LNG for Aircrafts

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PRESENTED BY IGU gti iif iir

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

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Global Warming from Air Traffic

Process	Pollutant	Contribution to anthropogene green house effect	RFI factor related to CO2
CO_2 direct	CO_2	+1.6%	1.0
Ozone Formation	NO_x	+1.4%	0.8
Methane Reduction	NO_x	-0.7%	- 0.5
Water Direct	H_2O Vapor	+0.1%	+ 0.05
Cooling by Shielding	Sulfate Particles	-0.2%	- 0.1
Soot Direct	Soot Particles	+0.2%	+ 0.1
Vapor Trail Formation	Particles	+0.6%	+ 0.1
Cirrus Cloud Formation	Particles	+3.4% (2%-5%)	0.5 - 3
Total		**approx. 7%**	**1.9 - 4.7**

Source: IPCC 2007

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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 then 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

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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

Tupulev

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

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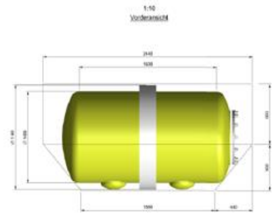
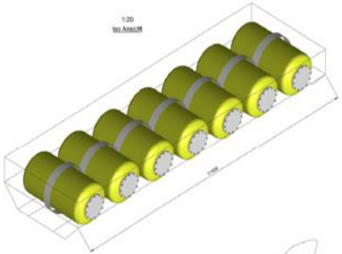
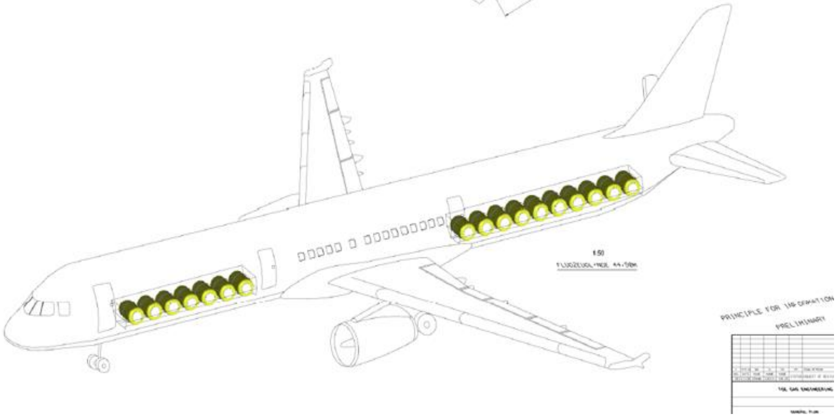
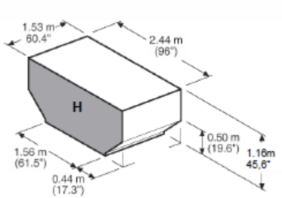
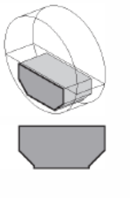
LNG Aircraft Tank Design –
LD3/LD6 Standard Freight Container

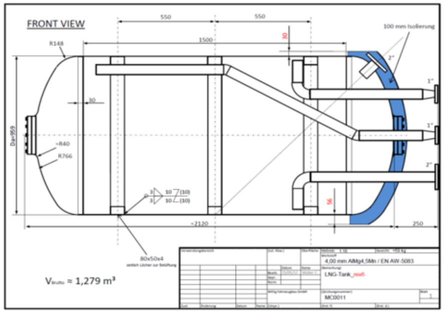








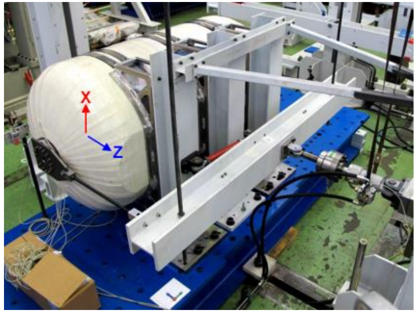




LNG Aircraft Tank Prototype & Tests

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

<u>Conclusion: All performed tests basically qualify this tank type technically for aircraft operation</u>



Tests at IMA Dresden

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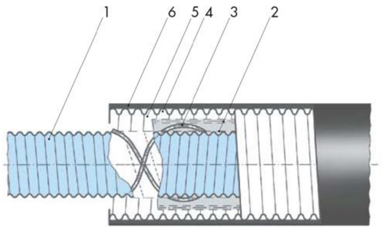
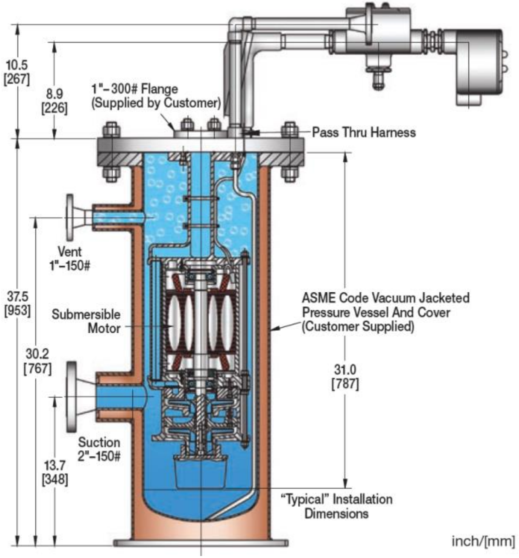
LNG On-board Fuel System / Available Technology & Equipment



Typical Nexans

- 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



Typical ACD Pumps

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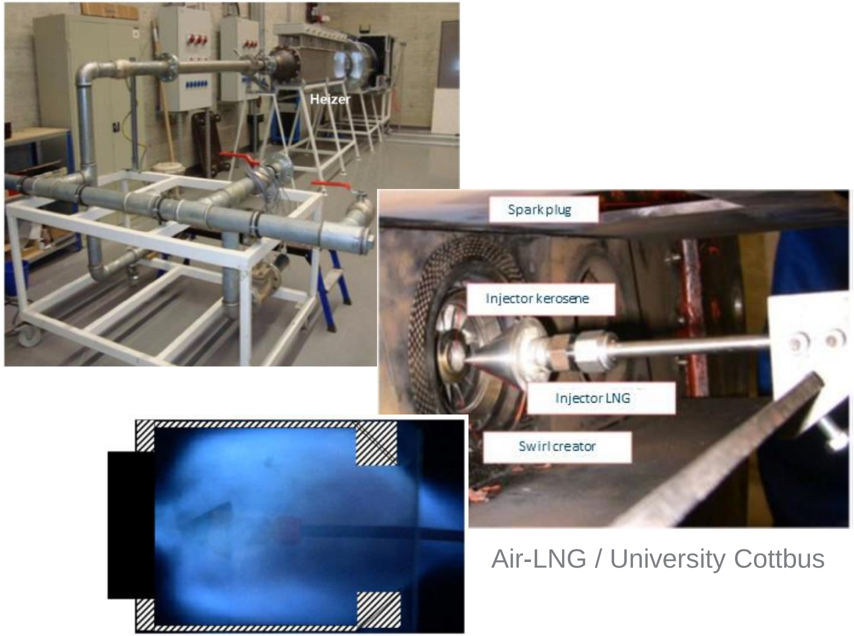
Advantages of LNG / Combustion and Emission Tests



Air-LNG / University Cottbus

- 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

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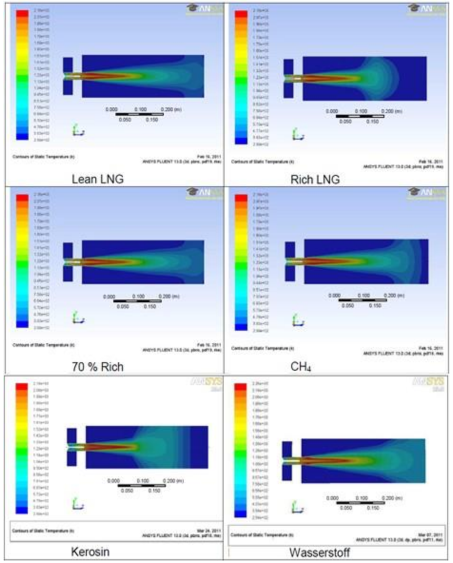
Advantages of LNG / Combustion and Emission Tests

- Similar burn characteristics to kerosene
  → minimal effort to retrofit
  → easier adaption compared to H_2
- Significant emissions reduction to kerosene
  → - 25% CO_2
  → - 80% NO_X
  → no emissions of soot, sulphur and aromatics
  → further reduction of CO_2 by use
  or mixing Bio-LNG
  → Less vapor trail
- High energy content (49 MJ/kg)



Air-LNG / University Cottbus

Fuel Costs Relation LNG / Jet-Fuel A1 – Compared at Same Energy on Board

Jet Fuel Price	2013 994 $/t 127 $/barrel	2016 313 4$/t 40 $/barrel	2017 516$/t 66 $/barrel	Remark
3.3 $/MMBTU = 156 $/t	13%	43%	26%	LNG price @HenryHub March 2017
6 $/MMBTU = 284 $/t	*24%*	*78%*	*47%*	*LNG price scenario 1*
10 $/MMBTU = 474 $/t	*41%*	*129%*	*79%*	*LNG price scenario 2*

- Cost comparison for both fuels with prices from stock market without transportation to airport
- Jet-Fuel A1 price monitor: (http://www.iata.org)
- LNG Price Henry Hub: (https://www.eia.gov →Henry Hub)
- Fuel Energy: H_LNG = 50 GJ/t / H_Jet-Fuel A1 = 42.8 GJ/t

Example:
Airbus A-340 One-Way Munich – New York 47t LNG instead of 55t Jet-Fuel A1
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)

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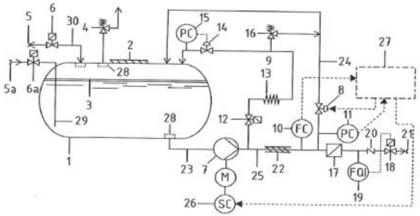
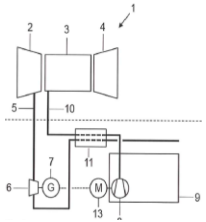
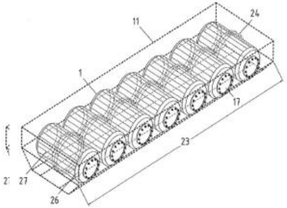
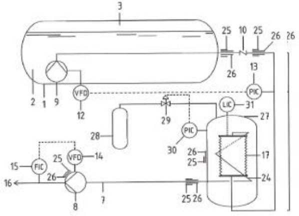
Process Technology Developed During FAIR Project

- „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)“









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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
- More stakeholders involved
- Considerable investment for aircraft manufacturer and aviation company
- Aircraft equipment must have the approval from aviation safety agencies
- No aircraft in operation without secured airport LNG infrastructure
- No airport LNG infrastructure without a long-term secured business

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Vision:

Fly LNG

Mission:

- World Gas Industry Drives Vision
- Politics Move
- Entrepeneur Invests

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