

# Energy Transition in Aviation: a possible role for cryogenic fuels

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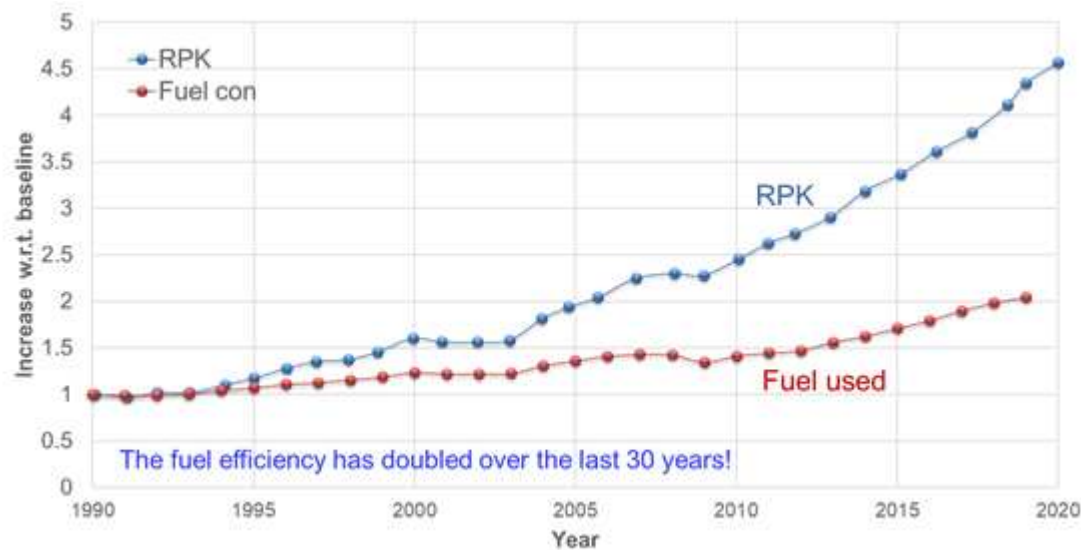
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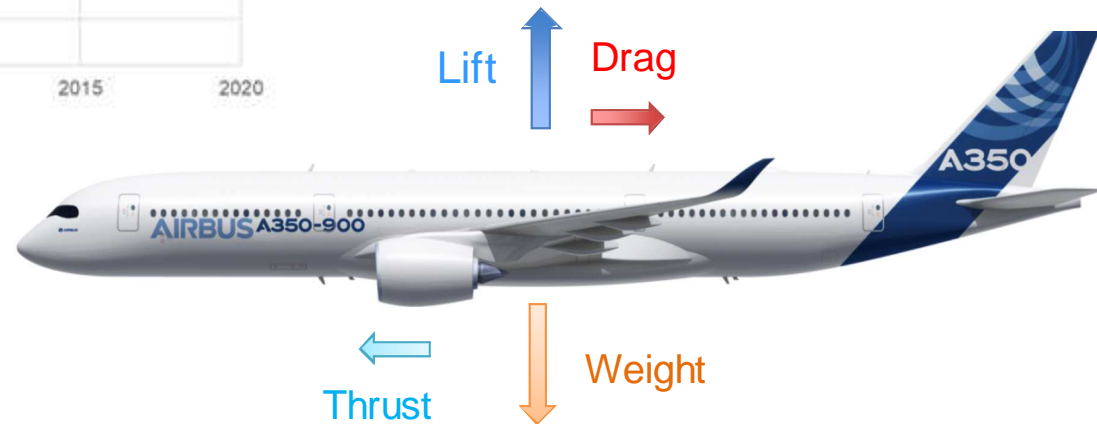
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# How can we make aircraft efficient?



- Reduce weight
- Reduce drag
- Improve engine efficiency
- Increase aircraft occupancy
- Better routing and operations
- New Energy Carriers



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# Evolution of Humans

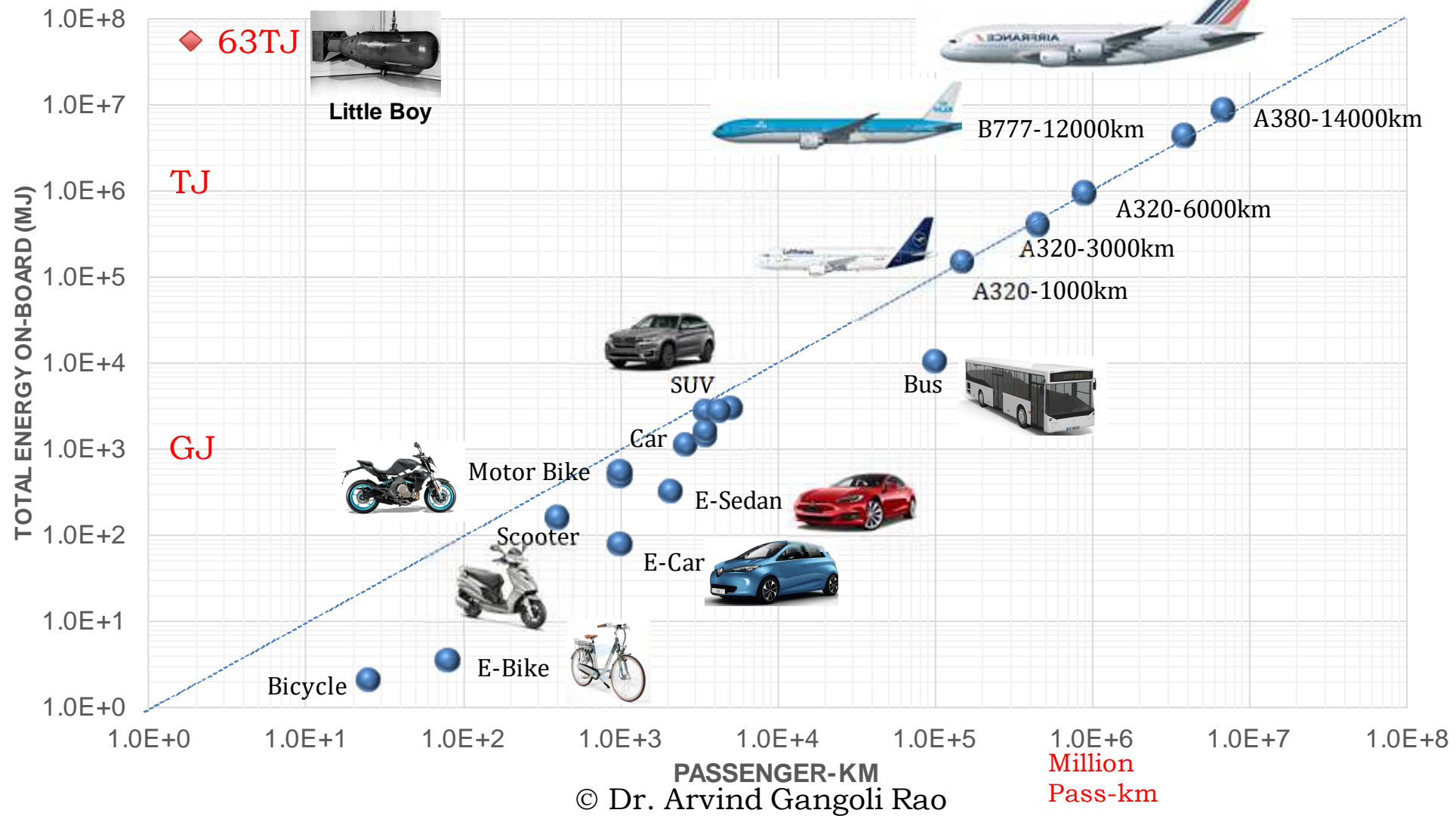


In 2010 Average adult Americans were about one inch taller, but nearly 25 pounds heavier than they were in 1960, according to a new report from the Centers for Disease Control and Prevention (CDC)

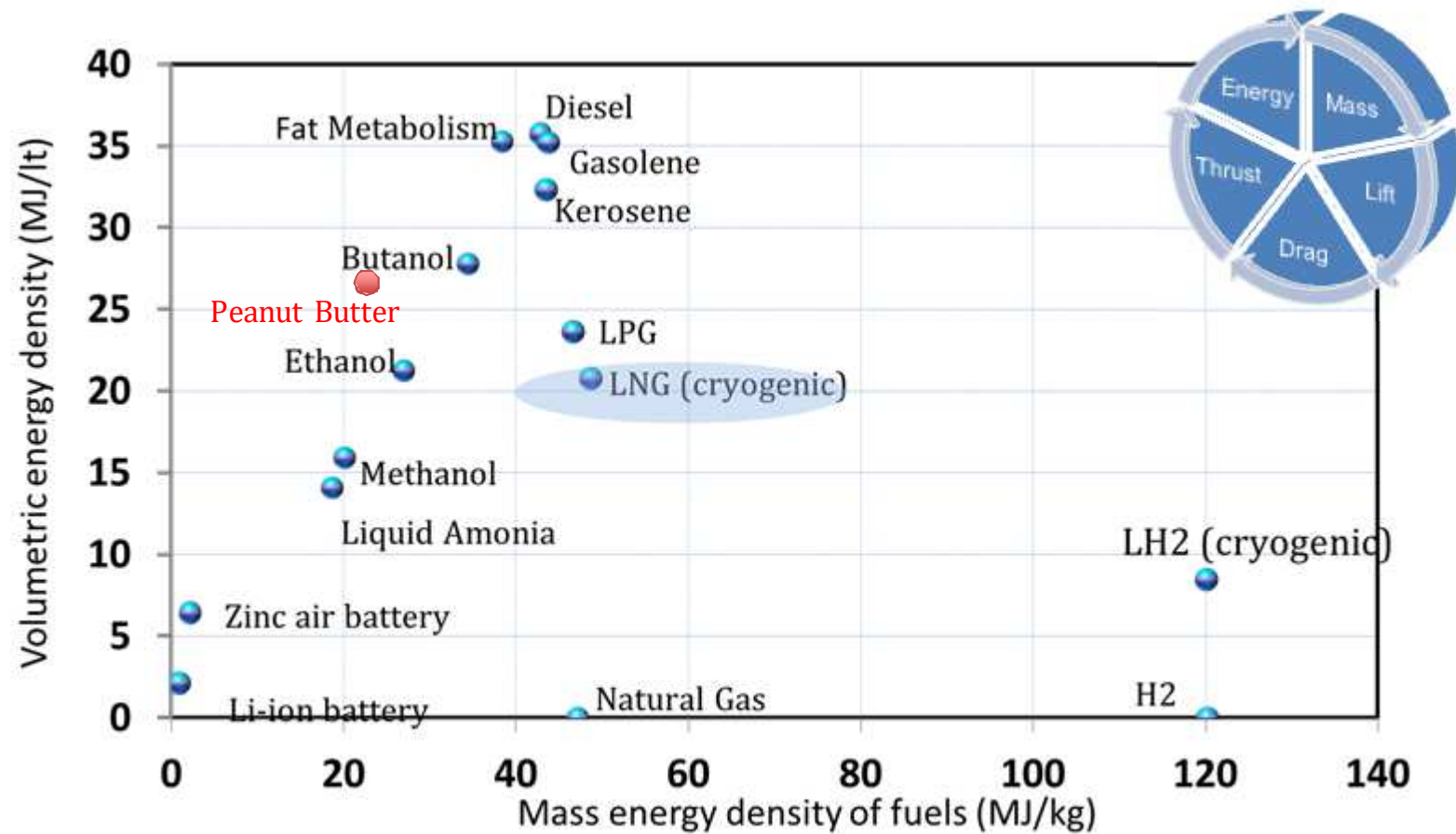


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# Vehicle Energy Requirement












# Energy sources for aviation



“No fuel is cheap when you have to make it yourself” -Prof. G. Eitelberg

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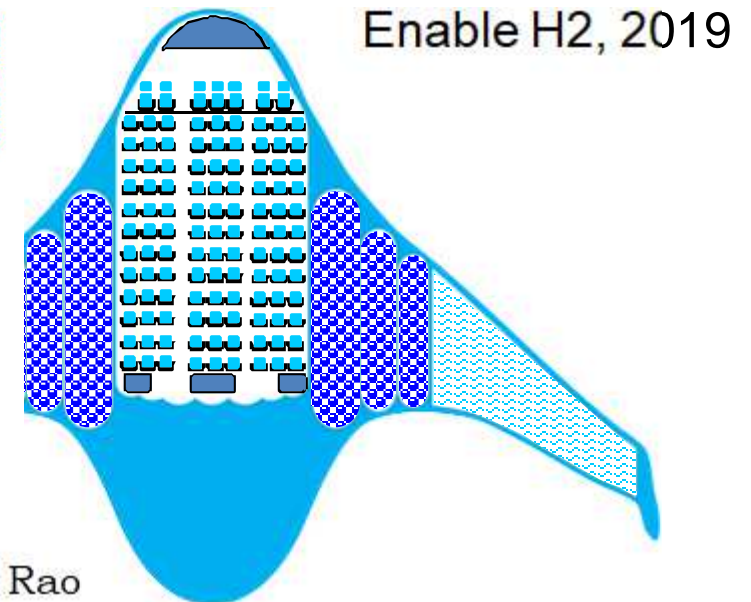
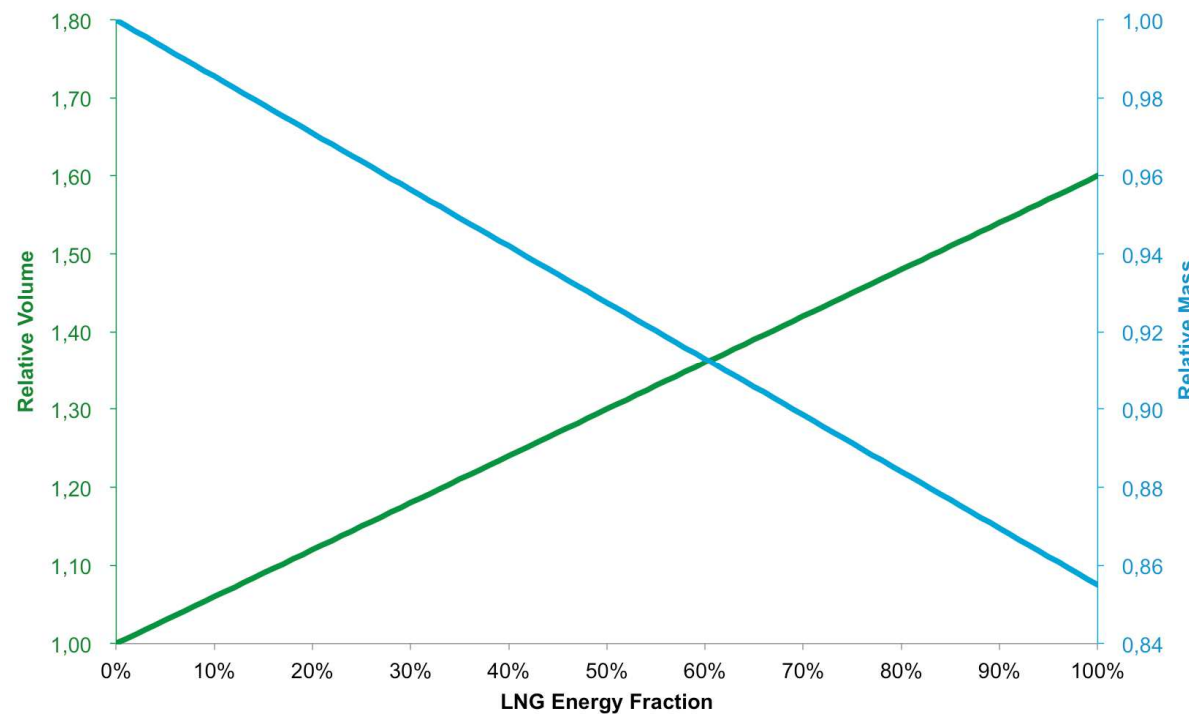
# A Simplistic Overview

	Parameter	Kerosene	Biofuel	Syn-Ker	Batteries	LNG	LH2
	Energy Density	+	+	+	- -	+	++
	Vol. Density	++	++	++	- -	+/-	-
	Emissions	- -	+	+	++	+	+
	Cost	++	-	- -	+	++	-
	Availability	++	-	- -	- -	+	+/-
	Infrastructure	++	-	- -	+/-	+	-
	Safety	+	+	+	-	+/-	- -
	Compatibility	++	++	++	-	+/-	-
	Policy	-	+	+	+	+/-	+

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# Storing Cryogenic Fuels



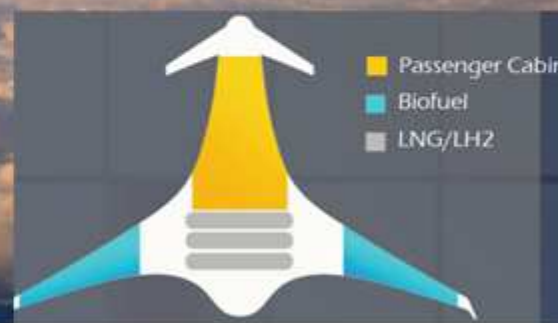
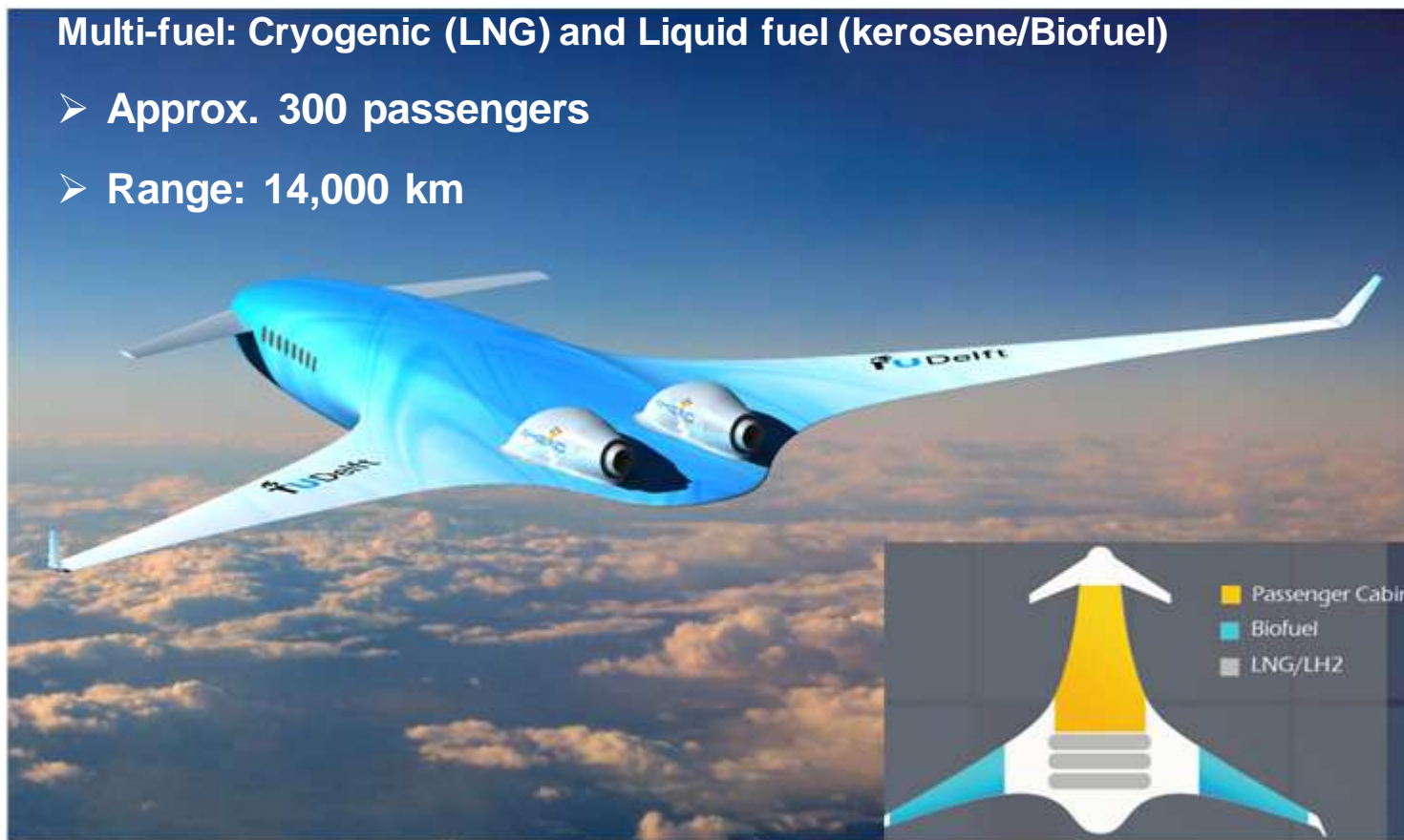
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# The Multi-Fuel BWB Aircraft



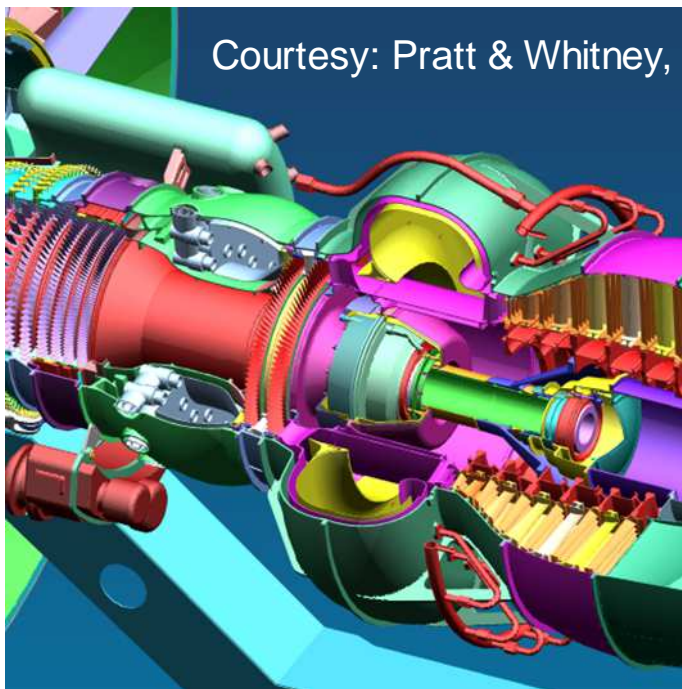
Multi-fuel: Cryogenic (LNG) and Liquid fuel (kerosene/Biofuel)

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





# Hybrid Engine



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



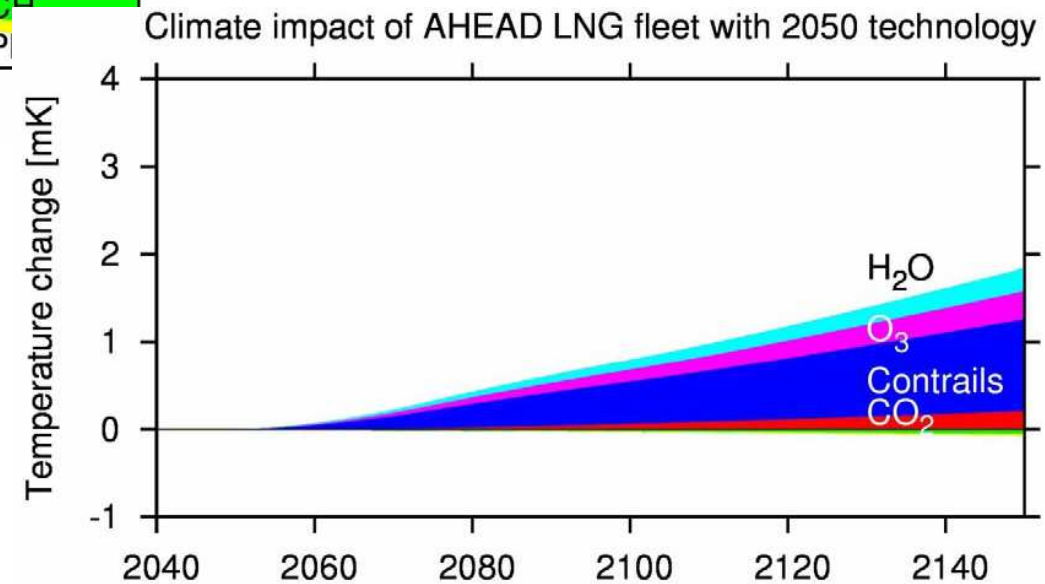
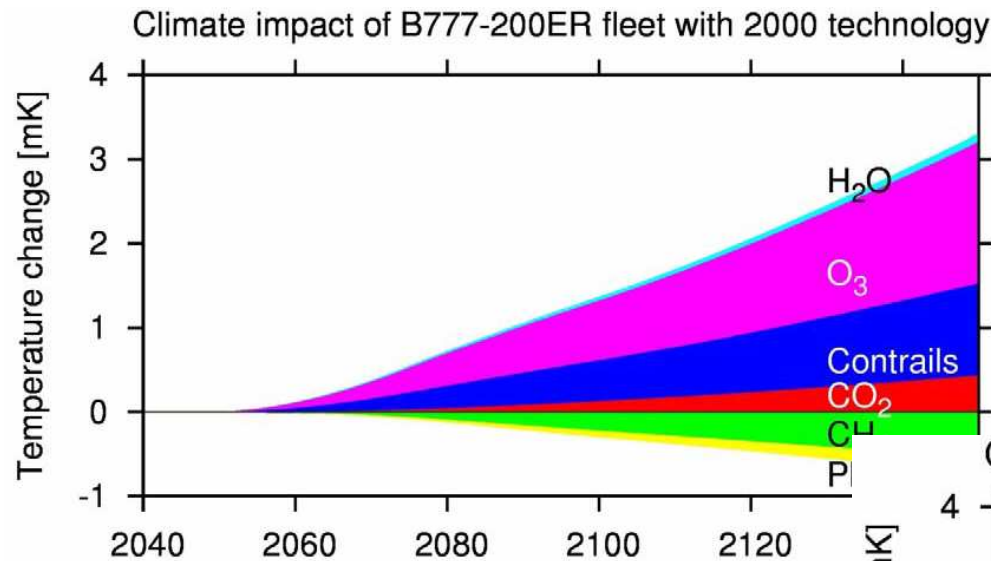
## Comparison with Boeing 777-200ER

- LNG used as fuel.
- CO<sub>2</sub> emissions reduced by around 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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# 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

## Who is going to pay?



**SAF**



**Zero-E,  
Airbus**



400 kg LH<sub>2</sub>   -20% CO<sub>2</sub>   -50% LTO   BLI   160-180   2035   4000 km   Steeper descent



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Global Challenges. Smart Solutions.



Sometimes, evolution is better than revolution





## Points of attention

- Physics is independent of opinions!
- The low energy density of batteries make them useless for civil aviation.
- “Energy Mix” will be the key for future of aviation.
- Life cycle analysis and climate analysis should be looked into carefully before jumping on to a solution.
- Renewable energy is finite, use it carefully!
- “No fuel is cheap when you have to make it your self”.
- The choice of energy source/carrier will be customised to aircraft mission.
- LNG could be the stepping stone towards using  $\text{LH}_2$  in aviation
- Technology cannot be the only solution to mitigate the ill effects of Human Greed!

# Thank You

Prediction is difficult, especially if it is about the future: Niels Bohr



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