CNG – Present Status and Future Challenges

Michael Nikolaou
Michael J. Economides
Xiuli Wang
Natural Gas Transportation

• Current
  – 70% via pipeline
  – 30% as LNG

• Economics

![Graph showing gas delivery and distance to consuming market](image)
Globalization of Gas Trade

Source: International Energy Agency
Potential CNG Markets
CNG vs. LNG Marine Transport

**CNG**
- Gas Pipe
- Compression
- Gas Load System
- Transport
- GasUnload System
- System
- Compression
- Market

**LNG**
- Gas Pipe
- Liquefaction
- Gas Load System
- Transport
- GasUnload System
- Regasification
- Market

**CNG Vessels**
- CNG Transport:
  - CAPEX optimization

**Case Studies**

**Conclusions**
Loading and Offloading Terminals for LNG and CNG

CNG Vessels

CNG Transport:
CAPEX optimization

Case Studies

Conclusions

Source: http://www.xgas.us
## CNG vs. LNG

<table>
<thead>
<tr>
<th></th>
<th>CNG</th>
<th>LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CNG Vessels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>Compressed gas &lt;1:300 (Possibly chilled)</td>
<td>gas $\rightarrow$ liquid $\rightarrow$ gas (1:600)</td>
</tr>
<tr>
<td><strong>Loading</strong></td>
<td>Dehydrate, compress</td>
<td>Treat, liquefy, store</td>
</tr>
<tr>
<td><strong>Terminals</strong></td>
<td>Jetty or buoy</td>
<td>Jetty or regas offshore</td>
</tr>
<tr>
<td><strong>Ships</strong></td>
<td>Simple – like bulk-carrier</td>
<td>Sophisticated, efficient</td>
</tr>
<tr>
<td><strong>Receiving</strong></td>
<td>Decompress (&amp; heat) – utilize energy released</td>
<td>Store, regasify</td>
</tr>
</tbody>
</table>
Marine CNG History

Source: companies’ web sites
ABS, DNV Approval

- EnerSea (steel, vertical pipes, 130 bar, -29°C)
- SeaNG (Coselle 275 bar)
- Knutsen (steel, vertical pipes, 250 bar)
- CETech: (steel, horizontal pipes, 200-250 bar)
- TransCanada (wrapped steel liner)
- Trans Ocean Gas (composite)
# CNG Vessels Trivia

<table>
<thead>
<tr>
<th>CNG Transport: CAPEX optimization</th>
<th>Articulated Tug Barge</th>
<th>Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>0.7-2 MMcm (25-75 MMscf)</td>
<td>8-29 MMcm (300-1000 MMscf)</td>
</tr>
<tr>
<td>Loading unloading rates</td>
<td>0.3-2 MMcm/day (10-75 MMscf/day)</td>
<td>2-14 MMcm/day (75-500 MMscf/day)</td>
</tr>
<tr>
<td>Distance</td>
<td>100-1000 km (50-500 nautical miles)</td>
<td>250-5000 km (135-2700 nautical miles)</td>
</tr>
<tr>
<td>Speed</td>
<td>&lt;25 km/hr (&lt;14 knots)</td>
<td>&lt;33 km/hr (&lt;18 knots)</td>
</tr>
<tr>
<td>Estimated cost</td>
<td>$15-35 million</td>
<td>$150-350 million</td>
</tr>
</tbody>
</table>
CNG Technologies: Coselles (Compression only)
CNG Technologies: Compression and Chilling

Source: EnerSea
Why Compression and Chilling?

\[ V \sim \frac{zT}{P} \]
Loading and Offloading
Natural Gas Transport: Fixed Cost

CAPEX Distribution

- Permanent Assets
- Flexible Assets

- CNG
- LNG
- Pipeline

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
CNG Distribution Patterns: Logistics Matter!

- Hub-and-Spoke

- Milk-Run

![Diagram of Hub-and-Spoke distribution pattern]

![Diagram of Milk-Run distribution pattern]
CNG Distribution

- CNG
- CNG Vessels
- CNG Transport: CAPEX optimization
- Case Studies
- Conclusions

[Map of CNG distribution in the Caribbean, showing countries and their gas imports in cubic meters per year (Gcm³/yr)].

Key:
- 0 Gcm³/yr
- 5000 Gcm³/yr
- 10,000 Gcm³/yr
- 15,000 Gcm³/yr
- 20,000 Gcm³/yr

Countries represented:
- Cuba
- Dominican Republic
- Haiti
- Jamaica
- Guadeloupe
- Martinique
- Saint Lucia
- Trinidad
- Aruba
- Netherlands Antilles
- Grenada
- Barbados
- Venezuela
- Bermuda

Distances marked: 500 km, 1000 km, 2000 km, 2500 km, 5000 km.
CNG Fleet Size Bounds

- Feasible number of vessels
- 2 to 10% of gas load spent as fuel

Minimum number of vessels, \( n_{\text{min}} \)

Consumption rate, \( q_c \)

Loading rate, \( q_{\text{load}} \)
CNG Distribution in the Caribbean

- Individual bars and cumulative dots
- CNG requirement in Bcm per year

Countries:
- Puerto Rico
- Dominican Republic
- Jamaica
- Trinidad and Tobago
- Bahamas
- Guadeloupe
- Netherlands Antilles
- United States Virgin Islands
- Barbados
- Martinique
- Aruba
- Bermuda
- Haiti
- Cayman Islands
- Saint Lucia
- Grenada
- Saint Kitts and Nevis
- Saint Vincent and the Grenadines
- Antigua and Barbuda
- Dominica
- Anguilla
- British Virgin Islands
- Turks and Caicos Islands
- Montserrat

Graph showing the distribution and requirement of CNG in the Caribbean region.
CNG Distribution in the Caribbean: The Big 4
CNG to the Big 4: Fleet Capacity

- Puerto Rico
- Dominican Republic
- Jamaica
- Bahamas

Case Studies

Conclusions
CNG to the Big 4: Travel Time

Puerto Rico

Dominican Republic

Jamaica

Bahamas

Time days

Offloading time

Travel and loading time

Time days

Offloading time

Travel and loading time

Time days

Offloading time

Travel and loading time

Time days

Offloading time

Travel and loading time
CNG Distribution in the Caribbean: The Small Ones

CNG Vessels

CNG Transport:
CAPEX optimization

Case Studies

Conclusions
CNG to the Small Ones: Itinerary

CNG
CNG Vessels
CNG Transport: CAPEX optimization
Case Studies
Conclusions
CNG to the Small Ones: Fleet Capacity

- **Case Studies**
- **Conclusions**

**Graphs:**
- Plot showing capacity for different n values
- G_{storage} [MMscf] vs. number of vessels (4 to 10)
CNG to the Small Ones: Reduced Itinerary
CNG to the Small Ones: Fleet Capacity for Reduced Itinerary

Case Studies

Conclusions
Conclusions

• CNG ready for prime time
  – Room for further improvement

• CNG complements LNG
  – Several potential markets worldwide

• Logistics and fleet optimization important