LNG for Aircrafts

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Global Sky 2018:

145k-180k flights/d
4% annual growth air traffic
> 4 bill. passengers/a
~320 MTPA kerosene
~1000 MTPA CO$_2$ emission
Causes 7% of global warming
Global Warming from Air Traffic

<table>
<thead>
<tr>
<th>Process</th>
<th>Pollutant</th>
<th>Contribution to anthropogene green house effect</th>
<th>RFI factor related to CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ direct</td>
<td>CO₂</td>
<td>+1.6%</td>
<td>1.0</td>
</tr>
<tr>
<td>Ozone Formation</td>
<td>NOₓ</td>
<td>+1.4%</td>
<td>0.8</td>
</tr>
<tr>
<td>Methane Reduction</td>
<td>NOₓ</td>
<td>-0.7%</td>
<td>-0.5</td>
</tr>
<tr>
<td>Water Direct</td>
<td>H₂O Vapor</td>
<td>+0.1%</td>
<td>+0.05</td>
</tr>
<tr>
<td>Cooling by Shielding</td>
<td>Sulfate Particles</td>
<td>-0.2%</td>
<td>-0.1</td>
</tr>
<tr>
<td>Soot Direct</td>
<td>Soot Particles</td>
<td>+0.2%</td>
<td>+0.1</td>
</tr>
<tr>
<td>Vapor Trail Formation</td>
<td>Particles</td>
<td>+0.6%</td>
<td>+0.1</td>
</tr>
<tr>
<td>Cirrus Cloud Formation</td>
<td>Particles</td>
<td>+3.4%</td>
<td>0.5 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2%-5%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>approx. 7%</td>
<td>1.9 - 4.7</td>
</tr>
</tbody>
</table>

Source: IPCC 2007
Project Alliance FAIR (Future Aircraft Research) / Scope of TGE Feasibility Study from 2010 - 2013

- During the FAIR project alliance, TGE/Air-LNG collaborated with Airbus, Airport Hamburg, EADS, Lufthansa, DLR und MTU. The project was funded by German Bundestag
- Requirement to exchange technology know-how across the aircraft industry and gas industry
- TGE has more than three decades of experience in the field of handling cryogenic liquids, in particular LNG. In regard to any aviation industry related matters TGE made use of information from the project alliance partners as well as public information sources
Other Known R&D Activities Regarding LNG as Aircraft Fuel

- The Russian aircraft Tupolev Tu-155 was a testing airplane that flew with LNG in the late 1980’s
Other Known R&D Activities Regarding LNG as Aircraft Fuel

Boeing/NASA Subsonic Ultra-Green Aircraft Research (SUGAR) project, 2012

Ref: NASA/CR-2012-217556

MIT Lab for Aviation and Environment:

Research on new aircraft design & alternative fuels, especially LNG
LNG Aircraft Tank Design – LD3/LD6 Standard Freight Container
LNG Aircraft Tank Prototype & Tests

1. Hydrostatic test: Successfully performed at 7.5 barg with TÜV certificate

2. Mechanical fatigue test’s: After 25 000 load load cycles according EASA requirements (equivalent 30 years of operation):
   - no damage on insulation system
   - no damage on bearings
   - no damage on inner vessel

3. Cryogenic test with liquid Nitrogen at -196°C performed at more extreme conditions than LNG during operations. Little visual loose snow on outer surface, no damages on tank system

Conclusion: All performed tests basically qualify this tank type technically for aircraft operation
LNG On-board Fuel System / Available Technology & Equipment

- Manufacturer of cryogenic pumps available, EASA permitting required
- LNG Evaporator / test results available by GE-NASA (GE-NASA Report TIS-R74AEG153)
- Vacuum insulated piping for LNG is standard technology
Advantages of LNG / Combustion and Emission Tests

- Dual fuel operation with LNG and kerosene is possible with minimum effort
- Remarkable reduction of emissions after adjustment of injectors and burner concepts
- Easy adaption to existing burner systems; just minor safety-related adjustments required
- Tested burner versions prove LNG is suitable to be used as aircraft fuel already with today's state of the art
Advantages of LNG / Combustion and Emission Tests

- Similar burn characteristics to kerosene
  → minimal effort to retrofit
  → easier adaption compared to H₂
- Significant emissions reduction to kerosene
  → - 25% CO₂
  → - 80% NOₓ
  → no emissions of soot, sulphur and aromatics
  → further reduction of CO₂ by use
    or mixing Bio-LNG
  → Less vapor trail
- High energy content (49 MJ/kg)
Fuel Costs Relation LNG / Jet-Fuel A1 – Compared at Same Energy on Board

<table>
<thead>
<tr>
<th>Jet Fuel Price</th>
<th>2013</th>
<th>2016</th>
<th>2017</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 $/MMBTU</td>
<td>13%</td>
<td>43%</td>
<td>26%</td>
<td>LNG price @HenryHub March 2017</td>
</tr>
<tr>
<td>6 $/MMBTU</td>
<td>24%</td>
<td>78%</td>
<td>47%</td>
<td>LNG price scenario 1</td>
</tr>
<tr>
<td>10 $/MMBTU</td>
<td>41%</td>
<td>129%</td>
<td>79%</td>
<td>LNG price scenario 2</td>
</tr>
</tbody>
</table>

- Cost comparison for both fuels with prices from stock market without transportation to airport
- LNG Price Henry Hub: [https://www.eia.gov](https://www.eia.gov) → Henry Hub
- Fuel Energy: \( \text{H}_{\text{LNG}} = 50 \text{ GJ/t} \) / \( \text{H}_{\text{Jet-Fuel A1}} = 42.8 \text{ GJ/t} \)

Example:
Fuel Cost Savings March 2017: 21,000$ → 55t Jet-Fuel at 516$/t – 47t LNG at 156$/t
(LNG fuel weight savings not considered for total consumption)
Process Technology Developed During FAIR Project

• "Fueling Facility for Cryogenic Liquids (Aircraft Fueling Vehicle)"
• "Method for Aircraft Revamp"
• "Supply of a Pump with Cryogenic Liquid"
• "Supply of a Pump with Cryogenic Liquid (Buffer)"
Next Development Steps

- Detail development of an LNG fuel system, permitting / approvals of aviation safety agencies
- Installation of a ground fuel system testing facility
- Revamping an existing aircraft for LNG operation
- Equipping airports with LNG storage and fuelling facilities
Market Entry Barriers

- Concerns in Feasibility
- Limited interest of established jet-fuel suppliers changing all infrastructure
- Considerable investment for aircraft manufacturer and aviation company
- More stakeholders involved
- Aircraft equipment must have the approval from aviation safety agencies
- No airport LNG infrastructure without a long-term secured business
- No aircraft in operation without secured airport LNG infrastructure
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Vision:
Fly LNG

Mission:
• World Gas Industry Drives Vision
• Politics Move
• Entrepreneur Invests
Contact

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