goal of the initiative is to increase the fuel efficiency of inland shipping by convincing shippers to sail more economically. The program consists of four aspects:

1. Communication program;
2. Platform introducing competition on fuel saving;
3. Training;
4. Provision of technical assistance applications.

The first step in the program was a broad communication program. The initiative was set up with many stakeholders including large shipping firms and industry organizations. The aim was to reach as many individual ship operators as possible and to convince them to join the program.

<sup>14</sup> See [www.voortvarendbesparen.nl](http://www.voortvarendbesparen.nl)

The second part of the program was a fuel saving competition. The fuel usage of ships that entered the competition was registered over a set period in 2009. The goal of the 2010 competition was for ship operators to save improve on the savings achieved in the previous year.

Ship operators could participate in a training programme on economic sailing to increase their chances in the competition. The key point of the training was to convince experienced ship operators of the costs and benefits of sailing more economically.

The last part of the program consisted of providing technical assistance for applications. The programme made it financially attractive to buy mechanisms such as the tempomaat (see section 2.4).

The program builds on the operational efficiency improvements as discussed in section 2.2.

## Examples of individual projects

### **EcoFlow**

EcoFlow is a Dutch project that will aim to design and build a green and economically sustainable inland ship. The goal is to put this “vessel for the future” into service in 2012. The vessel is to be cost efficient and will comply with all new laws and regulations.

EcoFlow will examine all aspects of ship configuration, including design, equipment, loading and unloading, propulsion and automation. It also looks at low emission sailing, hybrid propulsion, fuel savings, ship's build (underwater) and on board integrated control systems.

Combi International (supplier of inland vessels), Wärtsilä Netherlands (including marine engines and propulsion systems), TeamCo Shipyard (fitting-out) and Reederei Deymann (inland tanker shipping) each have their own field of experience and expertise in developing green and economically sustainable products. These four parties expect to provide derived solutions for greener, cleaner and more sustainable ships.

The project is currently in the preliminary phase with exploratory talks being held between several parties. Expert parties include government agencies, class societies, inland shipping interest groups and banks.

### **Project Energy-saving air-Lubricated Ships (PELS)**

PELS was set up to enhance scientific and technical knowledge about the effect of air lubrication on the behavior of inland and seagoing ships under various operational conditions. It aims to make safe and efficient application of air lubrication possible within 5-10 years, thereby to significantly reduce ship fuel consumption and emissions. There were two PELS projects: PELS I from 2001 – 2004 and PELS II from 2005 – 2009.

The project approach combined experimental and numeric research. Experimental research provided insight into the impact of air lubrication on frictional resistance, the flow patterns of water/air bubbles mixture around the hull, and information for validating the flow simulation tools that were developed.

The project was carried out by a consortium of shipbuilding enterprises and R&D organisations. Participants from the shipbuilding industry included Bodewes Binnenvaart, Damen shipyards, Van der Giessen – de Noord, Scheepswerf Grave en de Netherlands' Shipbuilding Industry Association (VNSI). Research organizations included the DK-Group NL, a subsidiary of a Danish enterprise developing fuel-efficient fast ships and the Maritime Research Institute of the Netherlands MARIN. The BOS Foundation was appointed by MARIN to coordinate the project. Economic evaluations were conducted of inland vessels of 110 m length, 11.4 m width and draft of 3.2 m (standard Rhine self propelled vessel). It was concluded that an earn back period of 2 years would be possible.

Friction with the surrounding water accounts for most of the resistance faced by ships. Efficiency improvements of up to 20% could be achieved by reducing resistance, though this would require improvements that go beyond what can be achieved by traditional means such as shape optimization and minimizing the radiated waves. Insulating the ship from the water by means of an air layer is a promising technique to reduce friction

### **Low Impact Urban Transport water Omnibus (LIUTO)**

The Industrial and Materials Technologies (BRITE/EURAM 3) programme fell under the European Commission's fourth Framework Programme. One of the projects in this programme was the Low Impact Urban Transport water Omnibus (LIUTO). The LIUTO industrial research project consisted of a collaborative venture between six partners from three European countries.

The principal objective of LIUTO was to design a hull shape that would minimize wave wash while maintaining or improving vessel maneuverability and performance. The LIUTO waterbus hull was designed, developed and refined by the Department of Naval Architecture (D.I.N.) of the Federico II University in Naples, Italy. The objectives were to create a lightweight, stress-resistant and low maintenance vessel with significantly reduced wave formation. The resulting modifications to the LIUTO design resulted in a 30 % reduction in wave generation at the ship's median speed.

The prototype's propulsion system consists of two electric motors powered by battery packs that are, in turn, charged by a diesel generator running at a constant speed. Low fuel consumption and low emissions are achieved by running the diesel engines at a single optimum efficiency level. Such hybrid diesel-electric power systems, although more costly to build, might find application in high-speed ferries.

The technology developed and perfected through the LIUTO project can be applied in other cities that rely on urban water transport, such as Amsterdam, Bangkok or Dhaka.

## **INBISHIP**

The EU research project INBISHIP™ developed a revolutionary approach to inland cargo ship design. The project takes into account quantified environmental impacts of a conventional inland freighter and develops a concept to significantly reduce these while improving safety and economic efficiency.

A concept was developed to improve the economic and environmental performance of conventional river ships, especially in instance where one is dealing with an imbalanced demand for downstream and upstream navigation.

It consists of the following elements:

- flexible propulsion power control – diesel-electric prime movers (generator sets) and Azipod electric propulsion
- stowage space for 14 TEU in length instead of 13 TEU at conventional vessel of the same standardized 110 m length
- azimuth pods and powerful bow thrusters enabling extraordinary maneuvering features thus improving safety of operation
- accommodation and wheelhouse arranged forward thus enabling an excellent visibility for the skipper and comfort for the crew far away from the vibrations and the noise of the machinery concentrated aft

Following these principles the ship gains some 7% container capacity compared to a conventional vessel of the same size, while reducing fuel costs through optimal use of on board power according to the loading and nautical conditions.

## **INBAT**

INBAT means Innovative Barge Trains for Effective Transport on Inland Shallow Waters and focuses on designing, producing and operating inland barge trains. Safe, environmentally friendly and efficient ships will enable more transport on smaller or seasonally not navigable inland waterways.

The final results of the INBAT project will enable cost effective transport at water depths of up to 1 m. This will be made possible by a combination of lightweight constructions based on new material application, an innovative barge train concept and improved propulsive systems. Changes at the design and production stages will reduce construction costs and improve payloads. The cost-benefit calculations executed within the INBAT project will identify where such innovative barge trains can be operated. The designed barge trains could substitute road transport and reduce the overall environmental impact.

## **e-Navigation**

In Europe and the USA, electronic systems are being developed to enhance traffic management, planning and safety. e-Navigation is a new concept that

aims to integrate existing/new vessel and shore-based navigational tools into an “all embracing” system. It was defined by the International Association of Marine Aids to-Navigation and Lighthouse Authorities (IALA) as:

The harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment”

Major components include electronic charts, radar, AIS, and precise positioning from satellite and/or land-based navigation systems. For inland navigation these technologies also apply. There are two major challenges when moving from concept to implementation:

1. Ensuring the availability of all system components and using them effectively to simplify the display of crucial navigation-related information.
2. Incorporating new technologies in a structured way while ensuring that their use is compliant with the existing navigational communication technologies and services.

Main components on which research is being conducted are:

- Electronic chart data/nautical pubs: these will allow an increased use of smart data (data tagged with intelligence), reduce (or eliminate) printed Notices-to Mariners (NotM), NTNI, & lock tickets, allow the use of system-wide updates of Aids-to-Navigation (AtoN), Notices to Mariners (NotM, notices to navigation, etc. and a seamless integration for the mariners, such as river permits, safety zones, CDC reports, air gap, lock lower gauge, etc.
- AIS (Automated Identification System) will be in widespread use by inland system operators in the near future. It will enable increased situational awareness from vessel and shore-based operators (e.g., location & movement of other vessels).
- Lock Operations: likely in the future more operation rules can be performed electronically (increase in assignment/management)
- VTS (Vessel Traffic Systems) will play an increased role (information on ice, flooding, buoys, etc.)
- AtoN (Aids to Navigation): Virtual buoys could be used in lieu of e.g. ice buoys.
- Finally, towboat operators wish for more information on e.g. current flow data (locks, dams, bridges, etc.) and on drift (floating debris).<sup>15</sup>

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<sup>15</sup> Summary Report Inland Navigation Technology '09, “Digital Technology’s Impact on Safety and Efficiency”

3-4 February 2009, US Army Engineer Research and Development Center Coastal & Hydraulic Laboratory, Vicksburg, MS

The use of satellite systems for positioning and communication are being explored elsewhere as well. For example in Malaysia, the use of GNSS is considered for inland water transport in Sungai Rajang.<sup>16</sup>

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## LIST OF ABBREVIATIONS

|                 |   |
|-----------------|---|
| B/C-ratio       | Benefit Cost ratio                          |
| Bhp             | Brake Horsepower                            |
| BIWTA           | Bangladesh Inland Water Transport Authority |
| BIWTC           | Bangladesh Inland Water Transport Company   |
| CBA             | Cost Benefit Analysis                       |
| CNG             | Compressed Natural Gas                      |
| CO <sub>2</sub> | Carbon Dioxide                              |
| DOS             | Department of Shipping                      |
| EIRR            | Economic Internal Rate of Return            |
| FTE             | Full-time equivalent                        |
| GDP             | Gross Domestic Product                      |
| GHG             | Greenhouse Gases                            |
| GJ              | Gigajoule (10 <sup>9</sup> joule)           |
| IPCC            | International Panel on Climate Change       |
| IW              | Inland Waterways                            |
| IWT             | Inland Waterways Transport                  |
| LNG             | Liquefied Natural Gas                       |
| MJ              | Megajoule (10 <sup>6</sup> joule)           |
| MOS             | Ministry of Shipping                        |
| Mt              | Million tons                                |
| MV              | Motor Vessel                                |
| NG              | Natural Gas                                 |
| NO <sub>x</sub> | Nitrogen Oxide                              |
| NPV             | Net Present Value                           |
| OEM             | Original Equipment Manufacturer             |
| SO <sub>x</sub> | Sulfur oxide                                |
| Ton-km, tkm     | Ton-kilometers                              |
| TTP             | Tank-To-Propeller                           |
| USD             | United States Dollars                       |
| WTT             | Well-To-Tank                                |



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