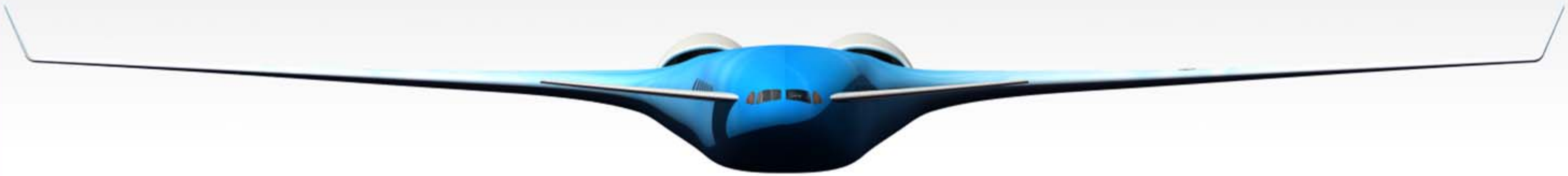

A possible role for LNG in meeting the energy demands of aviation

Cryogenic Mass & Heat Transfer, U. Twente, Nov 2019

Dr. Arvind Gangoli Rao
Associate Professor
Flight Performance and Propulsion
Faculty of Aerospace Engineering
T.U. Delft

SEVENTH FRAMEWORK PROGRAMME

Clean Sky 2

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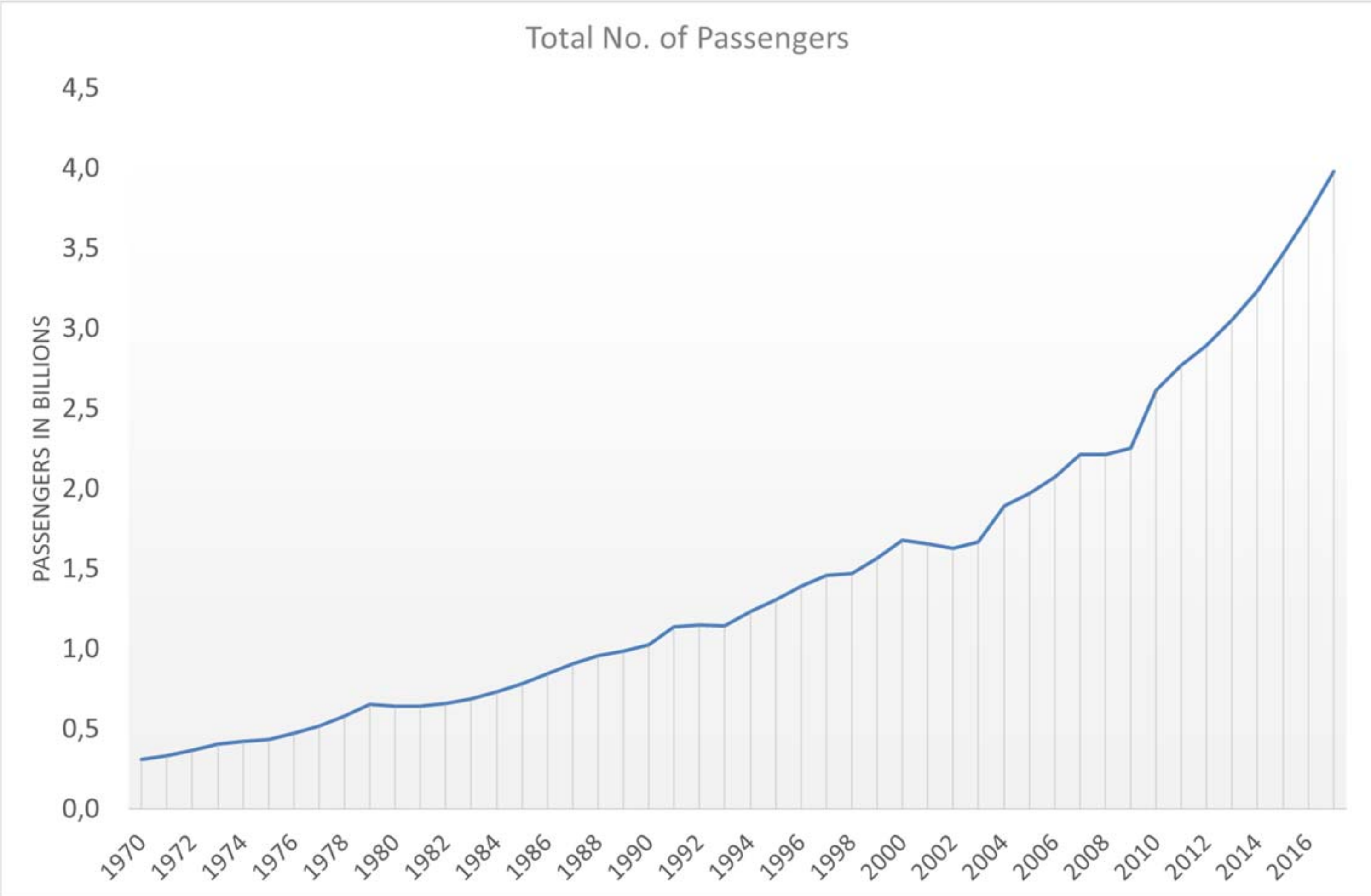
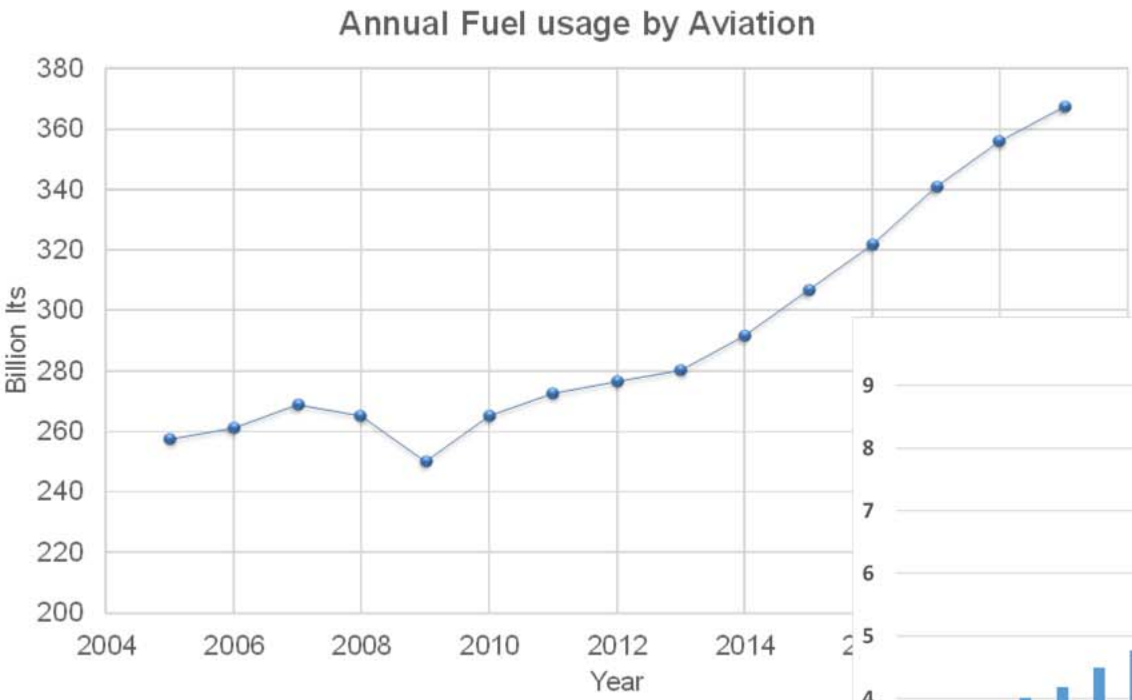
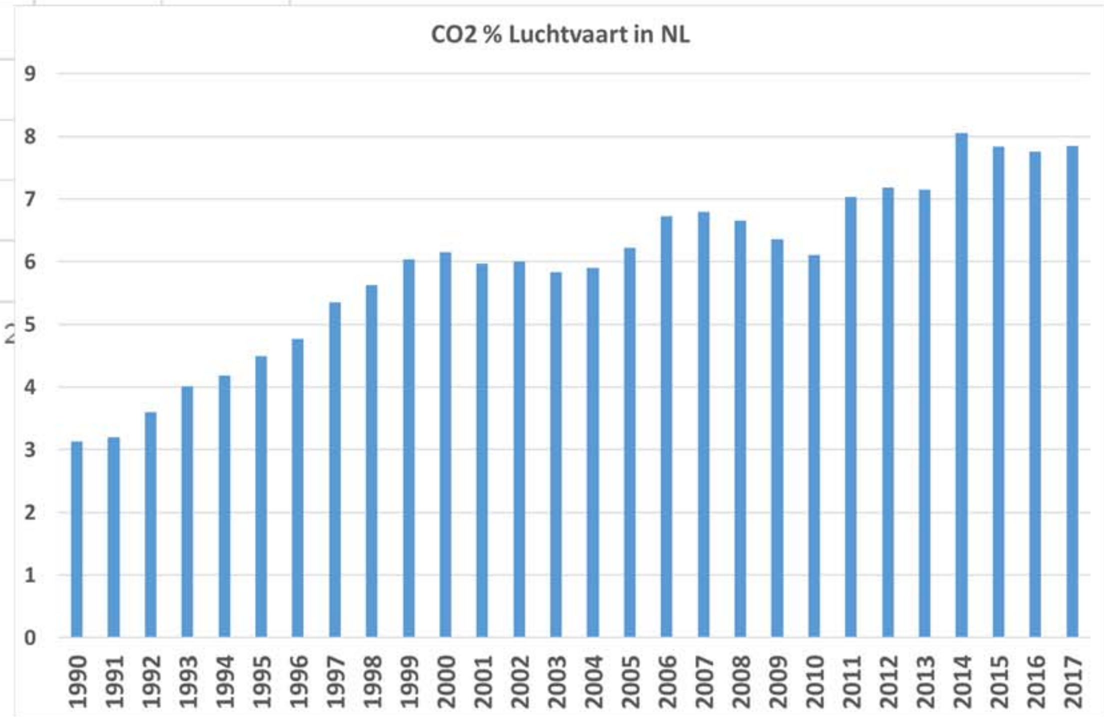
How many people travel?



Source: ICAO, world bank

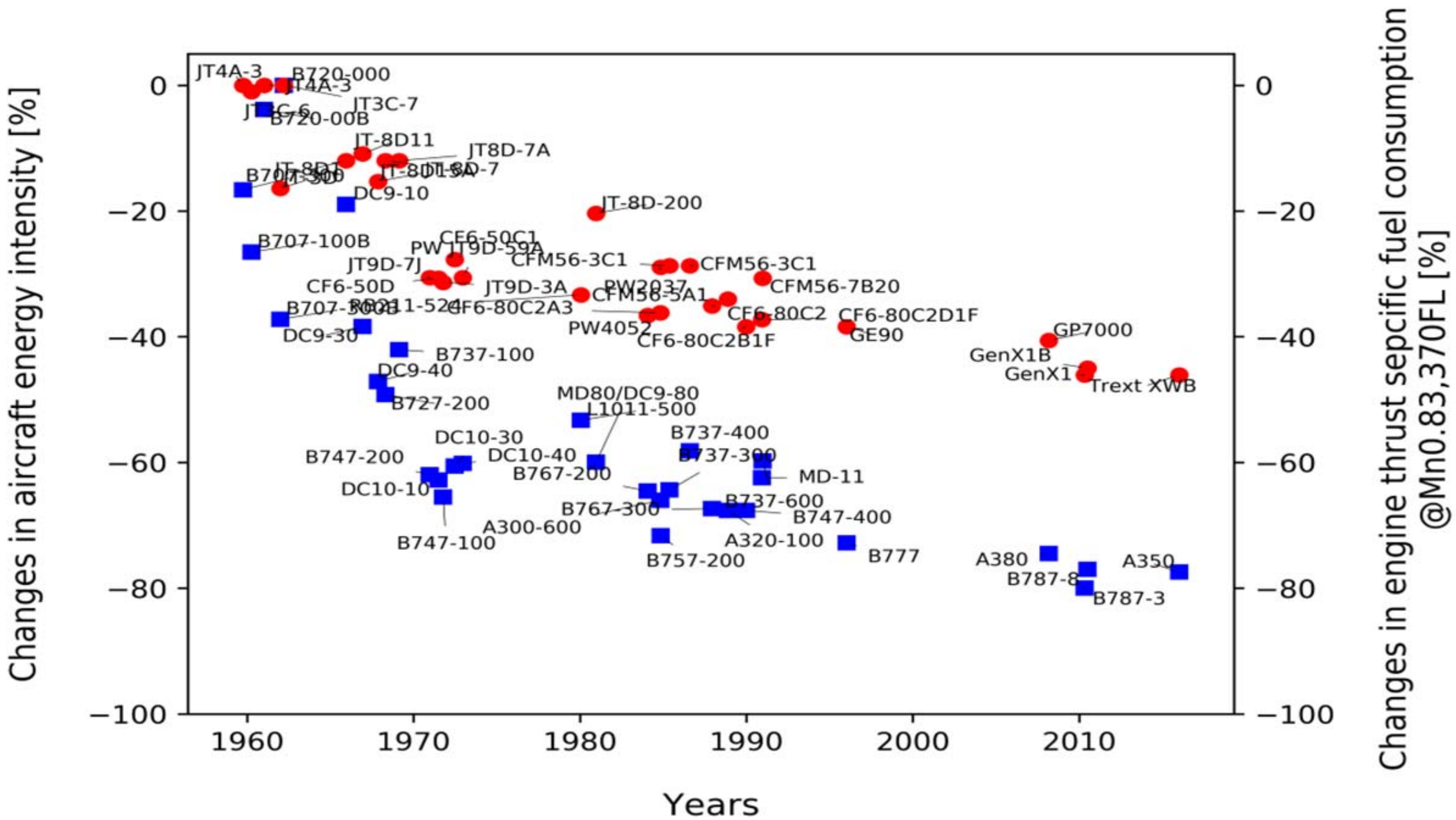
How much kerosene do we use?





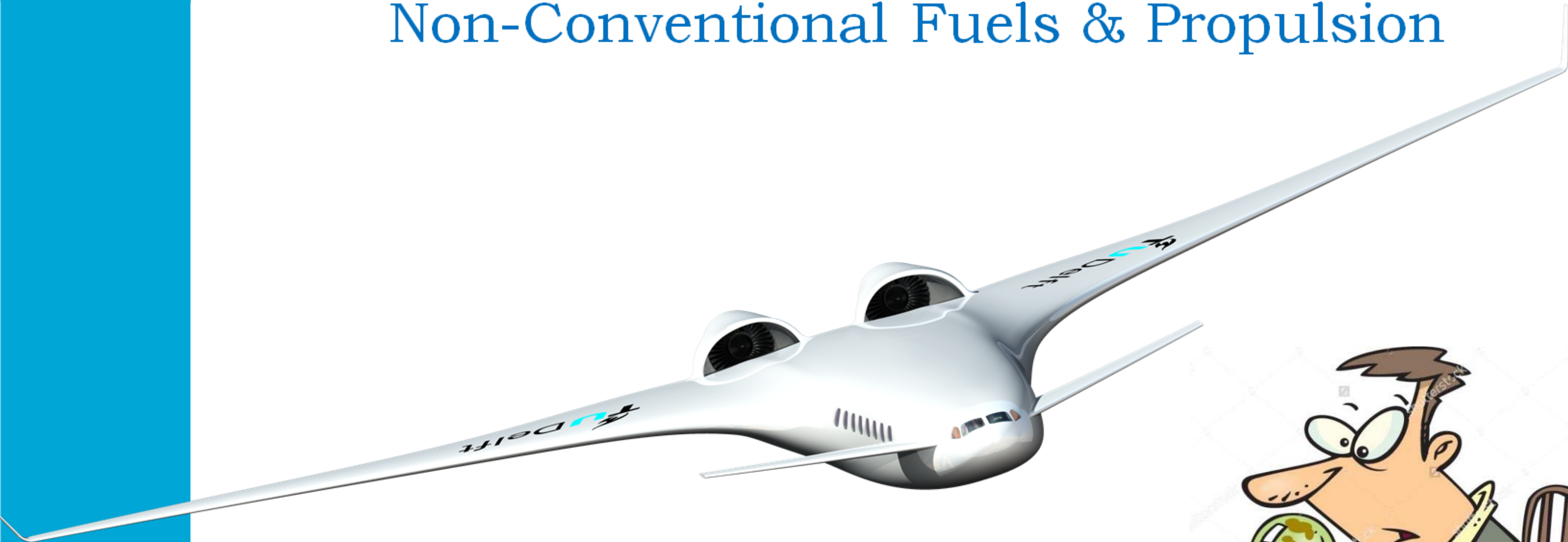
Source: Statistica, CBS,

Aircraft fuel burn

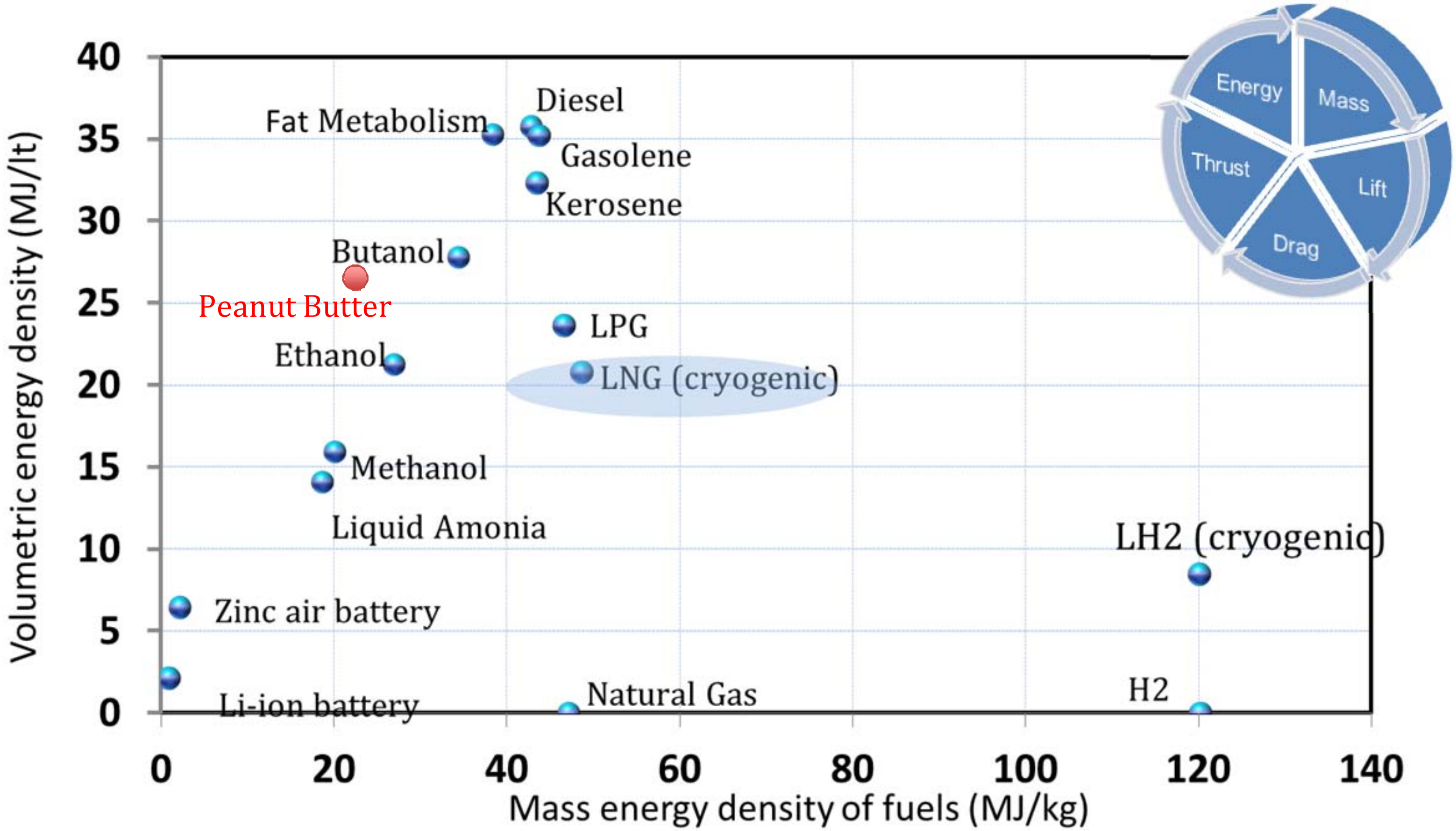


F. Yin & A. Gangoli Rao "A Review of Inter-stage Turbine Burner Turbofan Engine Concept for Future Civil Aviation" (Under Review)

Non-Conventional Fuels & Propulsion



Energy sources for aviation



A.Gangoli Rao, F.Yin and J.P. van Buijtenen, “A Hybrid Engine Concept for Multi-fuel Blended Wing Body”, Aircraft Engineering and Aerospace Technology, vol.6. No. 8, 2014

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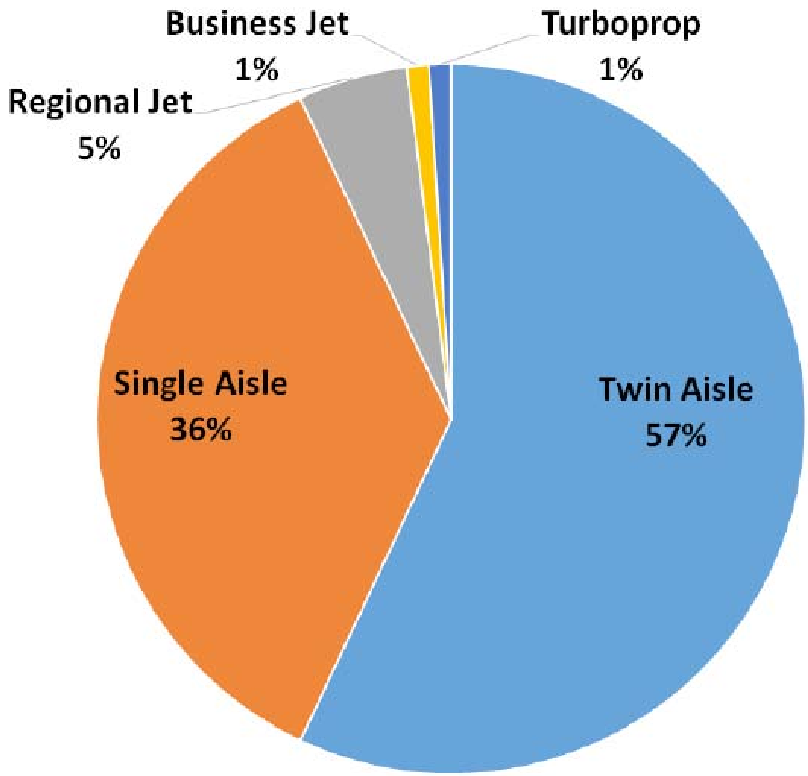
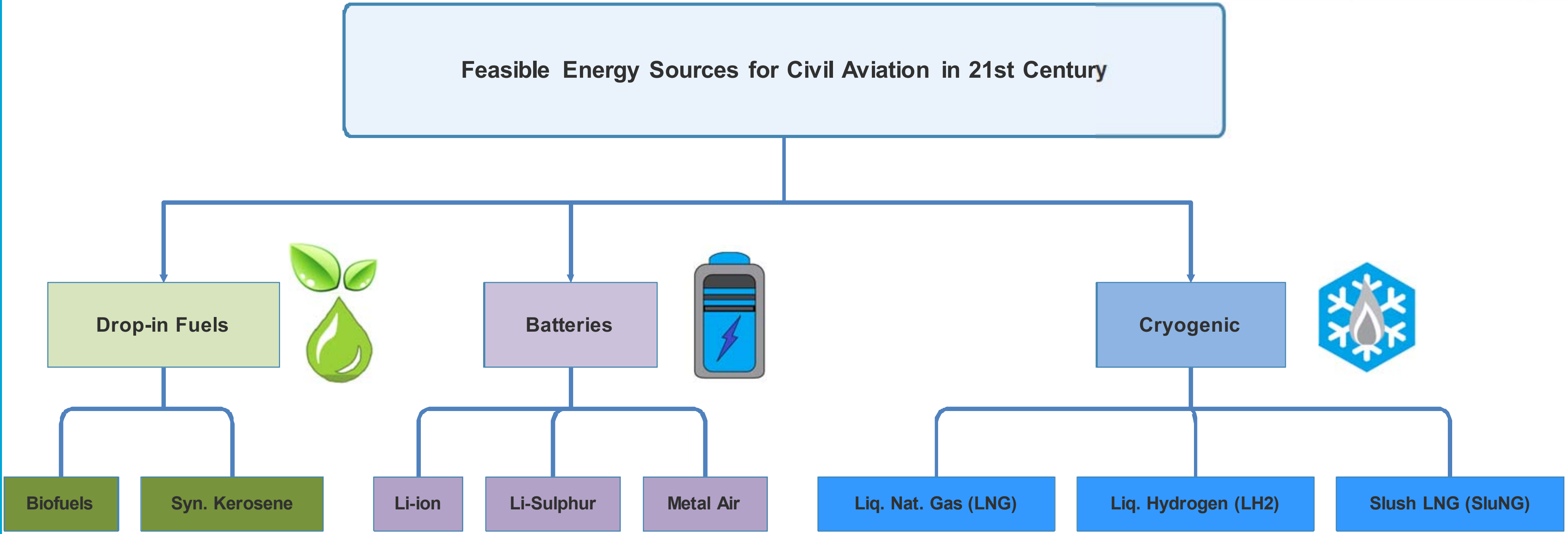
Fuel Consumption by segment



Global civil aviation fuel consumption. SOURCE: Data from B. Yutko and J. Hansman, 2011, *Approaches to Representing Aircraft Fuel Efficiency Performance for the Purpose of a Commercial Aircraft Certification Standard*, MIT International Center for Air Transportation, Cambridge, USA

Energy Sources



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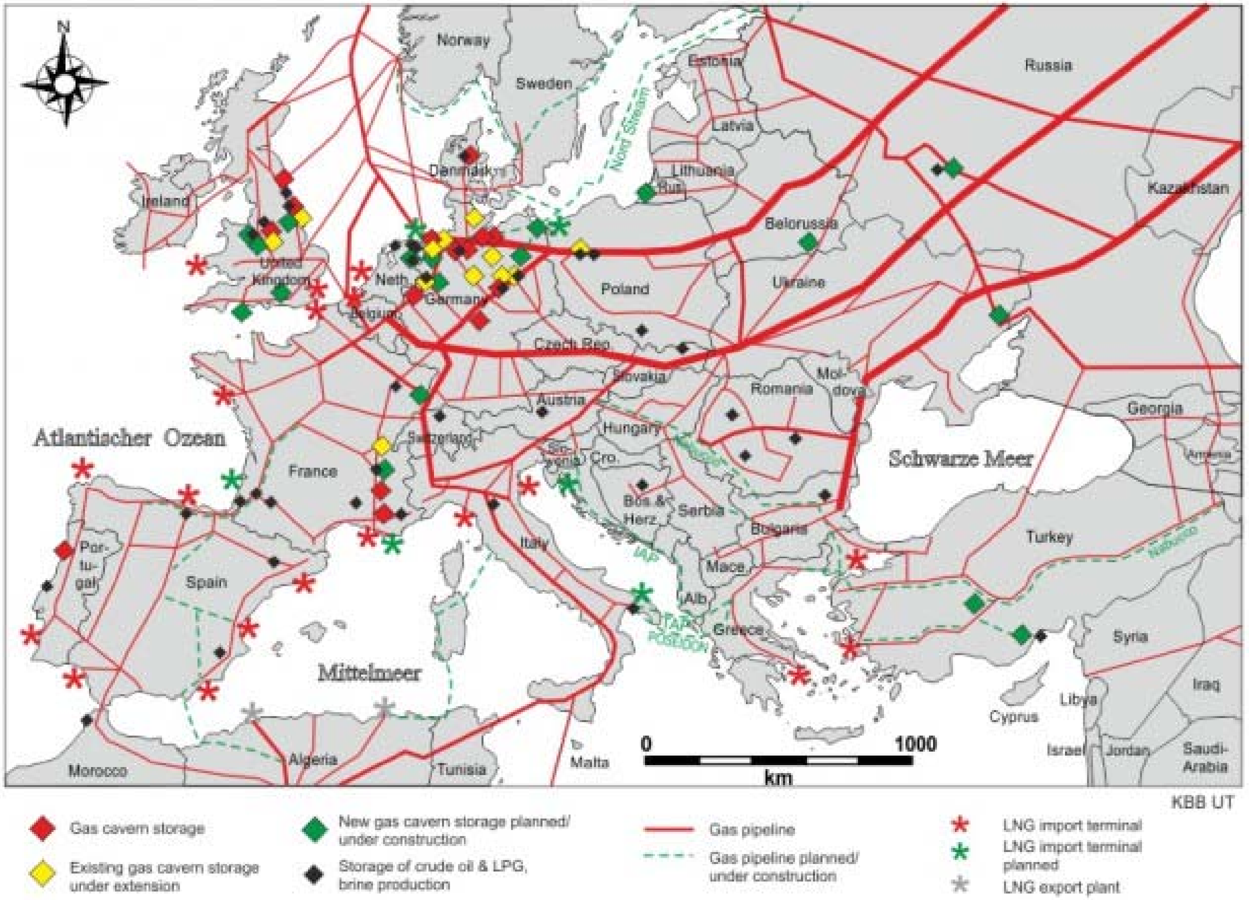
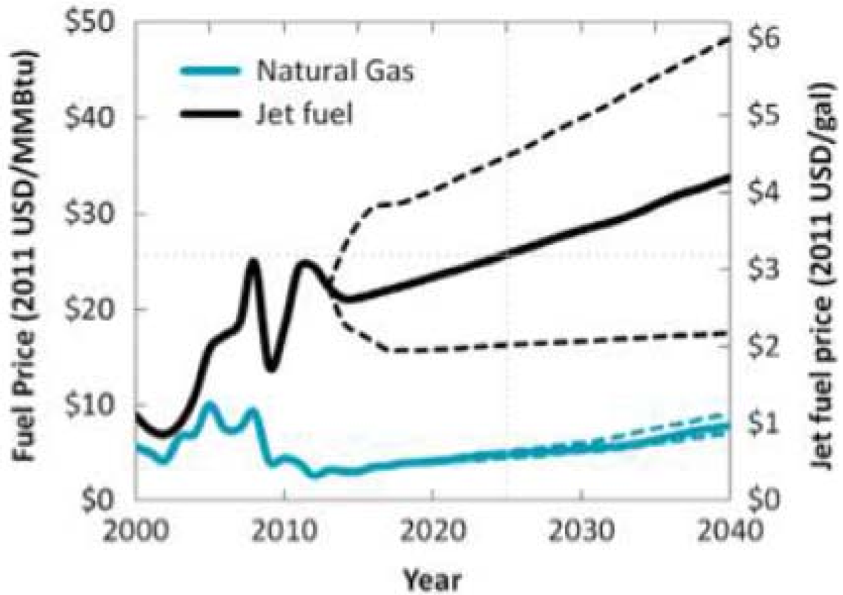
LNG Network in EU



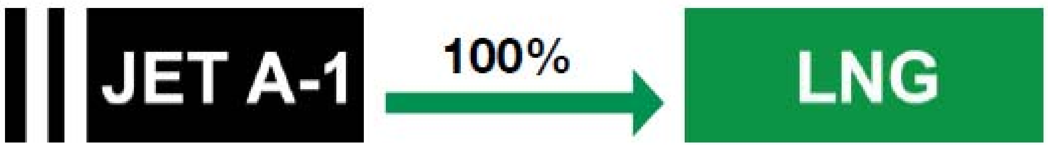
Natural gas pipelines, LNG terminals and storage caverns in Europe
(Source: KBB Underground Technologies GmbH).

LNG as an Energy Source



Conversion to LNG Price	
Natural Gas	$6.00
Liquefaction	$6.00
Transportation	$0.30
Storage	$0.82
Total LNG	**$13.12**

*Prices are per MMBtu



40.22 MJ/$** **80.38 MJ/$

LNG as an Energy Source

Advantages of LNG

- Lower fuel weight compared to kerosene.
- 25 % reduction in CO_2 emission.
- Significant reduction in NOx-and particulate emissions.
- The LNG is substantially cheaper than conventional jet fuels.
- Can be produced from renewable energy.
- Usage of cryogenic heat sink can increase engine thermal efficiency.

Disadvantages of LNG

- Requires pressurised and insulated tanks for storage resulting in increased aircraft OEW.
- Increased storage space for LNG compared to conventional jet fuels.
- Airport facilities and logistics for tanking LNG are required.
- Increased water vapour emission by 40%

AHEAD: Advanced Hybrid Engines for Aircraft Development

- Delft University of Technology
- Pratt & Whitney Reszov, Poland
- Technical University of Berlin
- DLR, IAP
- Israel Institute of Technology-Technion
- Ad Cuenta b.v.

Advisory Board

- MTU Aero Engines
- EASA
- KLM
- Airbus Group Innovations

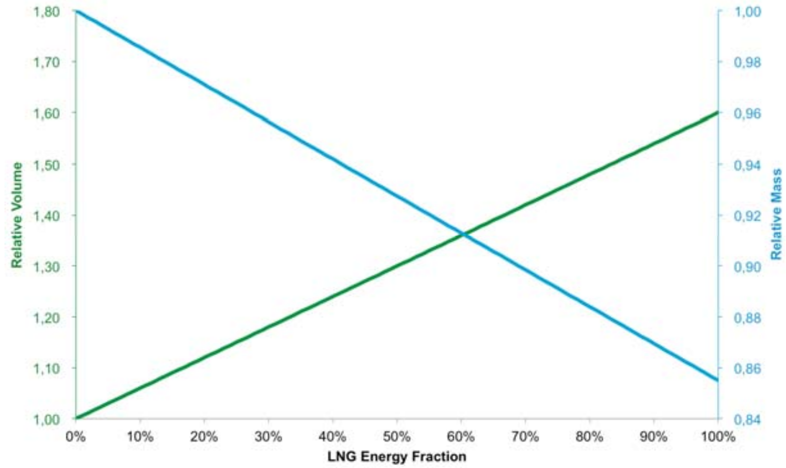
AHEAD
ADVANCED HYBRID ENGINES FOR AIRCRAFT DEVELOPMENT

SEVENTH FRAMEWORK PROGRAMME

http://www.ahead-euproject.eu/

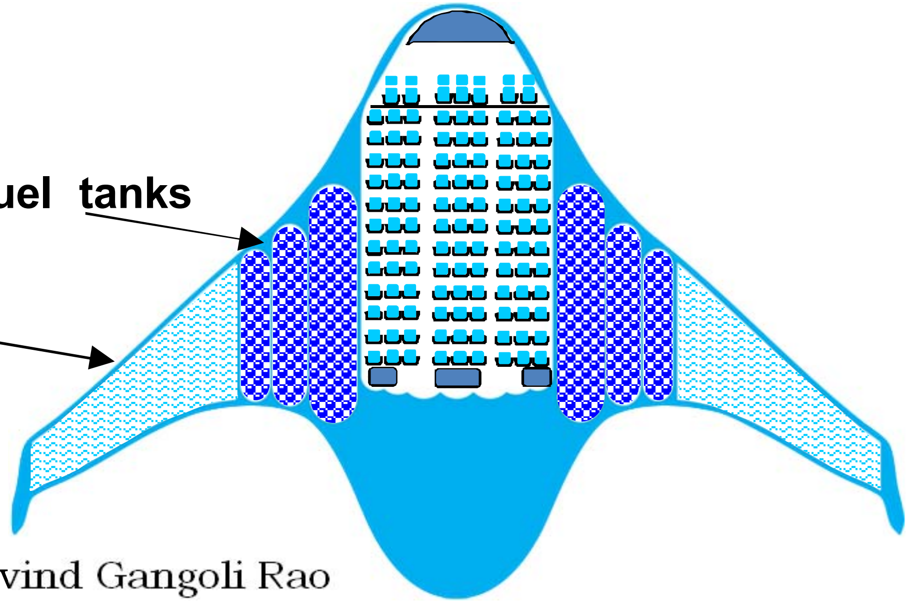
Storing Cryogenic Fuels

Cryoplane



Cryogenic fuel tanks

Kerosene/ Biofuels



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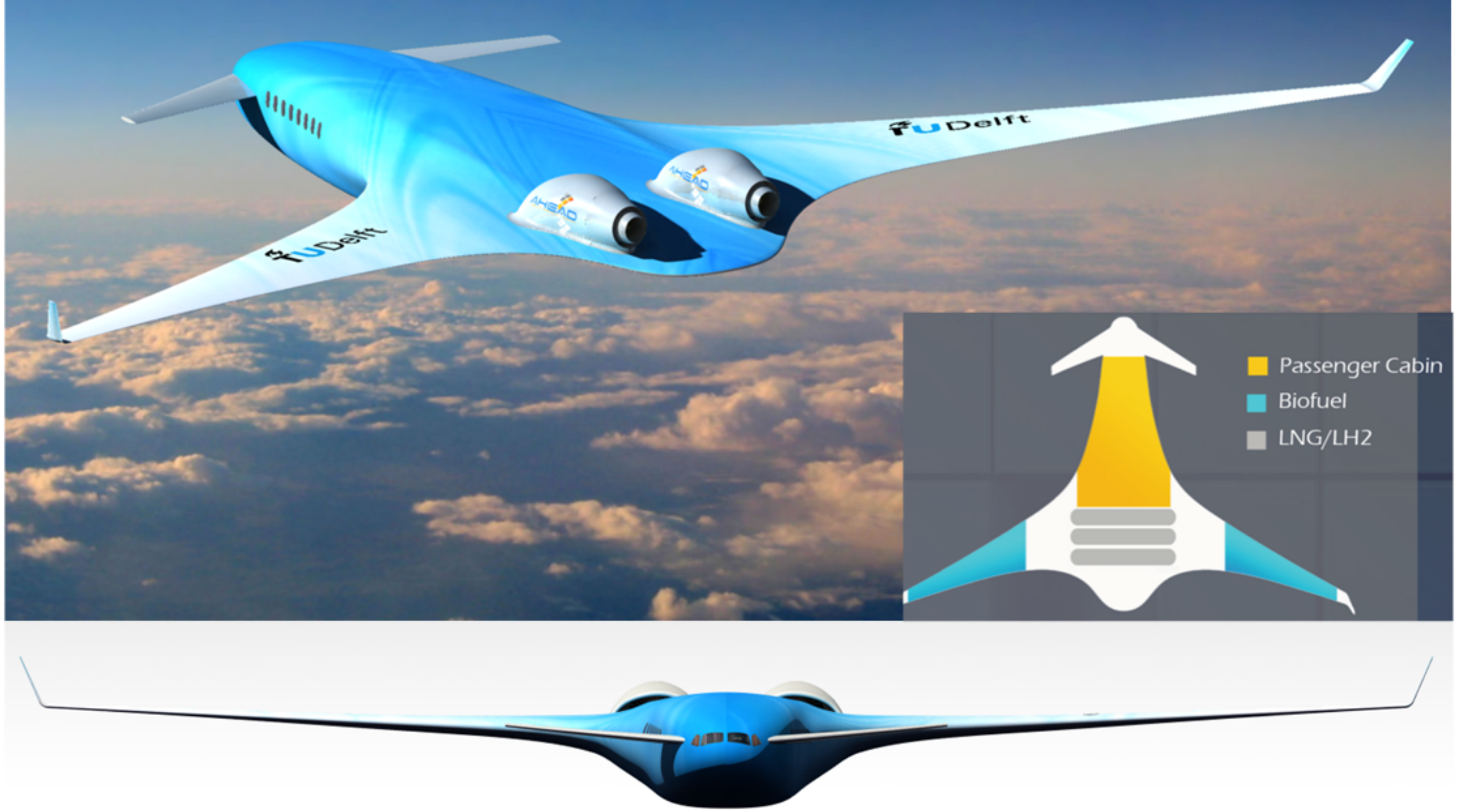
The Multi-Fuel BWB Aircraft

Multi-fuel: Cryogenic (LNG) and Liquid fuel (kerosene/Biofuel)

- **Approx. 300 passengers**
- **Range: 14,000 km**



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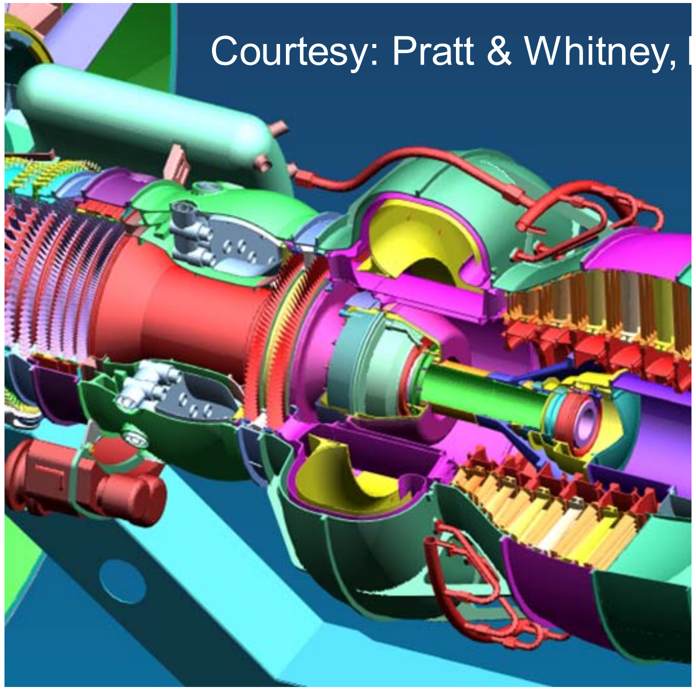
AHEAD
ADVANCED HYBRID ENGINES FOR AIRCRAFT DEVELOPMENT

Hybrid Engine



- LNG/ LH2 Main Combustor
- Inter Turbine Flameless Combustor
- Bleed cooling by LH2/LNG
- Counter rotating shrouded fans

Comparison with Boeing 777-200ER

- LNG used as fuel.
- CO_2 emissions reduced by more than 50%.
- Substantial NOx reduction expected > 80%

Feijia Yin & Arvind Gangoli Rao, “Performance Analysis of an Aero Engine with Interstage Turbine Burner”, *The Aeronautical Journal*, Vol. 121, pp. 1605-1626, 2017.

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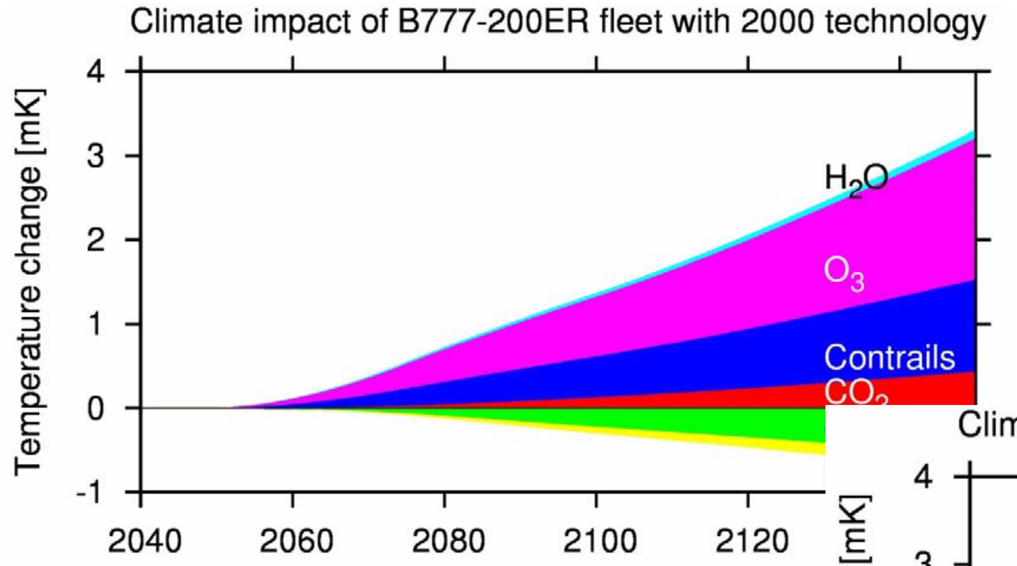
Economic Analysis of the AHEAD aircraft

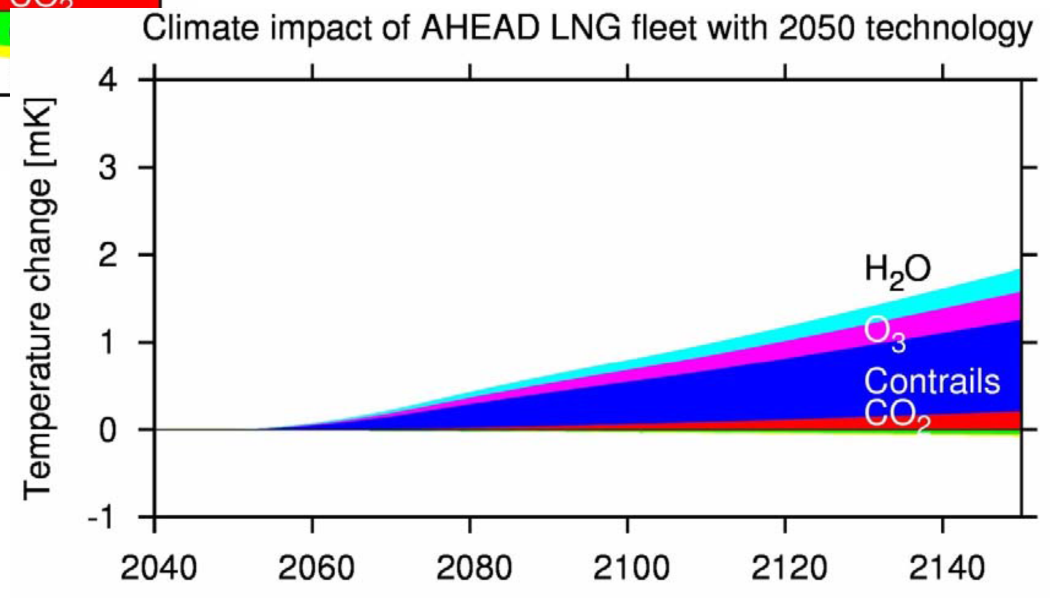
Difference in cost for a trip JFK/HKG:

	CO2 ETS low	CO2 ETS high
B777	€ 175,932	€ 182,654
MF BWB LNG	€ 131,662	€ 134,890
Difference	€ 44,270	€ 47,764
CO2 saving	174.7ton	174.7 ton
CO2 saving in %	52%	52%

Courtesy: Adrian de Graaff, Ad Cuenta

Climate Assessment





V. Grewe, L. Bock, U. Burkhardt, K. Dahlmann, K. Gierens, L. Hüttenhofer, S. Unterstrasser, A. Gangoli Rao, A. Bhat, F.Yin, T. G. Reichel, O. Paschereit and Y. Levy "Assessing the climate impact of the AHEAD multi-fuel blended wing body" *Meteorologische Zeitschrift*, DOI 10.1127/metz/2016/0758

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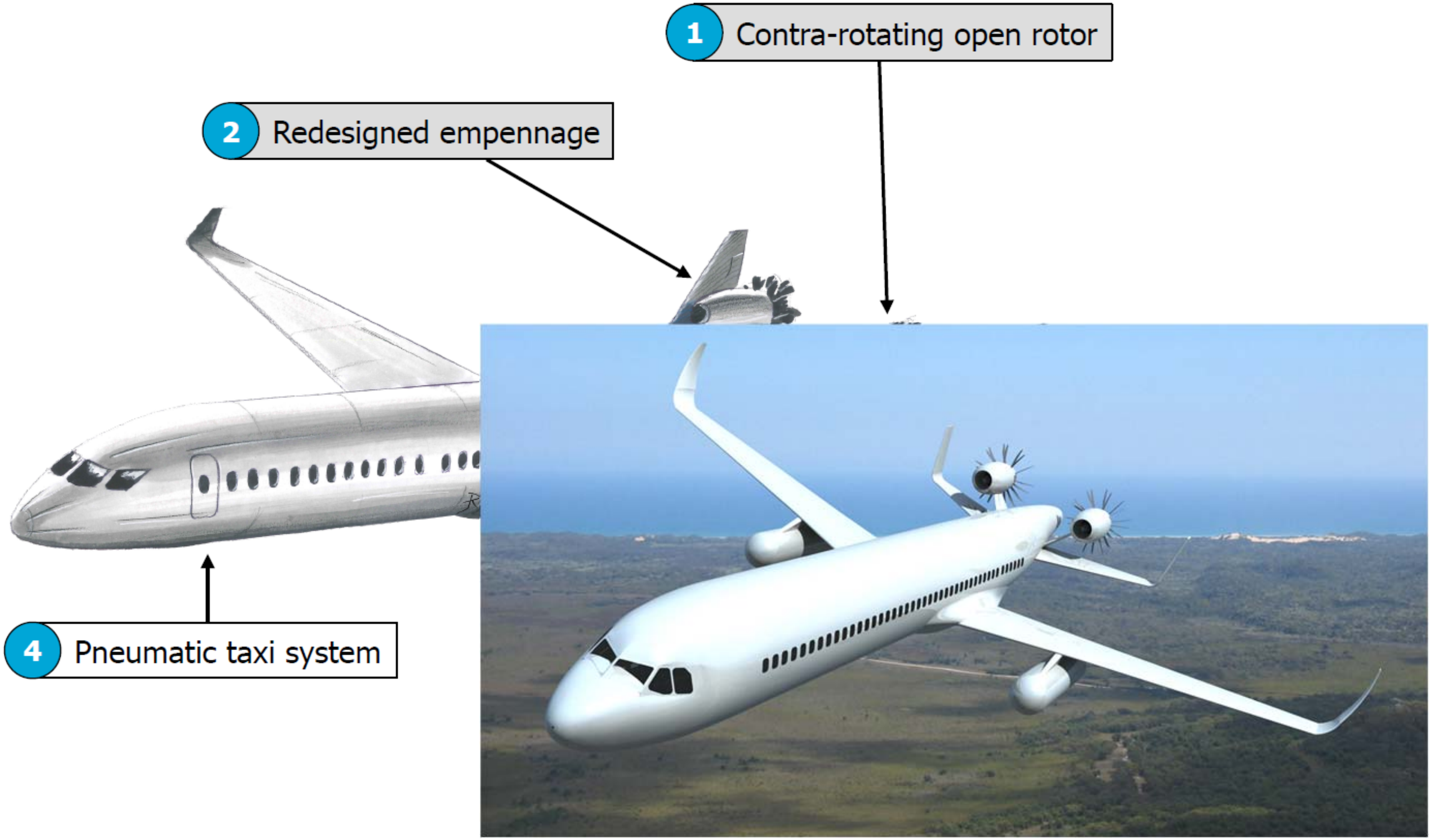
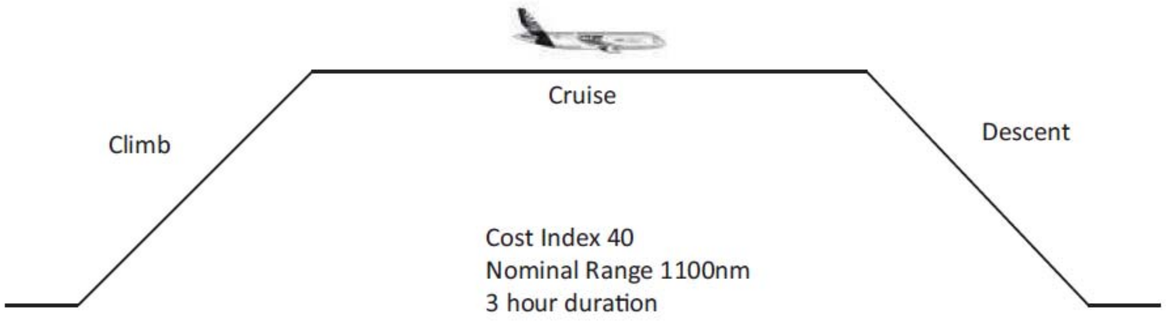
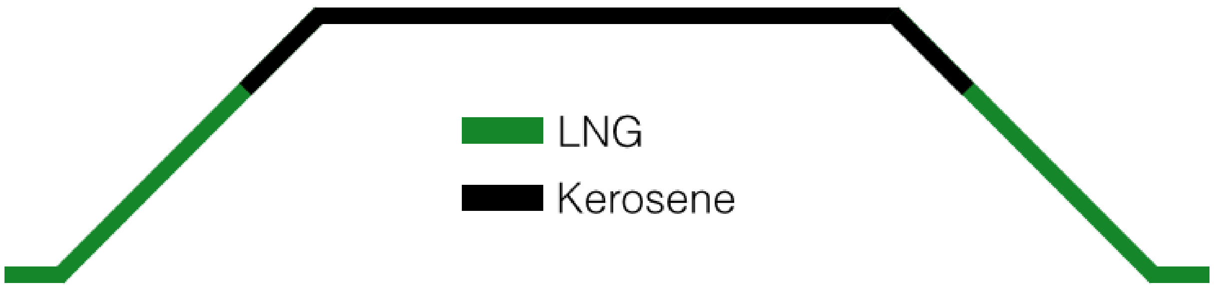
Final Design



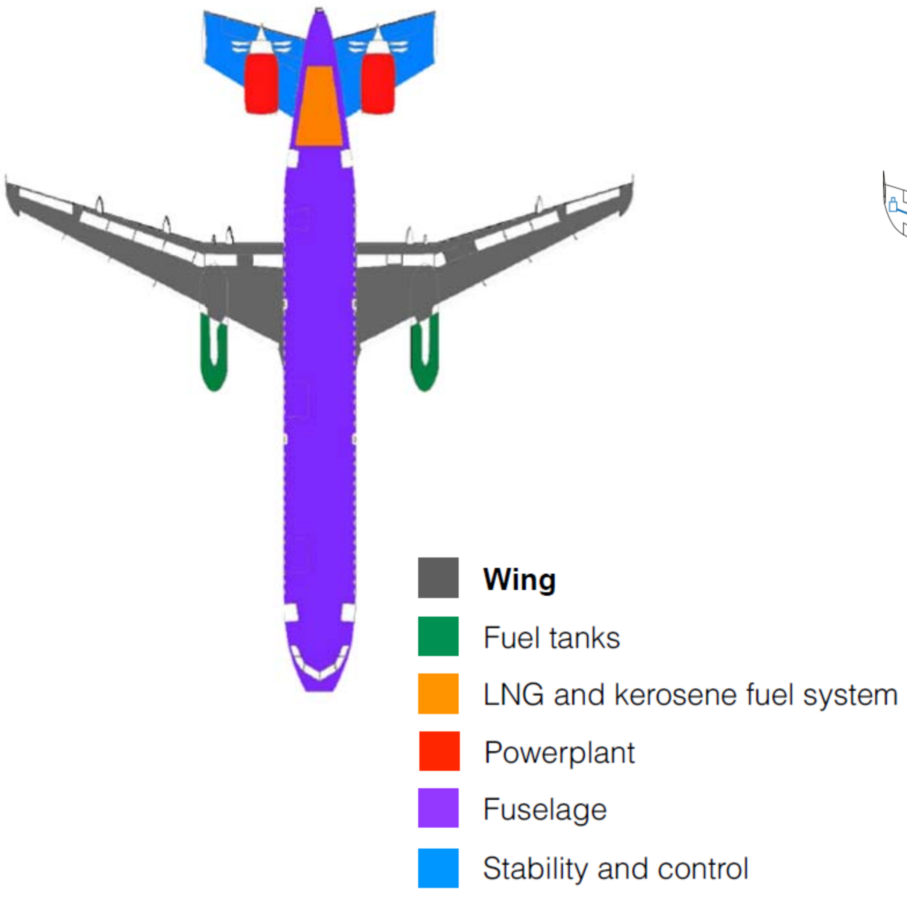
Why A320 with Hybrid Fuel?

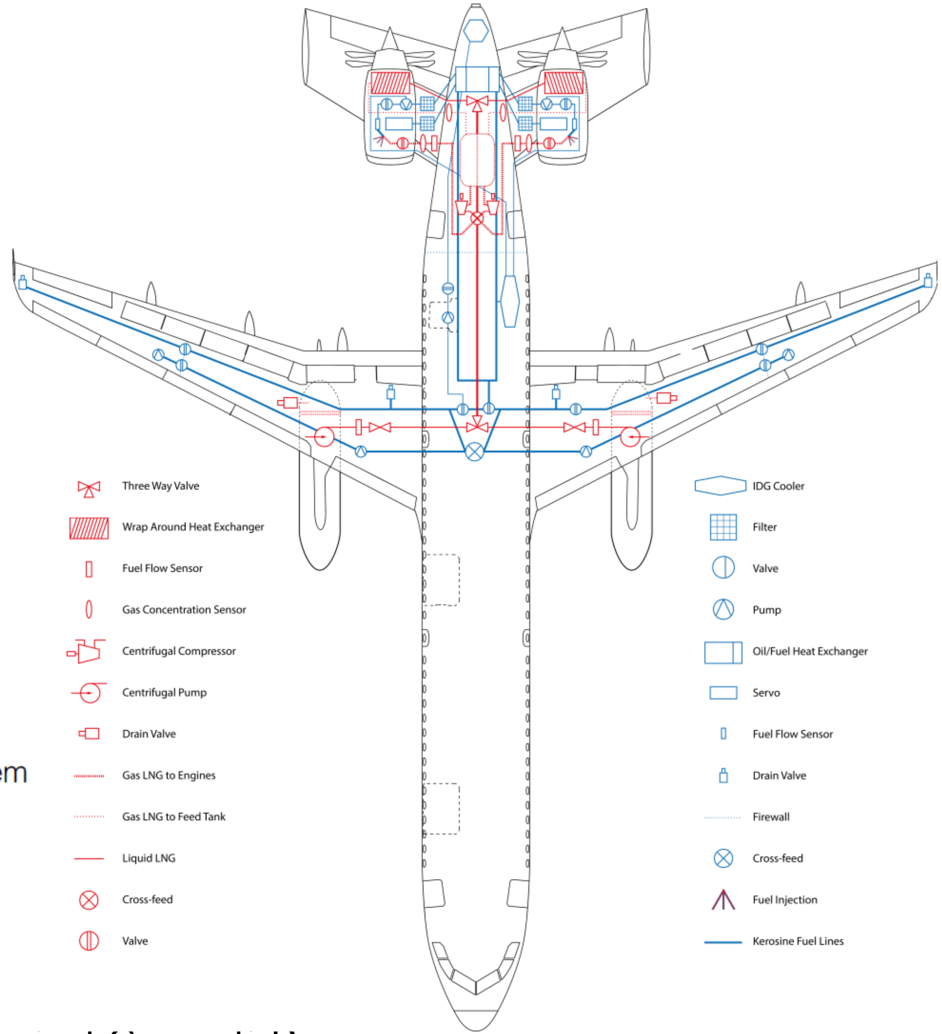


Phase	Fuel Used [kg]	Time	Distance [nm]
Climb	1897 (25%)	23.7 minutes	165
Cruise	5599 (73%)	2 hours 22 minutes	836
Descent	112 (2%)	14.9 minutes	90
Total	7608	3 hours	1091

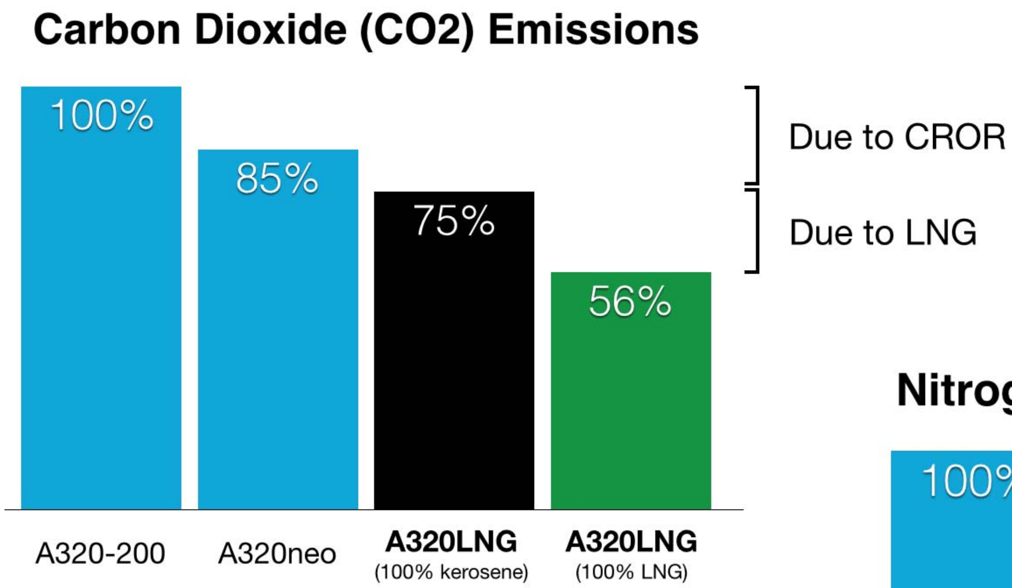


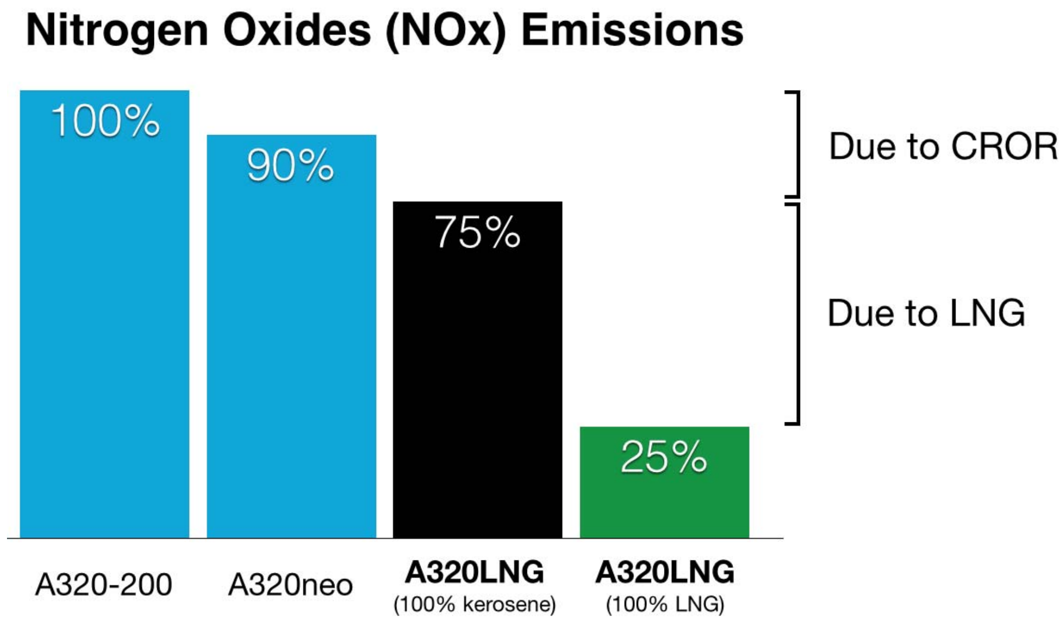
System Design





Comparison with A320





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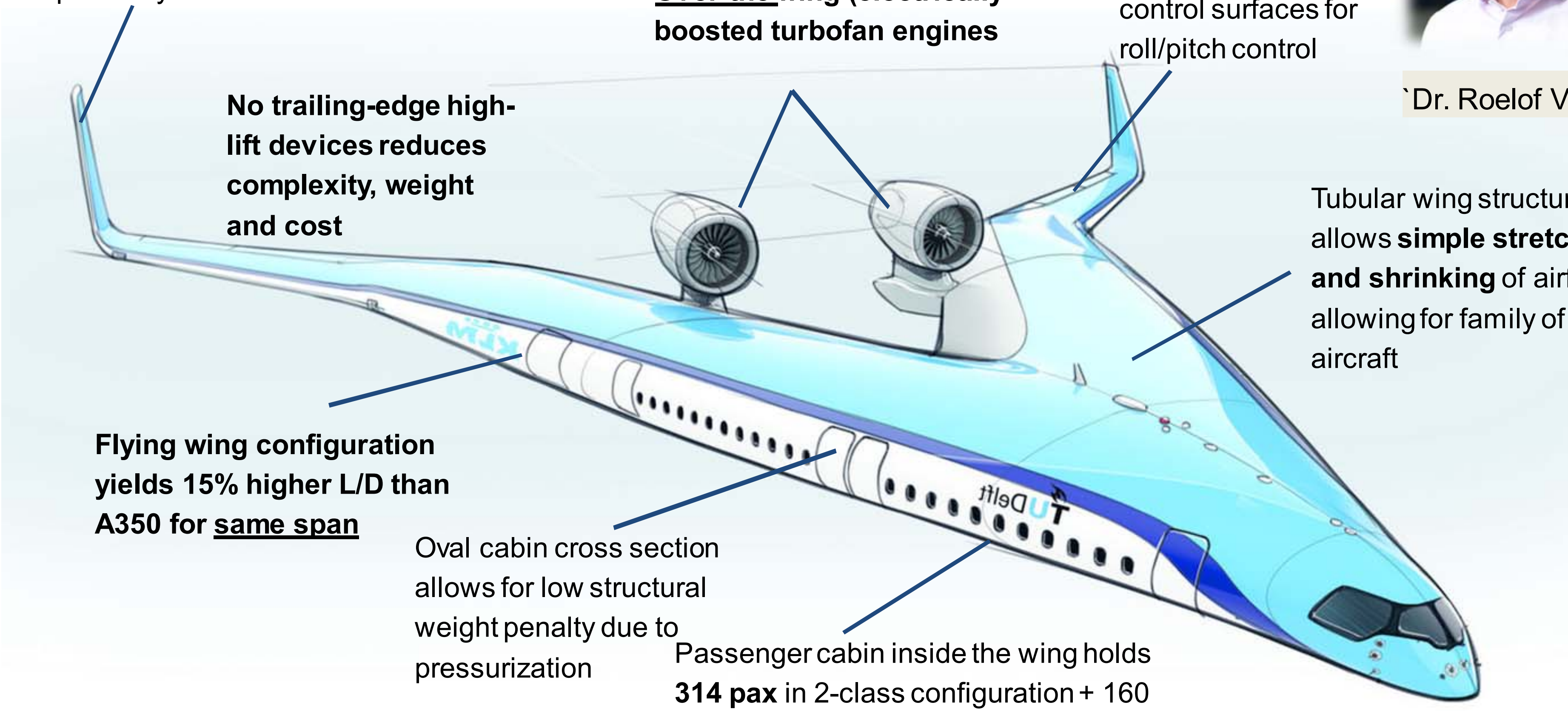
Flying V: Why and How?




`Dr. Roelof Vos

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Points of attention

- Aviation will grow substantially in the next few decades.
- Therefore the emissions from aviation cannot be ignored.
- "Energy Mix" will be the key for future of aviation.
- Life cycle analysis should be looked into carefully before jumping on to a solution.
- The low energy density of batteries limit their application to civil aviation, apart from their LCA footprint.
- The choice of energy source/carrier will be customised to aircraft mission.
- LNG is attractive due to its easy availability, cost and handling qualities
- LNG could be the stepping stone towards using H_2 in aviation

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