LNG as marine fuel and bunkering: technology & practice

Luo Xiaofeng
Director
Wuhan Rules & Research Institute, CCS
Who we are

Founded in 1956 and headquartered in Bei Jing, China Classification Society (CCS) is the specialized organization to provide classification services.
Who we are

- A full member of the International Association of Classification Societies (IACS) and one of major international classification societies.

- Authorized by the administrations of more than 34 countries or regions to perform statutory surveys for the ships flying their flags and recognized by the United States Coast Guard (USCG) and the European Union (EU);

- 4,100 employees and over 80 forming a global service network.

- By providing high quality technical services, CCS is lending a significant support to the clients in safety management, energy saving, environmental protection and risk management.
Who we are

CCS Global Service Network

32 overseas branches/offices

48 domestic branches

CCS Provides solution for waterborne LNG value chain
Table of content

- Background & environment for LNG used as marine fuel
- Status quo of LNG fuelled ships and LNG bunkering in China
- Technology development and cases study
- CCS R&D on waterborne LNG value chain
- Conclusion
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Regulatory background

- Increasingly stringent regulations on emission control
  
  **Existing regulations**
  - SOx
  - NOx
  - EEDI

  **Potential regulations**
  - Black carbon
  - PM

- More and more ECAs are expected to be set up
  
  - Taking Hong Kong as an example, although it’s not an international ECA today, its EPD (Environmental Protection Department) has issued the regulations requiring all ships in Hong Kong port to use low sulphur content fuel oil (< 0.5) since Jan 1, 2015.
  
  - Other potential ECAs: Singapore, Japan, Australia.
Regulatory background

**What about China?**

- As the 1st step, China is now considering to set up 3 SECAs, then steadily raise the emission standards for ships navigating or mooring in the ECAs.

- This September, China Ministry of Transport issued the *Action Plan for Preventing Pollution from Ships and in Ports (2015-2020)*, aiming at cutting SOx, NOx, PM emission by 65%, 20% and 30% respectively by the end of 2020 comparing with 2015 levels.

The 1st potential ECAs in China (draft)

Using LNG as marine fuel is an viable and practicable solution for the time being.
The Code for ships using LNG as fuel (IGF Code) is ready…

- CG was established to develop relevant requirements
- MSC 285(86)-Interim guidelines on safety for natural gas fuelled engine installations in ships was adopted
- IGF Code phase 1 (for natural gas fuelled ships) was finalized
- IGF Code phase 1 (for natural gas fuelled ships) was adopted

Enter into force


GLUTRA, the 1st LNG fuelled ship in the world

1st LNG fuelled coastal ship in China

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Clean Power for Transport: A European alternative fuels strategy

- A Communication laying out a comprehensive European alternative fuels strategy, for the long-term substitution of oil as energy source in all modes of transport;
- A Directive on the deployment of alternative fuels recharging and refuelling infrastructure;
- An accompanying Impact Assessment;
- A Staff Working Document setting out the needs in terms of market conditions, regulations, codes and standards for a broad market uptake of LNG in the shipping sector.

**Environment for LNG fuelled ships (Europe)**

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Environment for LNG fuelled ships (Europe)

The **LNG Masterplan** aims to create a platform for the cooperation of authorities and industry stakeholders with the purpose to facilitate the creation of a harmonized European regulatory framework for LNG as fuel and cargo in inland navigation and to promote the introduction of LNG as a fuel and cargo for inland shipping.

**GOAL**

- Identify and quantify pioneer markets and customers in the inland ports hinterland
- Analyse costs and savings/benefits of LNG use
- Transfer know-how from maritime into inland navigation sector and raise awareness
- Facilitate the creation of a harmonized European regulatory framework considering LNG as fuel and as cargo for inland navigation
- Deliver technical concepts for new and retrofitted vessels
- Elaborate supply chains to reach end-consumer
- Execute pilot deployments of vessels and terminals
- Develop a comprehensive strategy with a detailed roadmap for the implementation of LNG in line with the EU policies in transport, energy and environment
- Prepare wide-scale deployment with the help of CEF & other EU programs
Environment for LNG fuelled ships (China)

- China has established a comprehensive Regulatory framework for ships using LNG as fuel;
- China government is now encouraging the new building ships to use LNG as fuel by subsidy policies;
- Now the China Ministry of Transport is also considering incorporating new promotion policies for ships using LNG into its 13th 5-year plan;
- The “chicken egg trap” is being steadily broken in China.
Environment for LNG fuelled ships (China)

Deployment plan of LNG bunkering infrastructures in China

- Plan to construct about 35 bunkering infrastructures along the Beijing Hangzhou Grand Canal before 2030.
- Plan to construct about 35 coastal bunkering infrastructures before 2030.
- Plan to construct about 70 bunkering stations along the Yangtze River before 2030.
- Plan to construct about 16 bunkering infrastructures along the Pearl River before 2030.
The entry into force of 0.10% sulphur Regulation for SECAs accelerates the uptake of LNG fuel.

The adoption of IGF Code lay a solid Regulatory foundation for the international navigation LNG fuelled ships.

China (including Hong Kong) is now planning to set up SECAs, which will “push” the ship owners to consider using LNG; on the other hand, Chinese government is actively encouraging and guiding the use of LNG through a series of policies, which will effectively promote the use of LNG as marine fuel.

China has established a comprehensive framework of Regulations & Rules for waterborne LNG value chain, also has many successful cases of LNG fuelled ship, LNG bunkering pontoon and LNG bunkering barge, the practice proved that the safety of LNG application can be assured as long as appropriate risk control measures are used.
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Current status of LNG fuelled ships: China vs Europe

**CHINA**
- International (China not included)
- China domestic (Including in operation and ordered)

**EUROPE**
- Total in operation
- Total under construction/contract signed

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Which types of ships are most suitable for using LNG as fuel?

- **Ships navigating on fixed route**, due to that bunkering and ship design are much easier.
  - Car/passenger ferries
  - Platform supply vessels
  - Ro-Ro

- **Ships with large open deck** which is available for arranging LNG storage tank, to reduce the cargo tank loss.
  - Oil tankers
  - Chemical tankers
Current status of LNG carriers: China vs Europe

EU
Permitted the inland waterway LNG transport by revising table C of ADN. LNG can be transported by type G tank vessels, maximum permissible capacity of a cargo tank shall not exceed 1000cbm, and there’s no safety zone requirements for inland waterway LNG carriers.

Application for a recommendation on the use of membrane tanks for transport of liquefied natural gas on the tank vessel Argos-GL

Transmitted by the Government of the Netherlands

I. Introduction

1. Several vessels are now - on a trial basis - using LNG as fuel, and it is expected that more will follow in the future. Also the development of bunkering facilities along inland waterways is making progress.

2. To support these developments the Dutch delegation has proposed to include LNG (UN No. 1972) in Table C of ADN, and developed additional regulations for the carriage of liquefied gases. These proposals have been adopted and are expected to enter into force on 1 January 2015.
Current status of LNG carriers: China vs Europe

**China**:
A *Research on Risk Assessment and Risk-control Measures for Inland Waterway LNG Carriers* was conducted and the following conclusion was given:

- The collision design is required for inland LNG carriers;

- About safety zone
  - Normal condition: no safety zone requirement;
  - Failure condition of LNG carriers: the ships shall move to emergency anchorage ASAP, fore-and-aft 300m, port-and-starboard 100m is safety distance;
  - LNG leakage condition: 1100m around the ship is safety distance.

- The emergency anchorage shall be located at 1100m far away from other anchorages.

*CCS Provides solution for waterborne LNG value chain*
Current status of LNG bunker barges: China vs Europe

- CCS has finalized the *Rules for LNG Bunkering Vessels*, which will be published this year and expected to be the 1st Rules for LNG bunkering Vessels in the world;
- The 1st LNG bunkering barge in China is now under construction;
- 4 key issues for LNG bunkering barge:
  - Quantitative risk assessment to determine the safety distance;
  - Appropriate connection (hose + dry disconnection coupling);
  - Emergency break away;
  - Safe operation procedure
Milestones of LNG fueled vessel & LNG bunker in China

- CCS issued Rules for Natural Gas Fuelled Ships in 2013;
- CCS issued Rules for LNG Bunkering Pontoons in 2014;
- In Dec 2013, the 1st sea-going dual fuel vessel — 6500HP harbor tug “CNOOC 521” delivered, classed by CCS;
- This July, the Asia 1st pure LNG fuelled tugs was delivered, classed by CCS;
- The 1st new built LNG bunkering barge in China will be delivered this year, classed by CCS

<table>
<thead>
<tr>
<th>CNOOC No.521</th>
<th>CNOOC No.522</th>
<th>1100 TEU</th>
<th>LNG bunker</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="CNOOC No.521" /></td>
<td><img src="image2" alt="CNOOC No.522" /></td>
<td><img src="image3" alt="1100 TEU" /></td>
<td><img src="image4" alt="LNG bunker" /></td>
</tr>
</tbody>
</table>

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The start of using LNG as marine fuel in China is later than in Europe, but the development of LNG fuel ships in China is much faster;

Both Europe and China has realized that the development of LNG fuelled ships depends on the whole waterborne LNG value chain, which including LNG transport, LNG bunkering, etc;

The LNG bunkering solutions are various, which could be chosen based on specific condition. Ship to ship bunkering is a flexible solution;

Inland LNG transport in bulk was not allowed before in Europe nor in China, but the situation is now regularly changing;
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Fuel gas storage & supply system

The following common technologies/systems are used for LNG fuelled ships, LNG carriers and LNG bunkering barges, so in our R&D, they are considered “modules”:

- Fuel/cargo containment system;
- Fuel gas supply system;
- LNG power system, such as gas engine;
- LNG bunkering system or LNG cargo handling system;
- Risk assessment
Fuel gas storage & supply system

- Membrane tanks: becoming more flexible to better meet the demands from LNG fuelled ships and LNG bunkers;
- Type C tanks: upsizing (Max. volume is about 9000cbm for single tank);
- New opportunity for type A and type B tanks

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**Location of gas fuel storage tank**

**IGF Code (IMO MSC 391.(95))**

**Protective location of LNG tanks**

### Deterministic approach

- The distance is explicitly given

### Probabilistic approach

- Calculating $f_{CN}$, then compare with the criteria

### The above approaches are alternative

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#### CCS Provides solution for waterborne LNG value chain

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#### 5.3.4

As an alternative to 5.3.3.1 and 5.3.3.3 above, the following calculation method may be used to determine the acceptable location of the fuel tanks:

1. The value $f_{CN}$ calculated as described in the following shall be less than 0.6135 for passenger ships and 0.398 for cargo ships:

$$f_{CN} = \frac{d}{d_1}$$

where:

- $d$ is calculated by use of the formulations for factor $p$ contained in SOLAS regulation 5.2.(1.1.1.1). The value of $d$ shall correspond to the distance from the aft terminal to the foremost boundary of the fuel tank and the value of $d_1$ shall correspond to the distance from the aft terminal to the foremost boundary of the fuel tank.

- $f_{CN}$ is calculated by use of the formulations for factor $r$ contained in SOLAS regulation 5.2.(1.1.1.1). The value of $r$ is the probability that the damage penetrates beyond the outer boundary of the fuel tank. The formulation is:

$$f_{CN} = 1 - (1/2.8^r)$$

2. The $f_{CN}$ is calculated by the following formulation:

$$f_{CN} = \frac{d}{d_1}$$

where:

- $f_{CN}$ is the distance from baseline, in meters, to the foremost boundary of the fuel tank, and $d$ is the deepest draught (summer load line draught).

### 5.3.5

The boundaries of each fuel tank are taken as the extreme outer longitudinal, transversal, and vertical limits of the tank structure including its tank valves.
Deterministic approach

- To side: \( \min\{B/5, 11.5\text{m}\} \)

- To bottom: \( \min\{B/15, 2.0\text{m}\} \)

- Min. to side shell or aft terminal (also applied to probabilistic approach):
  
  \[
  \begin{align*}
  &\text{for } V_c \text{ below or equal } 1,000 \text{ m}^3, 0.8 \text{ m}; \\
  &\text{for } 1,000 \text{ m}^3 < V_c < 5,000 \text{ m}^3, 0.75 + V_c \times 0.2/4,000 \text{ m}; \\
  &\text{for } 5,000 \text{ m}^3 \leq V_c < 30,000 \text{ m}^3, 0.8 + V_c/25,000 \text{ m}; \text{ and} \\
  &\text{for } V_c \geq 30,000 \text{ m}^3, 2 \text{ m},
  \end{align*}
  \]

  \( V_c \): 100% of the gross design volume of the individual fuel tank.
Probabilistic approach

\[ f_{CN} = f_l \times f_t \times f_v \]

- **\( f_{CN} \):** damage porbability
- **\( f_l \):** is calculated by use of the formulations for factor p contained in SOLAS regulation II-1/7-1.1.1.1.
- **\( f_t \):** reflects the probability that the damage penetrates beyond the outer boundary of the fuel tank.
- **\( f_v \):** reflects the probability that the damage is not extending vertically above the lowermost boundary of the fuel tank.

For cargo ships: \( \leq 0.04 \)

For passenger ships: \( \leq 0.02 \)
## Cases of using probabilistic approach

<table>
<thead>
<tr>
<th>Ship types</th>
<th>20000 oil tanker</th>
<th>900TEU</th>
<th>2500 TEU</th>
<th>14000TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank type</td>
<td>TPYE C</td>
<td>TPYE C</td>
<td>TPYE C</td>
<td>membrane</td>
</tr>
<tr>
<td>Volume(m³)</td>
<td>570</td>
<td>600</td>
<td>650</td>
<td>22000</td>
</tr>
<tr>
<td>location</td>
<td>Open deck</td>
<td>Open deck</td>
<td>Open deck</td>
<td>Below deck</td>
</tr>
<tr>
<td>parameters</td>
<td>length(m)</td>
<td>159</td>
<td>138.3</td>
<td>208</td>
</tr>
<tr>
<td></td>
<td>beam(m)</td>
<td>24</td>
<td>22.6</td>
<td>29.8</td>
</tr>
<tr>
<td></td>
<td>X1(m)</td>
<td>39</td>
<td>17</td>
<td>21.87</td>
</tr>
<tr>
<td></td>
<td>X2(m)</td>
<td>69</td>
<td>30</td>
<td>34.87</td>
</tr>
<tr>
<td></td>
<td>b(m)</td>
<td>4.8</td>
<td>4.3</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td>H(m)</td>
<td>13.2</td>
<td>12.5</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>draught(m)</td>
<td>9</td>
<td>8</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>fcn</td>
<td>0.025</td>
<td>0.007</td>
<td>0.004</td>
</tr>
</tbody>
</table>

**CCS Provides solution for waterborne LNG value chain**
Fuel gas supply system (FGSS)

- **low pressure FGSS**
  - Gas supply pressure: below 10 bar
  - Wasilla 34DF: 6~7bar
  - Guang Chai: 5~8bar

- **high pressure FGSS**
  - Gas supply pressure: higher than 10 bar
  - MAN ME-GI: 300~450bar

Note: non-traditional LP GFSS has arisen, e.g. a GFSS with gas supply pressure of 16 bar for Wasilla Flex50DF

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Low pressure fuel gas supply system

CCS Provides solution for waterborne LNG value chain
High pressure fuel gas supply system

- LNG tank
  - Immersed pump
  - HP pump
  - HP vaporizer
  - Buffer tank
- BOG
- Collected or to auxiliary engines

- LNG
- CNG
- GRU
- ~300bar

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Power system

- The risk of gas fuel leakage is higher than that of conventional oil power system
- Less operational data of onboard gas fuel engines
- Redundancy is the first choice to assure safety of power system

Redundancy

Fuel redundancy
- 1 Dual fuel engine

Installation redundancy
- 2 or more main engines
- 2 or more propulsion motors
- 2 gas supply lines
- Installation of PTI

System redundancy

CCS provides solutions for waterborne LNG chains
## Gas engine

<table>
<thead>
<tr>
<th>Engine type</th>
<th>High pressure direct injection DF</th>
<th>Low pressure DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power range</td>
<td>MAN: 3275 - 82400 kW</td>
<td>Wärtsilä: 4775 – 25800 kW</td>
</tr>
<tr>
<td>fuel flexibility</td>
<td>Suitable for various MNs</td>
<td>Methane number (MN) &gt; 80</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>Relatively worse in gas mode, better in oil mode</td>
<td>Better in gas mode, relatively worse in oil mode</td>
</tr>
<tr>
<td>/NOx emissions</td>
<td>Tier II (Tier III with EGR or SCR)</td>
<td>Tier III</td>
</tr>
<tr>
<td>SOx emissions</td>
<td>SECAs</td>
<td>SECAs</td>
</tr>
<tr>
<td>Initial cost</td>
<td></td>
<td>Equivalent</td>
</tr>
<tr>
<td>Gas supply system</td>
<td>~300bar</td>
<td>~16bar</td>
</tr>
<tr>
<td>Transient response characteristics</td>
<td>Same as diesel engine, can be coupled with FPP</td>
<td>Relatively worse, normally coupled with CPP or electric propulsion</td>
</tr>
<tr>
<td>Ship space occupied</td>
<td>large (with after-treatment equipment)</td>
<td>Small</td>
</tr>
<tr>
<td>Retrofit flexibility</td>
<td>simple</td>
<td>complex</td>
</tr>
</tbody>
</table>

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Bunkering system

QRA (Safety Alert)  Check List  ESD & ERC  Operation procedure

Relative motion and acceleration  Berthing and Unberthing  Insulation Connection  Hose Connection

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Cases study

2×25 cbm LNG tanks with cold boxes

Characteristics of Hai Yang Shi You 521

<table>
<thead>
<tr>
<th>Dimension</th>
<th>41m × 11.6m × 6m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine power</td>
<td>dual-fuel, 6500HP</td>
</tr>
<tr>
<td>Operational</td>
<td>since Dec 2013, operate in Zhu Hai Port</td>
</tr>
</tbody>
</table>

The 1st LNG fuelled seagoing vessel in China

CCS Provides solution for waterborne LNG value chain
Cases study

The 1st LNG fuelled seagoing vessel in China

<table>
<thead>
<tr>
<th>Gas pipe on engine</th>
<th>Double wall pipe</th>
<th>Gas valve unit</th>
</tr>
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<tbody>
<tr>
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</tr>
</tbody>
</table>

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Cases study

1st LNG bunkering barge in China

- 200cbm type C LNG tank;
- crane + bunkering hose
- Cargo used as fuel and dedicated LNG fuel storage tank
- Pure LNG powered with electric propulsion

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Cases study

- Bi-lobe type C tanks
- DFDE
- Rudder propeller

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Our philosophy & methodology for R&D

- Risk-based philosophy
  - Required by IMO GBS.
  - Required by the characteristic of LNG fuelled ships
    - Lack of experience and practice
    - LNG has its unique characteristic and hazards:
      - Cryogenic
      - Fire & explosion
      - Dispersion

- Risk-based approach
  - Risk analysis (theoretical analysis by simulation, such as CFD)
  - Experimental verification
How do we develop Rules?

**CASE: experiment study**

Experimental Study on **Cold Box** to verify:
- Accumulated pressure in the box after LNG leakage
- Temperature distribution within the box
- Hi-hi level auto shut down device

Cold box
How do we develop Rules?

- risk assessment and simulation

HazID

Risk Assessment

Acceptance criteria

Risk control measures

Guidelines & Rules

CFD gas leakage study

CFD Sloshing study on fuel tank

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CCS Rules for Waterborne LNG value chain

- Rules for Natural Gas Fuelled Ships
- Rules for LNG Bunkering Pontoons
- Rules for LNG Bunkering vessels (finalized)
- Guidelines for LNG STS Bunkering
- Rules for Liquefied Gas Carriers in bulk
- Guidelines for Survey of Gas Fuelled Ships
- Guidelines for survey of type B tanks
- Guidelines for FMEA

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Involvement in development of international Codes/Standards

- **IMO**: Member of the IMO Correspondence Group (CG) on development of IGF Code, which will be adopted at MSC 95 this June;

- **ISO**: Member of ISO Working Group on developing LNG bunkering guidelines (WG 8);

- **IACS**: Participating in 2 project teams (PTs) to develop technical requirements regarding LNG risk assessment and LNG bunkering;

- **SGMF**: Association member of *Society for Gas as a Marine Fuel* (SGMF).
Integrated solutions

Zhou Shan International LNG
Bunkering Infrastructure Project

- HAZID;
- Quantitative Risk Assessment on major accident scenario;
- Risk mitigation/control measures;
- Optimization solutions on the arrangement of onshore LNG storage tanks and onshore bunkering station;
- Safety distance for LNG STS bunkering operation.
- ……

CCS Provides solution for waterborne LNG value chain
Integrated solutions

CCS provides LNG Fuel Ready solution for different types including VLCC, VLOC, MEGA containerships.

Whether need LNG ready solution?
Based on the following analysis to decide whether LNG Ready solution is needed:
• analysis of ship operational data
• concept design
• Economic analysis of different emission reduction solution
• LNG bunkering availability analysis

How to carry out LNG ready?
If LNG Ready solution is accepted to ship owners, then will do:
• technical solution analysis
  - selection of engines
  - selection of storage tanks
  - Miscellanea
• Financial analysis
Quantitative risk assessment (QRA)

Special risk related to LNG

- cryogenic
- dispersion
- Fire & explosion

IGF Code

4.2 Risk assessment

4.2.1 A risk assessment shall be conducted to ensure that risks arising from the use of low-flashpoint fuels affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed. Consideration shall be given to the hazards associated with physical layout, operation and maintenance, following any reasonably foreseeable failure.

4.2.2 Details of risks, and the means by which they are mitigated, shall be documented to the satisfaction of the Administration or its recognized organization acting on its behalf.

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Quantitative risk assessment (QRA)

**CASE:** ENN 200cbm LNG bunker barge

Scenario: Ф25mm LNG pipe rupture during STS bunkering, LNG leaks between two ships for 30 seconds

Simulation on LNG dispersion after leakage during bunkering
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Players for waterborne LNG value chain in China

Regulatory framework development
- Water Transport Bureau
- CCS

Cryogenic equipment
- CPMC
- ZHANGFANG PULIC
- DEFON

Gas handling
- LGI

Oil majors & energy enterprises
- ENN
- NC
- CNPC

Academics
- 

Gas engine
- GDF

Ship owners
- 

Design of LNG fuelled vessels and bunkers
- CSMC
- CSSC

CCS Provides solution for waterborne LNG value chain
Conclusion

- The marine LNG technology is mature, the practice of LNG fuelled ships has proven that the safe and reliable operation of LNG fuelled ships can be assured by technical, administrant and operational means.

- The Industry in China is able to provide necessary products and services to support the development of LNG fuelled ships.

- China Classification Society is willing to provide technical service on waterborne LNG value chain for our clients with our R&D
Thank you for your kind attention

For more details, please contact
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