Economic Design Concept for Small LNG Carriers

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Trends in LNG shipping

- **Larger** LNG carriers for "**classical**" LNG transportation market (up to 270,000 m³)
- **Smaller** LNG carriers for **new** LNG transportation market
  - Clean fuel power plants for remote industrial areas or islands
  - Regions without pipeline grid (e. g. Norwegian coast)
  - Short sailing times in relation to LNG consumption
  - Design requirement for partial filling

Trends in LNG shipping

- **Smaller** LNG carriers
  - A Japanese yard is building a 19,000 m³ vessel with 3 spherical tanks (delivery: 2007).
  - An Australian company is developing projects of up to 30,000 m³ transport capacity.
  - Standard designs for LNG ships (spherical aluminium tanks or membrane tanks) are expensive → economics for such niche markets have to be improved.

Trends in LNG shipping

- **Very Small** LNG carriers (for coastal trade)
  - First very small ship (1,000 m³) for Norwegian coast delivered in 2004 (stainless steel tanks, electric propulsion)
  - Two LNG ships of 2,500 m³ delivered in 2003/5 for Japanese coast (cylindrical aluminium tanks)
  - Anthony Veder (NL) is building a 7,500 m³ LNG/Ethylene carrier for coastal transport in Norway (vessel design and gas plant supplied by TGE)

TGE's design approach to small LNG carriers

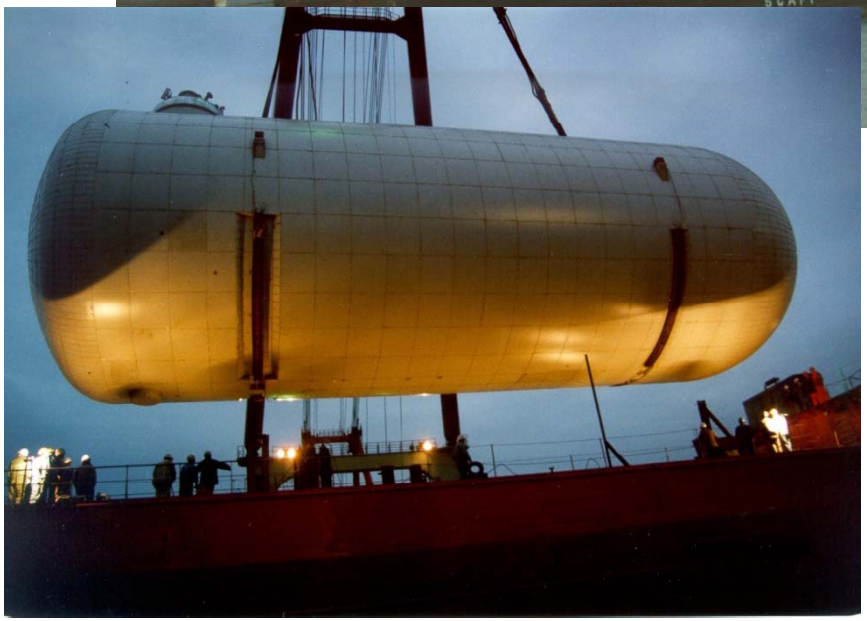
- Objective: minimize the CAPEX
- Utilize the know-how from design of Ethylene carriers
  - Ethylene ships: TGE's market share for delivery of gas handling systems and cargo tanks is more than 80%
  - Actual order book: 32 ethylene carriers
- Maximize operation flexibility for a combined LNG/Ethylene/LPG-carrier
- Main questions:
  - Cargo tank design
  - Boil-off gas handling / propulsion system

Types of cargo tanks for gas carriers

- (Internal insulation tanks)
- (Integral tanks)
- (Semi-membrane tanks: very few applications)
- **Membrane tanks**
- **Independent tanks**
  - (Type A)
  - **Type B**
  - **Type C**

TGE's design approach: independent Type C tanks

- self-supporting pressure vessel
- cylindrical or bilobe with outside insulation
- no secondary barrier required
- no restriction concerning partial filling



Cargo tanks for 22,000 m³ Ethylene-carrier

- 5,700 m³ (4 tanks)
- 4.7 bar g
- 480 t
- 5% Nickel steel

Type C tanks for LNG

- Ship capacity below 15,000 m³
  - Cylindrical tank design
    - 2 tank design up to abt. 10,000 m³
    - 3 tank design up to abt. 15,000 m³
- Ship capacity above 15,000 m³
  - Bilobe tank design
    - 3 tank design up to 25,000 m³
    - 4 tank design up to 35,000 m³ (or even 40,000 m³)

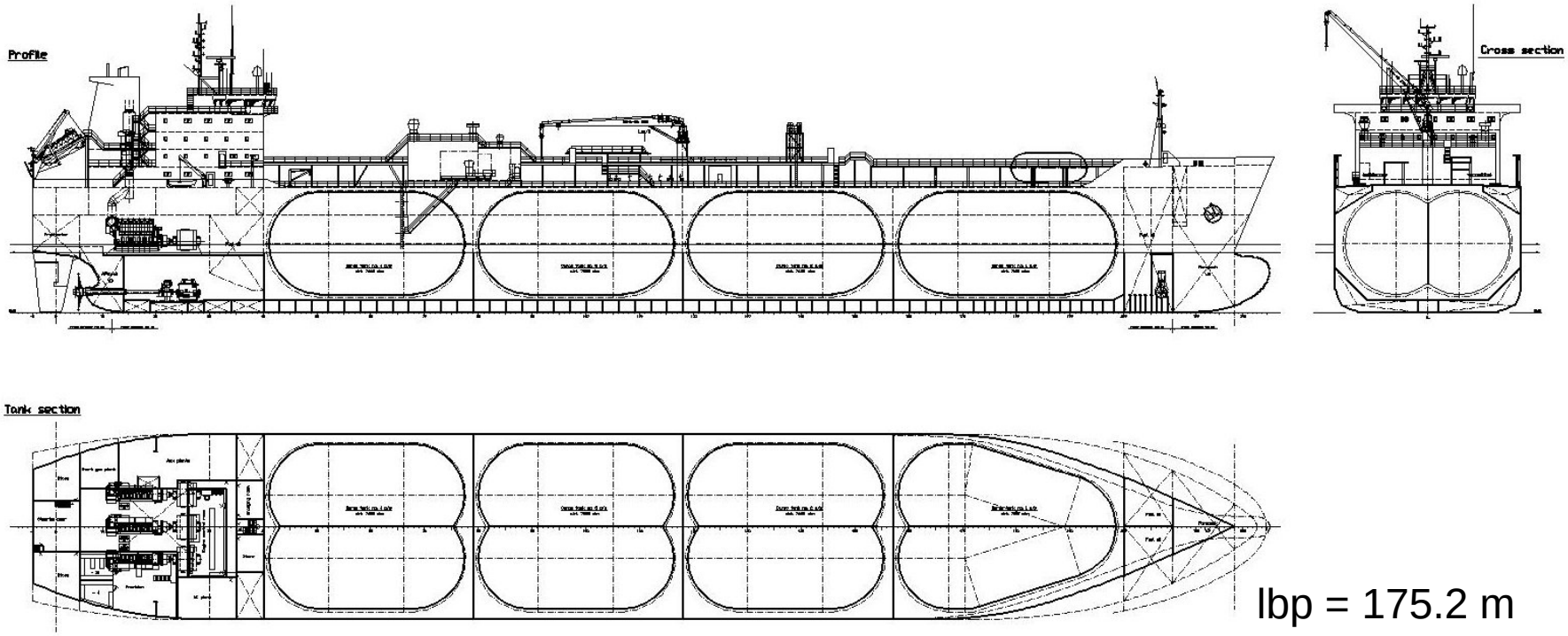
Type C tanks for LNG

- Tank design temperature: -163°C
- Tank material:
  - (Aluminium)
  - (9% Ni-steel)
  - SS AISI 304L

Type C tanks for LNG

- Ship design example: 30,000 m³ capacity:
  - 4 Bilobe tanks each abt. 7,500 m³ capacity
  - Min. design pressure @ density 500 kg/m³:
    - AISI 304L: 2.74 bar g
  - Tank weights:
    - AISI 304L: abt. 530 tons

30,000 m³ LNG-Carrier



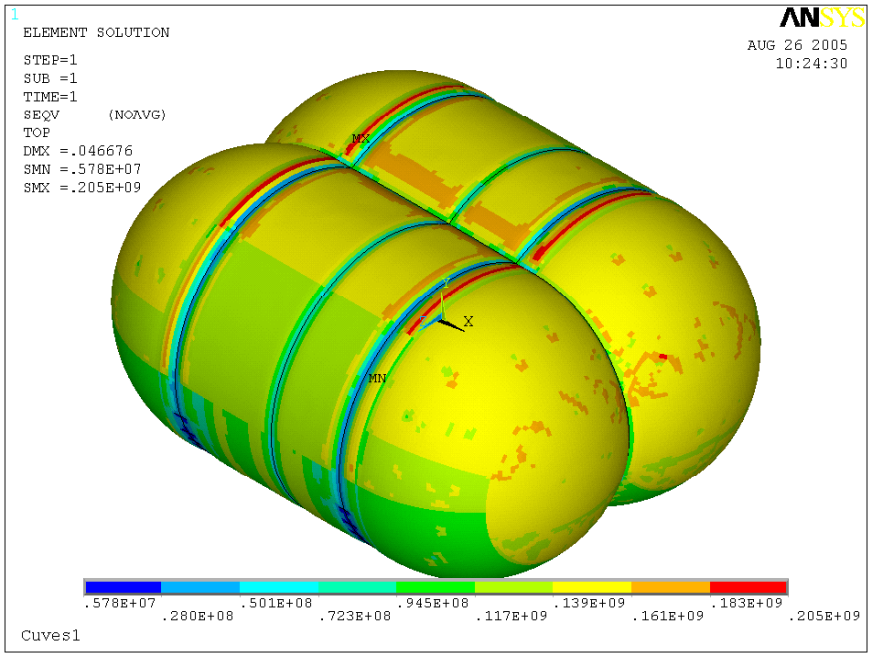
lbp = 175.2 m
b = 27.6 m
d = 8.8 m
speed = 17.5 kn

Type C tanks for LNG

- Design constraints for LNG compared to Ethylene:
  - Higher material shrinkage due to:
    - Larger delta T during cooling down
    - Higher material shrinkage factor for AISI 304L
  - Problem especially for bi-lobe tanks:
    for 15 m diameter tanks the shrinkage is 35 mm (304L)
  - Detailed design review and complete re-design of supports necessary (displacement and stress analysis, temperature profiles)!

Type C tanks for LNG

- Design appraisal by a classification society
  - FEM analysis of tank shell, supports and shipside steel structure for different loading cases



Tank insulation for LNG

- Tank insulation for Ethylene:
  - Typical Polystyrene panels glued to tank surface with abt. 230 mm thickness
- Tank insulation for LNG application
  - Same insulation type may be applied (spherical LNG tanks use same technology)
  - Insulation thickness of 300 mm (boil-off rate abt. 0.35 – 0.45 %/day)
  - Design details modified (shrinkage, stress)

Type C tanks for LNG – new design

- Concept approval certificate already issued by Class
- Patent pending
- 30 … 35,000 m³ designs have been discussed for a specific project with three shipyards on the basis of confidentiality agreements concerning design details

Boil-off gas handling / propulsion system

Alternatives for boil-off gas handling considering typically short voyages and small BOG quantities:

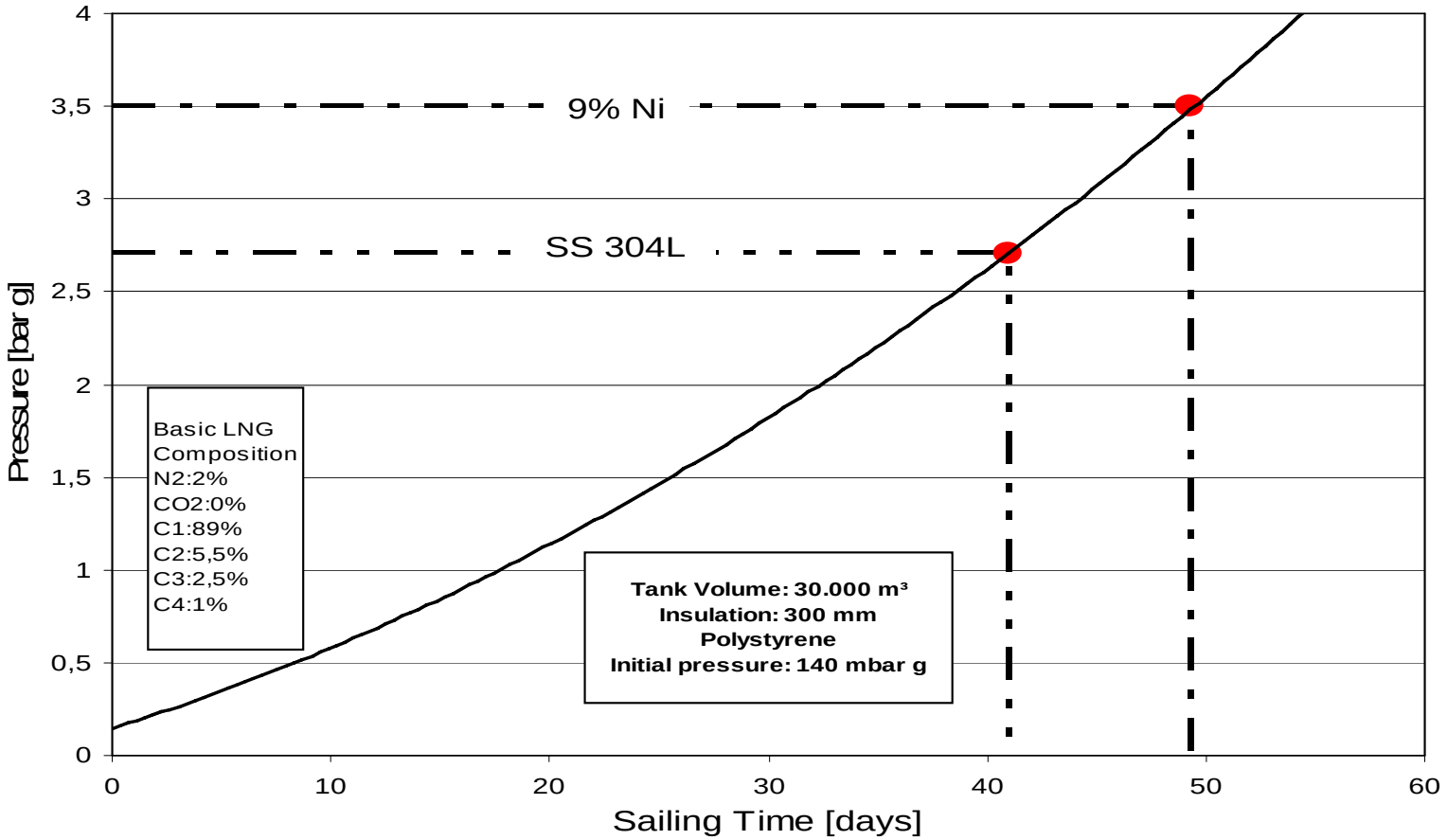
a) Burn the BOG in a thermal oxidiser (combustor)

b) Accept a pressure increase during voyage, provided that receiving terminal can accept it

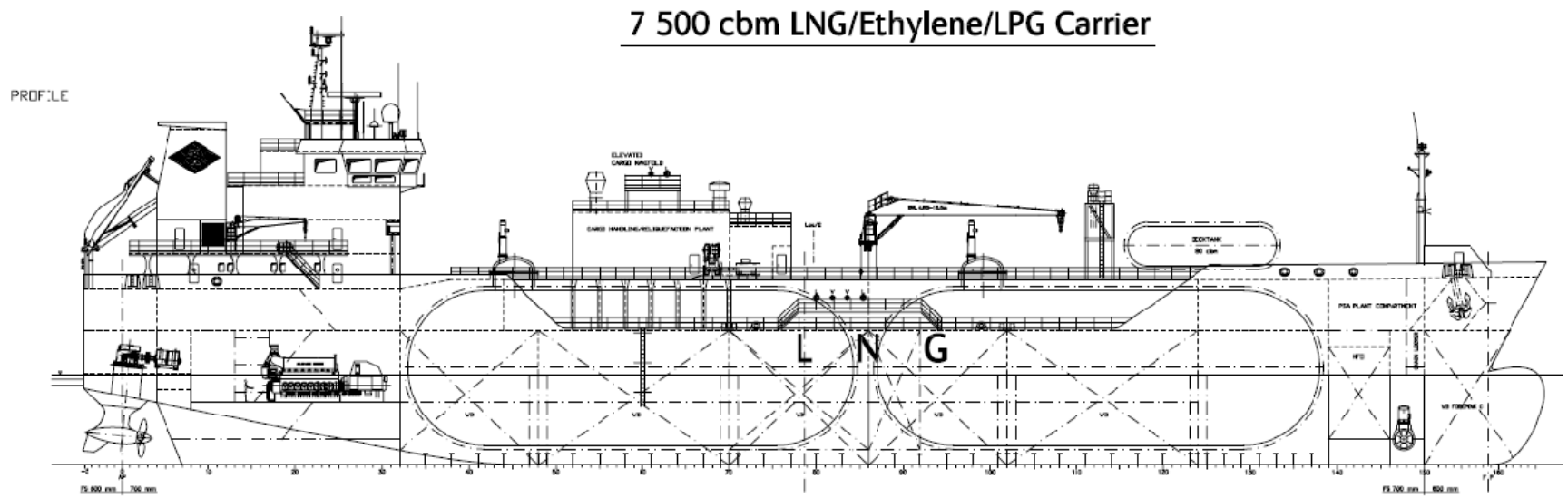
c) Utilize BOG for propulsion (electric power production)

d) Reliquefaction

Boil-off gas handling
b) Pressure increase

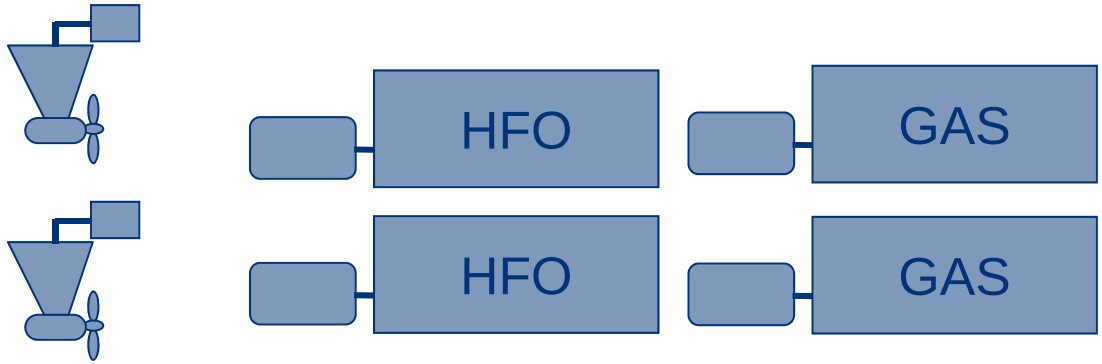


Boil-off gas handling
c) Utilize BOG for propulsion



- Owner: Anthony Veder, NL (design and gas plant supplied by TGE)
- Project: Coastal transport in Norway
  - LNG to be used as fuel
  - HFO to be used as fuel for transportation of other cargoes

Boil-off gas handling
c) Utilize BOG for propulsion



7,500 m³ LNG/LEG/LPG carrier for Anthony Veder

Electric propulsion (Gas, HFO):

- HFO generator sets: 2 x 3,685 kW
- Gas generator sets: 2 x 2,280 kW
- thrusters for optimum manoeuvrability

Boil-off gas handling
d) Reliquefaction

- Electric propulsion (utilize LNG and HFO as fuel) → high CAPEX
- Conventional slow speed diesel-mechanic (HFO) → BOG reliquefaction needed (CAPEX !), if pressure increase is not an option
- Alternative concepts based on mature technology:
  - pure LNG carriers: nitrogen system (Brayton cycle)
  - combined LNG/LEG carrier: utilize cascade technology from Ethylene ships (under development)

Combined LNG/Ethylene/LPG Carrier

- Changing grade from LNG to Ethylene or LPG requires tank warming up
- Changing grade is time consuming (especially from LNG to LPG)
- Cargo contamination may be an issue (for some cargoes visual inspection may be required)
- → Frequent grade changes are not economic

Combined LNG/Ethylene/LPG Carrier

- Small LNG ships with type C cargo tanks can easily be “upgraded” to combined gas carriers (installation of BOG reliquefaction for Ethylene)
- LNG transportation in smaller quantities is not a mature market
- Combined LNG/Ethylene/LPG carriers – like 7,500 m³ vessel – meet the demands of a developing market
  - increase operating flexibility
  - seasonal LNG transportation demands
  - up to 35,000 m³

Economics of small LNG carriers

- CAPEX:
  - Little changes for ship‘s hull construction (steel grade of tank supports)
  - Tanks and cargo handling system more expensive than for Ethylene carriers
  - TGE estimation shows an overall CAPEX abt. 10 – 15 % above the corresponding Ethylene-carrier price, depending BOG handling concept

Conclusion

- Target market: small gas consumers without access to a pipeline grid
- TGE's design approach with type C tanks is based in vast experience with Ethylene carriers
- The combined 7,500 m³ LNG/Ethylene/LPG carrier demonstrates that TGE's approach meets the requirements of this developing market
- Small LNG carriers can be economical with type C cargo tanks up to 35,000 m³ capacity
- TGE has received a „Concept Approval" of a modified tank design with a classification society
- A patent is pending for the new tank design

Thank you for your attention!

For any questions please contact TGE:
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