OPTIMISATION OF LNG SUPPLY IN INDONESIA

In co-operation with: Åbo Akademi University, Turku, Finland

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AGENDA

• About Wärtsilä
• Model Description
• Example 1: One time period: 14 days
• Example 2: Five time periods: 14 days
• Example 3: Five time periods: 10 days
ABOUT WÄRTSILÄ
SOLUTIONS FOR

Marine Offshore  Power Generation

Net sales by business 2015
Listed in Helsinki
5.0 billion € turnover
Solid financial standing

Marine Solutions 34%
Energy Solutions 22%
Services 43%

18,900 Professionals

LEADER IN
EFFICIENCY  GAS AND DUAL-FUEL SOLUTIONS  ENVIRONMENTAL SOLUTIONS

THIS IS WÄRTSILÄ
A leader in the global energy industry

**ENERGY EFFICIENT SOLUTIONS**
- Smart Power Generation combining energy efficiency, fuel and operational flexibility
- Most complete offering of marine products and integrated solutions, including a broad portfolio of environmental products
- Optimized asset performance over the lifecycle

**GAS-BASED TECHNOLOGY**
- A forerunner in gas and multi-fuel engines, fuel systems, technology and services
- Offering that covers gas value chain from exploration to end consumers
- Wide offering in small scale LNG

**INNOVATIVE SOLUTIONS**
- Global track record in distributed energy
- Project management and engineering competence create customer value
- Making use of digital technology
YOUR SHORTER ROUTE TO THE GAS AGE

Let the leader in LNG enable your smooth transition to gas. We have the expertise, experience and offering you need. Our offering covers integrated solutions*, EPC turnkey delivery**, services and products for all phases of the LNG lifecycle.

*Integrated solutions include engineering, procurement and construction of facilities from design to delivery.
**EPC turnkey delivery includes engineering, procurement and construction services for complete facilities.

EXPLORATION AND DRILLING > PRODUCTION AND LIQUEFACTION > TRANSPORT > STORAGE AND DISTRIBUTION > END CONSUMERS
Wärtsilä’s involvement in LNG infrastructure development

We provide our full range of project and lifecycle support to LNG liquefaction plants & terminals to deliver EPC projects worldwide. We have the capability to develop the entire LNG value chain in partnership with our customers.

As a forerunner in gas and multi-fuel engines, fuel systems, technology and services, Wärtsilä wants to participate in the global shift to gas also with LNG infrastructure projects.
Experience built on the acquisition of Hamworthy in 2012

### ONSHORE

- **2003** Snurrevarden liquefaction plant, Norway. 22,000 TPA.
- **2007** Kollsnes II liquefaction plant, Norway. 84,000 TPA.
- **2008** Dual and Triple Brayton high-efficiency liquefaction processes launched.
- **2010** Kiiplanti liquefaction plant, Finland. 20,000 TPA.
- **2012** MiniMR liquefaction process launched with pilot liquefaction plant.
- **2013** EGE Biogas mini liquefaction plant, Norway. 4,000 TPA.
- **2015** Tornio Manga LNG terminal, Finland. 50,000 m³ tank.

### OFFSHORE

- **2006 - 2008** 31 LNG BOG reliquefaction systems delivered for Q-Flex LNG carrier fleet. 58,000 TPA each.
- **2007** Open & closed loop LNG regasification processes launched with pilot re-gas plant.
- **2009** Golar Winter FSRU with seawater/ propane LNG regasification system. 4 LNG BOG reliquefaction systems for BG Shipping DFDE LNG carrier fleet.
- **2010** GDF Suez Neptune and Cape Ann SRVs with steam/water-glycol LNG regasification systems. Golar Freeze FSRU with sea water/ propane LNG regasification system.
- **2011** LNG fuel systems installed in multiple coastal ships and ferries.
- **2012** LNG regasification systems delivered as turnkey single-lift modules to Golar Kharun FSRU, PETRONAS JRU project and HHI Höegh Generic FSRU.
# Wärtsilä LNG solutions

<table>
<thead>
<tr>
<th>ONSHORE</th>
<th>OFFSHORE</th>
<th>LIFECYCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small LNG liquefaction plants</td>
<td>LNG regasification</td>
<td>Lifecycle services</td>
</tr>
<tr>
<td>Mini LNG liquefaction plants</td>
<td>BOG reliquefaction</td>
<td>Start-up support</td>
</tr>
<tr>
<td>Medium-scale LNG terminals</td>
<td>Cargo handling system</td>
<td>Product and technical support</td>
</tr>
<tr>
<td>Small satellite LNG terminals</td>
<td>Fuel gas handling system</td>
<td>Spares</td>
</tr>
<tr>
<td>LNG storage &amp; regasification barge</td>
<td>Ship and cargo tank design</td>
<td>Tank control systems</td>
</tr>
</tbody>
</table>

**About Wärtsilä and its involvement in LNG**

- Wärtsilä LNG solutions
  - Onshore:
    - Small LNG liquefaction plants
    - Mini LNG liquefaction plants
    - Medium-scale LNG terminals
    - Small satellite LNG terminals
    - LNG storage & regasification barge
  - Offshore:
    - LNG regasification
    - BOG reliquefaction
    - Cargo handling system
    - Fuel gas handling system
    - Ship and cargo tank design
  - Lifecycle:
    - Lifecycle services
    - Start-up support
    - Product and technical support
    - Spares
    - Tank control systems
Simplicity and flexibility are necessary for the small-scale business model:

- Ability to ramp-up/ramp-down according to supply/demand variation
- Multiple LNG/gas loading/unloading options

CAPEX reduced by:

- Elimination/simplification of equipment that is unjustified or impractical for small-scale LNG
- Maximizing the use of standard components & modularization

OPEX reduced by:

- Optimal trade-off between process efficiency and simplified operation (high availability / high level of automation) that enables low lifecycle costs

Safety measures taking into consideration that the consequence of potential incidents in small-scale LNG are smaller
Modularisation and standardisation

**Modular skids** are built and quality checked under factory conditions

- All critical components are tested in the factory before delivery
- Modules are easy to transport and quick to install
- Modules can be added to increase capacity/redundancy

**Standardization** of functionalities, choice of components and modularization principles

- Utilisation of proven designs lowers design, purchasing and installation costs as well as ensures a high level of quality
Complete solutions that bring value to customers

CUSTOMER VALUE PROPOSITIONS

- Project Development & Financing
- Technology
- EPC
- Operations & Maintenance

LNG terminal or liquefaction plant
Gas / dual-fuel power plant
### Comparison between terminal options

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>ON-SHORE</th>
<th>OFF-SHORE</th>
<th>NEAR-SHORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset flexibility</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Weather sensitivity</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Low-High</td>
<td>Medium</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>OPEX</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Small size</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>On-shore permits</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Delivery Time</td>
<td>1-4 years</td>
<td>2-3 years</td>
<td>1-2 years</td>
</tr>
</tbody>
</table>
Barges as alternative to onshore terminals

- Storage capacity of up 1,000-30,000 m$^3$ LNG and on-board regasification
- Comparable to a small-scale FSRU
- Ideal for providing fast and flexible access to gas in new areas
  - For land unsuitable for onshore LNG tanks or difficult to permit
  - Where there is a lack of skilled labour and local construction material
- A mobile asset, possible to relocate or trade – ideal for temporary demand and uncertain market conditions
THE MOST COMPLETE MARINE OFFERING ON EARTH
COVERING ALL MARKET SEGMENTS

OFFSHORE  MERCHANT  CRUISE & FERRY  NAVY  SPECIAL VESSELS

OIL & GAS  SHIPPING
Our global network and wide range of products, services and expertise enable us to enhance our customer’s business – whenever, wherever
OUR PASSION: LIFECYCLE EFFICIENCY

PERFORMANCE OPTIMISATION

Longer term strategies are aimed at improving business efficiency. Optimising performance of installations reduces operational expenses and improves uptime.

ENVIRONMENTAL EFFICIENCY

Environmental legislation and energy efficiency are currently major concerns for our customers. Sustainable solution options enable a reduced environmental impact and improved operational efficiency.

PREVENTING THE UNEXPECTED

Reliable, continuous performance is essential. Planning operational reliability of installations through access to highest quality of technologies, services and competences ensures smooth operations and managing risk.
AFTER: CONVENTIONAL + SMALL-SCALE VALUE CHAIN
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MODEL DESCRIPTION – Assumptions

A small maritime supply chain of LNG is considered:

- **Locations**: Fixed demands which must be satisfied with LNG within the time horizon.

- **Ships**: Average parameters (speed, fuel consumption, loading/unloading rate). No limitations on the number of split deliveries.

- **Routing**: No limitations on the number of visits at a port within the time horizon.

- **Multi-period**: Five (5) periods of given time horizon and given demands. Sizing of storage and inventory.
MODEL DESCRIPTION – Not included

- Scheduling
- Waiting time at the harbour or other delays
- Demand variation
- Alternative fuel supply
- Boil-off
MODEL DESCRIPTION – Inputs

- Locations of supply and receiving ports
- Distances between all ports
- Demands at receiving ports
- Ship sizes, rental and propulsion costs
- Loading/unloading rates, berthing times
- Investment costs for terminals
- Time horizon for study
- Possible constraints
MODEL DESCRIPTION – Objective function (Cost minimization)

- Objective function  \( \text{Min } (\text{Costs}) \)

\[
\text{Costs} = \text{Shipping cost} + \text{Investment cost} + \text{LNG purchased at the supply terminals}
\]

\( \text{Shipping cost} \) includes renting cost, propulsion cost, and port fee.

\( \text{Investment cost} \) includes terminal and storage.

[Source: LNG Forum 2016 Bali/ Hitendra Shetty]
MODEL DESCRIPTION – Unknowns (x) determined by optimization

• How many vessels are needed?
• Vessel sizes?
• Time the vessels are in use?
• Vessel routes (from-to)?
• Storage size and “inventory”

• For the optimal solution, the cost break-down is also obtained
AGENDA

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• Example 1: One time period: 14 days
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• Example 3: Five time periods: 10 days
EXAMPLE 1: One time period – 14 days

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Fuel Cost [€/km]</th>
<th>Speed [km/h]</th>
<th>Capacity [m³]</th>
<th>Charter Cost [€/day]</th>
<th>Load/Unload rate [m³/h]</th>
<th>Pre- and post-loading time [h]</th>
<th>Availability [Ship]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type1</td>
<td>4.3</td>
<td>23.2</td>
<td>5000</td>
<td>20000</td>
<td>750</td>
<td>5</td>
<td>1</td>
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<tr>
<td>Type2</td>
<td>5.2</td>
<td>25.9</td>
<td>10000</td>
<td>27500</td>
<td>1000</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Type3</td>
<td>5.6</td>
<td>26.8</td>
<td>12000</td>
<td>29000</td>
<td>1000</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Type4</td>
<td>7.3</td>
<td>27.7</td>
<td>20000</td>
<td>35000</td>
<td>1000</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Type5</td>
<td>13.2</td>
<td>29.6</td>
<td>40000</td>
<td>40000</td>
<td>2500</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

SEA DISTANCES (km)

<table>
<thead>
<tr>
<th></th>
<th>Makassar</th>
<th>Alor</th>
<th>Bima</th>
<th>Kupang</th>
<th>P. Flores</th>
<th>Sumbawa</th>
<th>Waingapu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makassar</td>
<td>0</td>
<td>890</td>
<td>425</td>
<td>930</td>
<td>414</td>
<td>519</td>
<td>565</td>
</tr>
<tr>
<td>Alor</td>
<td>890</td>
<td>0</td>
<td>673</td>
<td>272</td>
<td>532</td>
<td>841</td>
<td>512</td>
</tr>
<tr>
<td>Bima</td>
<td>425</td>
<td>673</td>
<td>0</td>
<td>603</td>
<td>150</td>
<td>203</td>
<td>238</td>
</tr>
<tr>
<td>Kupang</td>
<td>930</td>
<td>272</td>
<td>603</td>
<td>0</td>
<td>594</td>
<td>780</td>
<td>3825</td>
</tr>
<tr>
<td>P. Flores</td>
<td>414</td>
<td>532</td>
<td>150</td>
<td>594</td>
<td>0</td>
<td>327</td>
<td>222</td>
</tr>
<tr>
<td>Sumbawa</td>
<td>519</td>
<td>841</td>
<td>203</td>
<td>780</td>
<td>327</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Waingapu</td>
<td>565</td>
<td>512</td>
<td>238</td>
<td>3825</td>
<td>222</td>
<td>400</td>
<td>0</td>
</tr>
</tbody>
</table>

Supply port 2141 m³/d

Demands in m³/d
EXAMPLE 1: One time period – 14 days

Optimization results
One ship, Type 1 (5,000 m³)
Three routes
MP→A→K→W
MP→M→B
MP→S→B

<table>
<thead>
<tr>
<th>Storage size [m³]</th>
<th>Alor</th>
<th>Bima</th>
<th>Kupang P.</th>
<th>M. PP Flores</th>
<th>Sumbawa</th>
<th>Waingapu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>840</td>
<td>4231</td>
<td>3796</td>
<td>1696</td>
<td>4231</td>
<td>840</td>
</tr>
</tbody>
</table>

Charter Cost 19.9 $/m³ 0.829 $/mmBTU
Propulsion Cost 1.36 $/m³ 0.057 $/mmBTU
Port Call Cost 1.07 $/m³ 0.045 $/mmBTU
Tot Shipping Cost 22.33 $/m³ 0.931 $/mmBTU

Time usage: 12 days
AGENDA

• About Wärtsilä
• Model Description
• Example 1: One time period: 14 days
• Example 2: Five time periods: 14 days
• Example 3: Five time periods: 10 days
EXAMPLE 2a: Five time period – 14 days

<table>
<thead>
<tr>
<th>Location</th>
<th>Storage size [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alor</td>
<td>840</td>
</tr>
<tr>
<td>Bima</td>
<td>4231</td>
</tr>
<tr>
<td>Kupang P.</td>
<td>3796</td>
</tr>
<tr>
<td>M. PP Flores</td>
<td>1696</td>
</tr>
<tr>
<td>Sumbawa</td>
<td>4231</td>
</tr>
<tr>
<td>Waingapu</td>
<td>840</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Charter Cost</th>
<th>Propulsion Cost</th>
<th>Port Call Cost</th>
<th>Tot Shipping Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.9 $/m³</td>
<td>1.36 $/m³</td>
<td>1.07 $/m³</td>
<td>22.33 $/m³</td>
</tr>
<tr>
<td>0.829 $/mmBTU</td>
<td>0.057 $/mmBTU</td>
<td>0.045 $/mmBTU</td>
<td>0.931 $/mmBTU</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 Ship usage [days]</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Tot LNG shipped [m³]</td>
<td>14070</td>
<td>14070</td>
<td>14070</td>
<td>14070</td>
<td>14070</td>
</tr>
</tbody>
</table>
EXAMPLE 2b: Five time period – 14 days – No Investment cost

<table>
<thead>
<tr>
<th>Storage size [m³]</th>
<th>Alor</th>
<th>4200</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bima</td>
<td>12693</td>
</tr>
<tr>
<td></td>
<td>Kupang P.</td>
<td>10789</td>
</tr>
<tr>
<td></td>
<td>M. PP Flores</td>
<td>5556</td>
</tr>
<tr>
<td></td>
<td>Sumbawa</td>
<td>11369</td>
</tr>
<tr>
<td></td>
<td>Waingapu</td>
<td>4200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Charter Cost</th>
<th>Propulsion Cost</th>
<th>Port Call Cost</th>
<th>Tot Shipping Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.9 $/m³</td>
<td>1.16 $/m³</td>
<td>1.07 $/m³</td>
<td>22.13 $/m³</td>
</tr>
<tr>
<td>0.829 $/mmBTU</td>
<td>0.048 $/mmBTU</td>
<td>0.045 $/mmBTU</td>
<td>0.922 $/mmBTU</td>
</tr>
</tbody>
</table>

- Route is travelled twice

<table>
<thead>
<tr>
<th>Time period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship usage</td>
<td>11.2</td>
<td>11.7</td>
<td>9.8</td>
<td>2.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Tot LNG</td>
<td>17820</td>
<td>14710</td>
<td>14040</td>
<td>5000</td>
<td>18780</td>
</tr>
</tbody>
</table>

[© Wärtsilä]

[LNG Forum 2016 Bali/ Hitendra Shetty]
EXAMPLE 2b: Inventory at the Receiving Ports
AGENDA

• About Wärtsilä
• Model Description
• Example 1: One time period: 14 days
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EXAMPLE 3: Five time period – 10 days

<table>
<thead>
<tr>
<th>Storage size [m³]</th>
<th>Alor</th>
<th>1200</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bima</td>
<td>3022</td>
</tr>
<tr>
<td></td>
<td>Kupang P.</td>
<td>2711</td>
</tr>
<tr>
<td></td>
<td>M. PP Flores</td>
<td>2033</td>
</tr>
<tr>
<td></td>
<td>Sumbawa</td>
<td>3622</td>
</tr>
<tr>
<td></td>
<td>Waingapu</td>
<td>1200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Time period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 Ship usage [days]</td>
<td>9.4</td>
<td>8.6</td>
<td>9.4</td>
<td>9.8</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>Tot LNG shipped [m³]</td>
<td>10000</td>
<td>10000</td>
<td>10000</td>
<td>10250</td>
<td>10000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Charter Cost</th>
<th>$/m³</th>
<th>$/mmBTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>1.52</td>
<td>0.063</td>
</tr>
<tr>
<td>Port Call Cost</td>
<td>1.09</td>
<td>0.046</td>
</tr>
<tr>
<td>Tot Shipping Cost</td>
<td>22.51</td>
<td>0.938</td>
</tr>
</tbody>
</table>

Charter Cost: $19.9/m³, $0.829/mmBTU
Propulsion Cost: $1.52/m³, $0.063/mmBTU
Port Call Cost: $1.09/m³, $0.046/mmBTU
Tot Shipping Cost: $22.51/m³, $0.938/mmBTU
EXAMPLE 3: Five time period – 10 days

- Alor
- Bima
- M. PP Flores

- Kupang P.
- Waingapu
- Sumbawa
ACKNOWLEDGEMENT

The optimizations were carried out at Åbo Akademi University, Finland, in cooperation with Wärtsilä.

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