Inland Waterway Gas-Fuelled Vessels: the Basis of an Innovative Concept Design for European Rivers

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Abstract: - The basic aspects of an innovative concept design for a vessel intended to be used on European inland waterways network are presented. The main requirements to be fulfilled concern technical matters for the vessel, and take into account all the constraints imposed both by the infrastructures present along the rivers/canals and by the normative about environmental protection. In particular, the paper deals with the definition of the framework of the problem, the analysis of suitable solutions and the possible adoption of innovative technologies nowadays available on the market. With reference to the latter issue LNG engines have been considered for both propulsion and generation, in order to low the emission of pollutants in air.

Key-Words: - inland waterway transport, pushboat, gas-fuelled vessel, LNG logistic chain, fleet reactivation, rules and guidelines

1 Introduction
The inland waterway navigation is often influenced by the particular environment and the infrastructures that are available into it. These circumstances make the development of alternative and more efficient transport solutions really complicated.
The dynamic nature of rivers requires constant monitoring and organizational flexibility by operators, in particular when environmental constraints such as channel width, depth or bridges are present.
Nowadays, inland waterway navigation is not fully exploited worldwide as a mode of transport for goods and passengers. Contrary to American Great Lakes and inner canals of China, which are almost the only way to place goods and move passengers, the European inland waterways have a largely developed alternative transport network on road and rail.
Recently, the lowering of the water level on both the Rhine and the Danube has pointed out a clear inadequacy of the existing fleet engaged in inland waterways due to a lack of new vessels in the last 45 years.
Often, the feasibility studies for new vessels are carried out for short range routes and are aimed to a short-term economic return on investment for shipping companies.
Relying on a solid logistic study, it is possible to better plan such a kind of transport, balancing dry and liquid cargo in order to obtain a significantly higher efficiency. In addition, the forthcoming entry into force of stronger restrictions on emissions will make the inland waterway navigation more efficient, safer and environmentally friendly. In fact, the latter intent will be attained by the new limitations on emissions of pollutants in terms of NOx and PM (solid particulate matter) as imposed by the European Community.
Since 2007, the thermal engines currently used in inland waterway navigation are subject to Stage IIIA regulations for pollutants (Directive 97/68/EC). Despite these regulations, the level of emissions of engines is still considerable, and corresponds to 17% of total emissions, with higher concentrations in cities and harbours.
Investing in innovative concept design would make it possible a drastic reduction of the emissions of pollutants. The replacement of the aged engines currently installed would lead to an improvement of both the transport efficiency and the air quality.
If no specific actions are undertaken, the level of emissions would remain constant or could rise further around inland waterways, while an investment on the new technologies of engines already available on the market, could dramatically reduce the air pollution level.
The aim of this work is to analyze firstly the reasons of the actual reduction of the inland waterway fleet.
and then to develop a new ship project in order to boost the economy of this mode of transport. The performed studies demonstrate that the few investments made in this direction have been mainly addressed towards a tonnage increase of the ships, but the conditions of use have been penalized, especially when canals depth and width are limited. In the analysis carried out the existing routes and the market demand have been considered in order to derive a new convenient transportation concept that can take advantage of the current technologies available on the market. The new concept design must demonstrate the possibility of trade-off for the market, considering the restrictions imposed by the normative related to the ship design and the emissions control. The work has been divided into the following steps, each one with a well defined goal to be achieved.

1. **Definition of the problem.** The reduction of the level of emissions for inland waterways is not remarkable because of alternative modes of transport (on rail or road) have been preferred by investors over the last 40 years.

2. **Analysis of possible solutions.** The merchant vessels engaged in inland waterways navigation are divided into self-propelled dry cargo or tank vessels, pushboats, tugs and non-motorized barges. The logistics of transportation, which currently is often not efficient, must be completely re-invented and addressed to attain economic convenience for shipowners. The key point is to reduce first cost and shipping times, and such an objective can be attained only by an efficient supply chain. Most barges operating on the canals are owned by the masters themselves, who in many cases are reluctant to invest for the renewal of the fleet. Therefore, the new concept will seek to keep costs down, taking into account both the economic return in the short term and the possibility to operate the vessels till 50 years.

3. **Innovative technologies and the new concept.** As already mentioned, the main target for the new concept is that to contain the first costs as much as possible, and be environmentally friendly and cheap in the long run. On these premises the improvement of a pushboat/non-motorized barges convoy has been considered, where the first costs are higher for the pushboat but are very low for the barges. The study has been based on the research of efficient solutions for the pushboat for what concerns optimal speed, cargo capacity, number of pushed barges and type of propulsion. The pushboat has been designed in accordance to the main Rules and Regulations for the construction of inland waterway vessels.

4. **Mathematical model.** All the boundary conditions previously identified have been collected and considered as inputs in a mathematical model, in order to determine among the countless hulls generated the ones more suitable. The best combination of the variables of the problem has been obtained by advanced decision-making methods based on the concept of concurrent engineering. The final solution then turns to be the optimal compromise among technical matters, rules and regulations, and economic aspects.

5. **Detailed analysis of the new concept design.** Once the final solution has been determined and validated by means of manual procedures, the more suitable and feasible pushboat has been designed as a whole. In a first step, structures and internal partitions have been defined in order to determine a possible displacement, from which depend the propulsive performances of the ship. Problems connected with the application of Liquefied Natural Gas (LNG) propulsion have been investigated with particular attention to the definition of the hazardous zones and related requirements in terms of insulation and ventilation. In addition to the LNG propulsion, another propulsive solution has been developed considering the application of an innovative LNG hybrid technology based on new generation battery packs and micro gas turbine.

6. **Market analysis, costs and return loss.** The first costs of the chosen solution must be considered together with the trend of the market and the costs of the logistic system. In fact, a proper logistic system reduces waiting times in harbour and also the operating costs related to the vessel. In the present paper only the results concerning the development of the items 1, 2 and 3 of the work program are shown.

### 2 Market Analysis

Taking into account the total inland waterway navigation system, the international waterway transport uses four waterways which represent more than 80% of the total (Table 1). In absolute terms, for instance, the total navigable length of rivers, lakes and canals in the Economic and Social Commission for Asia and the Pacific (ESCAP) region exceeds 290,000 km. On these inland
waterways, each year, more than 1 billion tons of freights and 560 million passengers are moved.

<table>
<thead>
<tr>
<th>Waterway</th>
<th>Annual freight traffic [million of tons]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESCAP</td>
<td>1000</td>
</tr>
<tr>
<td>Rhine River</td>
<td>101</td>
</tr>
<tr>
<td>Danube</td>
<td>40</td>
</tr>
<tr>
<td>Mississippi</td>
<td>425</td>
</tr>
</tbody>
</table>

Table 1: Annual freight traffic in the main inland waterways

In Europe, the inland waterway transport can contribute significantly to achieve the objectives established in the European "2030 framework for climate and energy policies" because it is characterized by the following intrinsic merits:

- very low direct movement costs;
- low energy consumption and low carbon footprint;
- low air pollution and noise levels;
- safe and secure services;
- spare capacity on the network, negligible congestion on the waterways;
- high transport capacity and reliability.

2.1 Types of vessels on European waterways

Inland vessels are classified according to their size and purpose. The type here considered concerns cargo vessels, which can be further distinguished, depending on the kind of transported commodity, into dry-cargo ships and tankers. Moreover, the merchant ships used in inland waterways can be divided into self-propelled dry cargo or tank vessels, pushboats, tugs and non-motorized barges.

In particular:

1. **Self-propelled cargo ships**. Dimensions vary from a small ship (Péniche) 38-40 m long with a draught of 2.5 m and a cargo capacity of about 300 t, to a large ship 110 m long with a capacity of about 1900 t at the same draught. In recent years on the Rhine river, much larger ships have become usual with length up to 135 m, breadth up to 17 m, cargo capacity of about 3500 t, and a draught of only 2.5 m.

2. **Self-propelled pushboats**. Inland pushboats designed for pushing barges are available in different sizes, configurations, accommodations and power. Some inland pushboats are set up to handle the intra-coastal waterways. They are called "ditch-boats" or "canal-boats", and are characterized by shallow draught and ability to traverse the canals. Pushboats are considered the "engines" of the inland waterway convoys, with power from 450 kW to 8000 kW.

3. **Barges pushed by self-propelled vessel (pushboat or pushing cargo ship)**. Pushed convoys usually consist of 2, 4 or 6 barges operated by one pushboat of adequate power. Standard European barges commonly used in large number on the Rhine-Main-Danube Canal have a length of 76.5 m, a breadth of 11.0 or 11.4 m and a cargo capacity of about 1650 t at a draught of 2.5 m. Therefore, the large 6-barge convoy has a total length up to about 250 m (one pushboat and three barges in length, two side-by-side). In downstream running, barges are usually arranged two in length and three linked in width, so resulting in a total breadth of about 34.2 m.

4. **Barges towed by river tugs**. This type of vessels are almost completely abandoned on European waterways, but still working in Asia.

3 Rules framework

The Rules to be considered in the design of a sea-going ship can be grouped in two categories:

a. Rules for the Classification of sea-going ships (IACS, LR, RINA, DNV, etc.);

b. International statutory Rules (SOLAS, COLREG, MARPOL, etc.).

In comparison with a sea-going ship, the design of a ship intended for inland waterway navigation meets more specific restrictions due to the particular environment. Shallow waters and/or narrow waterways have a great impact on the design of such vessels. Moreover, in EU countries a lot of International and Regional Rules and Guidelines for the construction and navigation of inland waterway ships are compulsory. The complete framework of the European Rules can be collected as follows:

1. **International Rules and Guidelines**: 

   a. Directive 97/68/EC as amended by 2002/88/EC, 2004/26/EC, 2006/105/EC, 2010/26/EC, 2011/88/EU and 2012/46/EU, also called Non-Road Mobile Machinery (NRMM), by which were introduced limitations on emissions for the engines of new vessels in terms of NOx;

   b. Directive 2006/87/EC, which established the technical requirements for inland waterway vessels, and the standards for the issuing of the Community Navigation Certificate;

   c. Directive 98/70/EC, as amended by 2009/30/EC, which determined the quality...
standards, in terms of SOx and PM, of the fuel oil to be used also for inland waterway navigation;

d. Rules for the Classification of inland waterway ships, issued by the different Classification Societies (RINA, GL, LR, etc);

e. European Code for Inland Waterways (CEVNI, 4th edition, 2009), which established the safety rules for inland navigation;


2. Regional Rules and Guidelines:

a. Central Commission for the Navigation of the Rhine (CCNR) Rules and Guidelines, among which the most important are the Rhine Police Regulation (RPR) and the Rhine Vessel Inspection Regulations (RIVR);

b. European Agreement on Main Inland Waterways of International Importance (AGN);


As mentioned above, additional Rules must be considered if the inland waterway ship will use gas-fuelled engines for the propulsion.

3. Additional Rules for gas-fuelled ships:

a. International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO IGC Code);

b. International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IMO IGF Code);

c. IMO Resolution MSC.285(86), Interim Guidelines on Safety for Natural Gas-Fuelled Engines;

d. Resolution MEPC.203(62) which amends the MARPOL Annex VI, introducing the Energy Efficiency Index for ships (EEI).

4. Environmental limits

In the design of a ship intended for inland waterway navigation also environmental limits shall be considered. The smallest lock sited along the waterway affects length and breadth of the ship, while the minimum depth of the waterway affects the draught. The height of the ship, instead, is limited by the clearance of bridges crossing the waterway.

The resistance against the smashing of waves of bottom and banks of navigation canals sets a limit to the maximum speed of the ship. The vessel must be able to maneuver in restricted fairways and the installed propulsion power must be also sufficient to permit upstream navigations. Furthermore, it must be considered the behavior of ships and pushed convoys when pass by or overtake in narrow straight stretches. Moreover, constraints imposed by the canal bends shall be considered. Essentially, the characteristics of every waterway define the size of ships capable to sail on it. The different waterways are categorized into different ECMT (Conférence Européenne des Ministres de Transport) classes (Table 2) in accordance to the maximum dimensions of the ships which can sail on them.

4.1 Cross sections of rivers and canals

Depth, width, cross sectional area and shape of the waterway are decisive factors that affect navigation, manoeuvring and speed of ships. On natural waterways (both free-flowing and regulated rivers) only a part of the waterway cross section is used for the navigation: the so-called "fairway" (Fig. 1).

The water level has a decisive influence on fairway depth and width and, then, on the navigability of the rivers. In general, navigable canals have a constant and regular cross-sectional geometry, with trapezoidal or rectangular shapes.

Free-flowing rivers may have considerable water level fluctuations ranging from 5 to 8 meters. Whereas low levels impose restrictions on draught (navigation with high risk of grounding), extremely high levels, due to the diminished bridge clearances, limit the transport of light-weight commodities (e.g. containers and general cargoes). Moreover, with high water levels the stream flow rate increases, resulting in higher propulsion power requirements for ships running upstream, and possibly in steering problems when ships running downstream.
downstream of a bend, the river will tend to be conditions of current and slope. For this reason, deposition may not reduce significantly the depth in shallow and unstable, but generally sediment and composition of bottom and banks. Natural streams tend to meander, developing a winding course. The sinuosity of a river depends on many factors as discharge, sediment load, valley slope, and composition of bottom and banks. Because of high velocity currents and turbulences in bends, much more sediments can be moved in sinuous rivers than in straight rivers with the same conditions of current and slope. For this reason, downstream of a bend, the river will tend to be shallow and unstable, but generally sediment deposition not reduce significantly the depth required for navigation.

4.2 Maneuverability
A ship operating in confined waterways, in relatively dense traffic, with sharp and narrow bends, numerous locks and bridges must comply with extraordinarily high maneuvering standards regarding course-keeping ability, turning, stopping, flanking and running astern. When a ship runs alone straight ahead on a canal generally keeps a central path, but if for some reason it comes nearer to a bank the pressure distribution around the hull becomes asymmetrical, and the ship is pushed toward the bank itself. In order to prevent the impact with the bank, the helmsman should turn the rudder to bring the vessel back to the centreline of the canal. In this manner the "straight" course becomes a "zig-zag" course consisting of a series of slight corrections of the heading, that leads to occupy a part of the river wider than the vessel’s breadth.

In general, slender ships have a better course-keeping characteristic than stubby ones. As a rough estimate it can be said that for a slender 100 m long ship at least 5% of its length (i.e., 5 m) have to be added to its breadth to take into account the course-keeping behaviour in upstream run, and such a value might even considerably increase when runs downstream. In fact, according to full scale measurements performed in flowing water with velocity of 6.0 km/h it was found out that in upstream navigation the path width becomes 9-10 m wider than the ship’s breadth, while in downstream is even 12-13 m wider. Thus, the minimum two-way canal width can be determined as the sum of the path widths of the vessels sailing upstream and downstream, a mutual safety distance between them (at least 10 m) and further safety distances between each path and the adjacent river banks (at least 5 m per bank). Assuming very tight standards for safety distances, the minimum width of a straight two-way navigable waterway should be about 64 m (Fig.2).

<table>
<thead>
<tr>
<th>Classification</th>
<th>Tonnage (GT)</th>
<th>Length (m)</th>
<th>Breadth (m)</th>
<th>Draught (m)</th>
<th>Air Height (m)</th>
<th>Notes</th>
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<tr>
<td>RA</td>
<td>5.5</td>
<td>2.00</td>
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<td>&quot;Open boat&quot;</td>
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<td>RB</td>
<td>9.5</td>
<td>3.00</td>
<td>1.00</td>
<td>3.25</td>
<td></td>
<td>&quot;Cabin cruiser&quot;</td>
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<tr>
<td>RC</td>
<td>15.0</td>
<td>4.00</td>
<td>1.50</td>
<td>4.00</td>
<td></td>
<td>&quot;Motor yacht&quot;</td>
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<tr>
<td>RD</td>
<td>15.0</td>
<td>4.00</td>
<td>2.10</td>
<td>30.00</td>
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<td>&quot;Sailing boat&quot;</td>
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<td>250–400</td>
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<td>5.05</td>
<td>1.80–2.20</td>
<td>3.70</td>
<td></td>
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<tr>
<td>II</td>
<td>400–650</td>
<td>50.0–55.0</td>
<td>6.60</td>
<td>2.50</td>
<td>3.70–4.70</td>
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<tr>
<td>III</td>
<td>650–1,000</td>
<td>67.0–80.0</td>
<td>8.20</td>
<td>2.50</td>
<td>4.70</td>
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<td>9.50</td>
<td>2.50</td>
<td>4.50; 6.70</td>
<td>&quot;Johann Welker&quot;</td>
</tr>
<tr>
<td>Va</td>
<td>1,500–3,000</td>
<td>95.0–110.0</td>
<td>11.40</td>
<td>2.50–4.50</td>
<td>4.95; 6.70; 8.80</td>
<td>&quot;Large Rhine&quot;</td>
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<td>Vb</td>
<td>3,200–6,000</td>
<td>172.0–185.0</td>
<td>11.40</td>
<td>2.50–4.50</td>
<td>4.95; 6.70; 8.80</td>
<td>1×2 convoy</td>
</tr>
<tr>
<td>VIa</td>
<td>3,200–6,000</td>
<td>95.0–110.0</td>
<td>22.80</td>
<td>2.50–4.50</td>
<td>6.70; 8.80</td>
<td>2×1 convoy</td>
</tr>
<tr>
<td>VIb</td>
<td>6,400–12,000</td>
<td>185.0–195.0</td>
<td>22.80</td>
<td>2.50–4.50</td>
<td>6.70; 8.80</td>
<td>2×2 convoy</td>
</tr>
<tr>
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<td>270–280</td>
<td>22.80</td>
<td>2.50–4.50</td>
<td>8.80</td>
<td>2×3 convoy</td>
</tr>
<tr>
<td>VII</td>
<td>9,600–18,000</td>
<td>195–200</td>
<td>33.00–34.20</td>
<td>2.50–4.50</td>
<td>8.80</td>
<td>3×2 convoy</td>
</tr>
<tr>
<td></td>
<td>14,500–27,000</td>
<td>285</td>
<td>33.00–34.20</td>
<td>2.50–4.50</td>
<td>8.80</td>
<td>3×3 convoy</td>
</tr>
</tbody>
</table>

Table 2: ECMT ship classes.

Regulated rivers or stretches of river with dams and locks ensure constant water level, low slope and moderate stream flow rate, and so favourable nautical conditions are created, but too many locks under way can considerably slow navigation or can represent a limit for the main dimensions of vessels. Natural streams tend to meander, developing a winding course. In general, slender ships have a better course-keeping characteristic than stubby ones. As a rough estimate it can be said that for a slender 100 m long ship at least 5% of its length (i.e., 5 m) have to be added to its breadth to take into account the course-keeping behaviour in upstream run, and such a value might even considerably increase when runs downstream. In fact, according to full scale measurements performed in flowing water with velocity of 6.0 km/h it was found out that in upstream navigation the path width becomes 9-10 m wider than the ship’s breadth, while in downstream is even 12-13 m wider. Thus, the minimum two-way canal width can be determined as the sum of the path widths of the vessels sailing upstream and downstream, a mutual safety distance between them (at least 10 m) and further safety distances between each path and the adjacent river banks (at least 5 m per bank). Assuming very tight standards for safety distances, the minimum width of a straight two-way navigable waterway should be about 64 m (Fig.2).
4.3 Navigation

Different aspects concern the inland navigation:

1. **Unrestricted waterways.** They are very wide and relatively deep waterways, and are ideal for navigation. Essentially, "very wide" means that the distance of the ship flank from the bank is at least a half length of the running ship (Fig.4), while "deep" means that the water depth is at least about six times the draught of the ship.

Considering the standard size of a large river ship with 110 m in length, 11.4 m in breadth and a usual draught of 2.5 m, the "unrestricted waterway" cross section should be approximately 130 m wide and 15 m deep.

Those dimensions are "wide enough" only if there are no other vessels passing by. If two 110 m long vessels pass by or overtake each other, the waterway width should be about 200 m to avoid mutual influences between the running ships. Unfortunately, with minor exceptions, such generous nautical conditions cannot be found anywhere on the European waterways.

"Unrestricted waterway" for smaller vessels need a lesser width, but being draught equal to 2.5 m anyway, the depth remains of about 15 m.

2. **Narrow and deep waterways.** They can be found only in certain gorges, but in general they are very unusual in major European waterways. In this kind of waterway the wave systems generated by a vessel hit hardly against the river banks, causing erosion and damages on the built-up structures, and also high impacts there will be on the running ship itself.

3. **Shallow and wide waterways.** They are generally present on all major rivers within the European network. The attainable ship speed will depend almost exclusively by the water depth.
4. *Shallow and narrow waterways*. They are mainly represented by the human-built canals. The maximum attainable ship speed depends on the velocity of propagation of waves, the shape of the canal (trapezoidal, rectangular, arch-form) and the ratio between the cross sectional area of the canal and the midship section.

5. *Bridges*. They are human-built structures placed to cross from one side to the other of the river. Most of them represents one of the main limitations to the height of the ship, and consequently to visibility requirements. The latter can be properly satisfied by means of retractable wheelhouses.

6. *Locks*. A lock is a device for raising and lowering vessels between stretches of waterways having different water levels. The distinguishing feature of a lock is a fixed chamber where the water level can be varied. Critical issues of locks are the aging of infrastructures (with very high replacement costs), the service interruptions due to lock closures (icing, very low water, etc.), the seasonality of demand and supply, taxes and subsidies.

Fig. 6 represents the working principle of inland waterways locks.

7. *Speed*. In general, the theoretical maximum speed is reduced by about 10% in order to avoid the considerable dynamic sinkage and trim under the influence of shallow water, and also to prevent a remarkable erosion of canal banks due to generated waves. Table 3 shows some examples of existing canals along with the main characteristics of typical ships.

![Fig. 5: Example of ship environmental limitations](image)

![Fig. 6: Working principles of inland waterways locks](image)

<table>
<thead>
<tr>
<th>Canal</th>
<th>Area</th>
<th>Water depth</th>
<th>Ship</th>
<th>Canal to ship area ratio</th>
<th>Ship critical speed</th>
<th>Ship allowable speed</th>
<th>Sinkage at critical speed</th>
<th>Sinkage at allowable speed</th>
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<tr>
<td>Cross sectional shape</td>
<td>[m²]</td>
<td>[m]</td>
<td>[m]</td>
<td>[-]</td>
<td>[km/h]</td>
<td>[km/h]</td>
<td>[cm]</td>
<td>[cm]</td>
</tr>
<tr>
<td>Rhine - Danube</td>
<td>Trapezoidal</td>
<td>172</td>
<td>4.0</td>
<td>9.50</td>
<td>11.40</td>
<td>2.50</td>
<td>2.80</td>
<td>7.2</td>
</tr>
<tr>
<td>Mittelland</td>
<td>Trapezoidal</td>
<td>164</td>
<td>4.0</td>
<td>9.50</td>
<td>11.40</td>
<td>2.50</td>
<td>2.80</td>
<td>6.9</td>
</tr>
<tr>
<td>Numerous EU</td>
<td>Rectangular</td>
<td>168</td>
<td>4.0</td>
<td>9.50</td>
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<td>7.1</td>
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<tr>
<td>Old German</td>
<td>Rectangular</td>
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<td>2.50</td>
<td>2.80</td>
<td>6.4</td>
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<tr>
<td>Elbe-Havel</td>
<td>Rectified arch</td>
<td>85</td>
<td>3.5</td>
<td>9.00</td>
<td>2.00</td>
<td>4.7</td>
<td>8.0</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Table 3: Major European inland waterways and typical ships
5 Re-activation of the fleet
Inland waterway transport has unquestionably been the most environmentally friendly mode of inland transport for decades. However, this advantage has continuously been eroded due to the rapid improvement of emissions from other transport modes. In particular, the road haulage sector has been subject to stricter emission standards combined with strong incentives given to operators. In contrast to the road haulage sector, the replacement rate of engines used by inland waterway vessels is very low and the emission standards for the new engines are much less strict regarding NO\textsubscript{x} and PM emissions. As a consequence, inland waterway transport for certain routes, cargo types and vessel sizes presents air pollutant emission levels higher than the ones for road transport. Without specific action on the fleet, the traditional environmental advantages of inland waterway transport will further deteriorate in the future.

In order to revitalize the small inland waterway network, adjustments of the infrastructures will be necessary in terms of enlarging and upgrading. The first step should upgrade the existing small inland waterway network from ECMT class II to class IV. The required values for a class IV waterway are 4.5 m of depth and 14 m of width. Thus, on the basis of the sizes of existing waterways, the costs of the upgrading operations can be evaluated. Fig.7 shows the different works that are necessary to convert a waterway from class II to class IV.

Besides the infrastructure upgrading, the renewal of the fleet has to be also considered. The adoption of the new technologies available on the market is necessary to attain a higher energy efficiency in an environmentally friendly framework. Currently, the land-based demand of innovative technologies, is mainly devoted to power generation by natural gas fuelled engines, also due to an efficient and widespread distribution network. Instead, the maritime LNG supply chain is still under development, and needs local support initiatives and governmental incentives to jump-start the market. In a future, a port that decide to arrange a LNG distribution network could benefit of incentives, as the well-known Energy Ship Index (ESI) discount on harbour dues. Other initiatives as the Green Award have developed a certification scheme for the inland navigation vessels in order to give recognition to clean inland shipping. Fig.8 shows the current situation of the maritime LNG supply chain in North Europe.

6 LNG propulsion system and LNG logistic chain
Nowadays, LNG projects are among the most expensive energy projects. Estimate of LNG plant costs are difficult to pinpoint since costs vary widely depending on location and whether a project is a greenfield one or an expansion of an existing plant. The high level of complexity along with the formidable costs associated with the setup of a LNG value chain often lead to long-term contracts, which are highly dependent on the successful execution of all the elements in the value chain itself.

Therefore, LNG used for propulsion purposes can be seen as an attractive alternative to heavy fuels in European waterways. Here below a brief analysis of the main advantages and disadvantages of the exploitation of LNG for inland waterways vessels is exposed.

**Advantages:**
- Emissions of SO\textsubscript{2} are low: 0.00154 g/kWh, complying with Sulphur Emission Control Area (SECA) restrictions.
• Emissions of NO\textsubscript{x} are low: 1.42 g/kWh.
• Emissions of CO\textsubscript{2} are relatively low: 75% reduction.
• LNG is approximately 8% cheaper compared to gas oil, and has a higher energy content in comparison with Diesel oil and gasoline, as shown in Table 6.

<table>
<thead>
<tr>
<th>Energy content</th>
<th>Diesel</th>
<th>LNG</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>MJ/l</td>
<td>36.4</td>
<td>25.3</td>
<td>34.0</td>
</tr>
<tr>
<td>MJ/kg</td>
<td>45.4</td>
<td>55.0</td>
<td>47.2</td>
</tr>
</tbody>
</table>

Table 6: Energy content

• The worldwide supply of LNG is expected to increase between 2015-2020. Once the technology will be beyond the initial adaption phase, operating and maintenance costs will be lower than Diesel oil.
• Lower bunkering prices are expected.
• Lower fuel consumption and lower maintenance costs compared with a Diesel engine. In addition, gas-fuelled engines are less noisy.
• The price of LNG is generally locked under long-time contracts.

Disadvantages:
• New LNG-fuelled ships have typically an added investment cost of 10-20% due to the LNG storage tanks onboard, fuel piping system and additional safety measures.
• Currently the small scale logistic network is at the first stage of development in all over the world. In fact, only a few nations (e.g. Norway) offer a suitable LNG bunkering network. The set up of LNG bunkering facilities, including LNG terminals and ship supply networks, is quite expensive.
• Retrofitting is expensive
• Volume for gas fuel storage is around three times higher than the one for fuel oil.

LNG-powered vessels is expected growing radically provided LNG fuel will be available in bunkering ports. Therefore, investment in logistical infrastructures for LNG bunkering is crucial, even if riskful within an uncertain market.

At the moment, the possibility to choose LNG instead of Diesel is not an option for small vessels, due to the limited space onboard and the low Return on Investment. However, it is clear that for pushboats, LNG is most profitable, due to no space problems and to the quite high Diesel fuel costs.

7 Conclusion
The conclusions that can be inferred from this study are different due to the complexity of the analysis and the various aspects involved, such as ship design, logistics and market trends. The possibility of using LNG is driving the market and has been indicated as the main source to reactivate the inland waterway transport. The developed concept design takes account of logistical solutions, network interactions and transport costs. Lately, the need for change represents a heavy toll on European level, so much so that in recent years more than five major research projects funded by the European Union have started. Everything leads us to believe that in the coming years further developments will be possible and that these projects will lead to a considerable development of efficient sustainable transport.