SAP

Cigars with wings and sustainable aircraft propulsion

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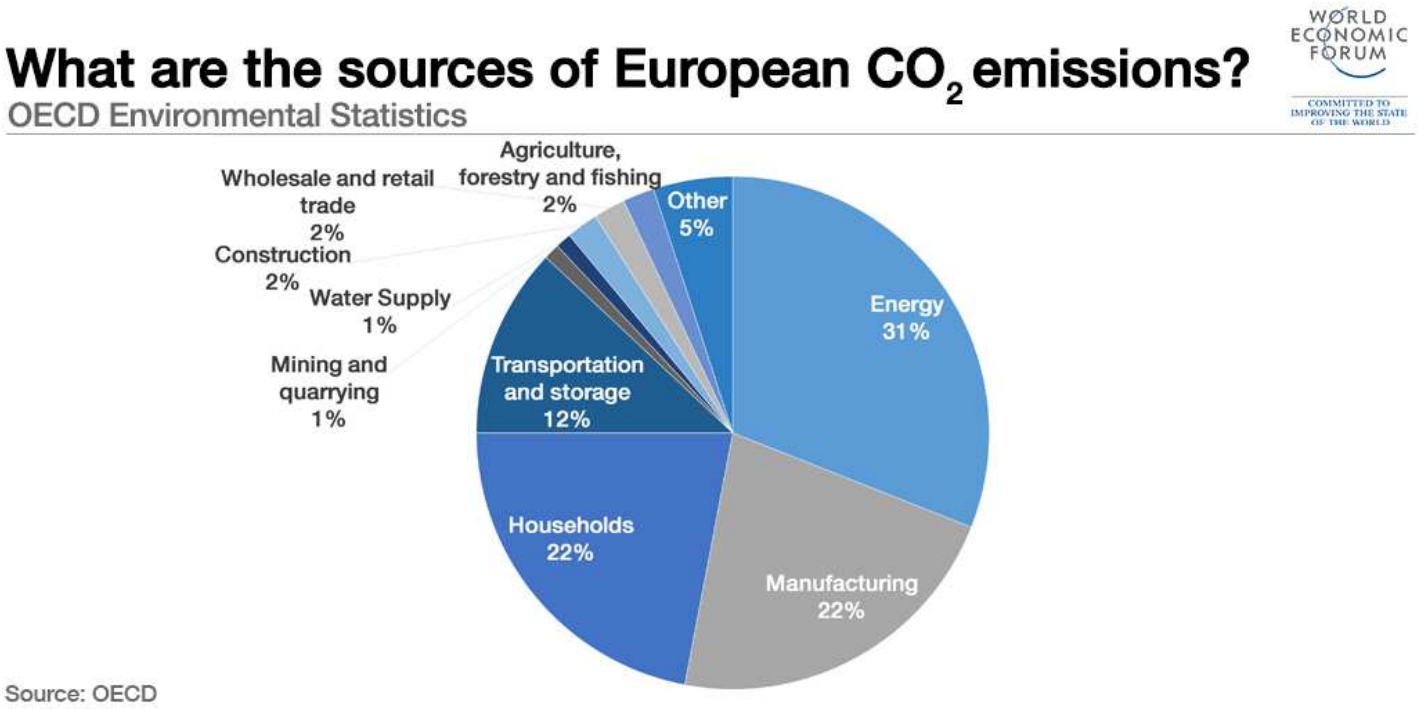
TU Delft

Greenhouse gas emissions



Aviation contributes 2 – 3% of CO2 exhaust, but…

There is more than CO2: Contrails, NOx, Water vapour, Noise, …

But also: Mobility, Efficiency, Escapism ;-), …

Fundamental requirements

The flying cigar

Lift:

$$L = \rho \cdot U_\infty^2 \cdot c_L \cdot S$$

Speed required for load-carrying capacity

c_L limited by $2\pi\alpha$

Drag:

$$D = \rho \cdot U_\infty^2 \cdot c_D \cdot S$$

Drag increases with the square of the speed

Manage the ratio of the characteristics!

Developments in the past

Computed aerodynamic characteristics[11]

Jetliner	cruise L/D	First flight
L1011-100	14.5	Nov 16, 1970
DC-10-40	13.8	Aug 29, 1970
A300-600	15.2	Oct 28, 1972
MD-11	16.1	Jan 10, 1990
B767-200ER	16.1	Sep 26, 1981
A310-300	15.3	Apr 3, 1982
B747-200	15.3	Feb 9, 1969
B747-400	15.5	Apr 29, 1988
B757-200	15.0	Feb 19, 1982
A320-200	16.3	Feb 22, 1987
A330-300	18.1	Nov 2, 1992
A340-200	19.2	Apr 1, 1992
A340-300	19.1	Oct 25, 1991
B777-200	19.3	Jun 12, 1994

Improvement in lift and drag;
Enabled by aerodynamics and structures.

Aerodynamic improvements, Wikipedia

Cigar with wings

The flying cigar

Power requirement

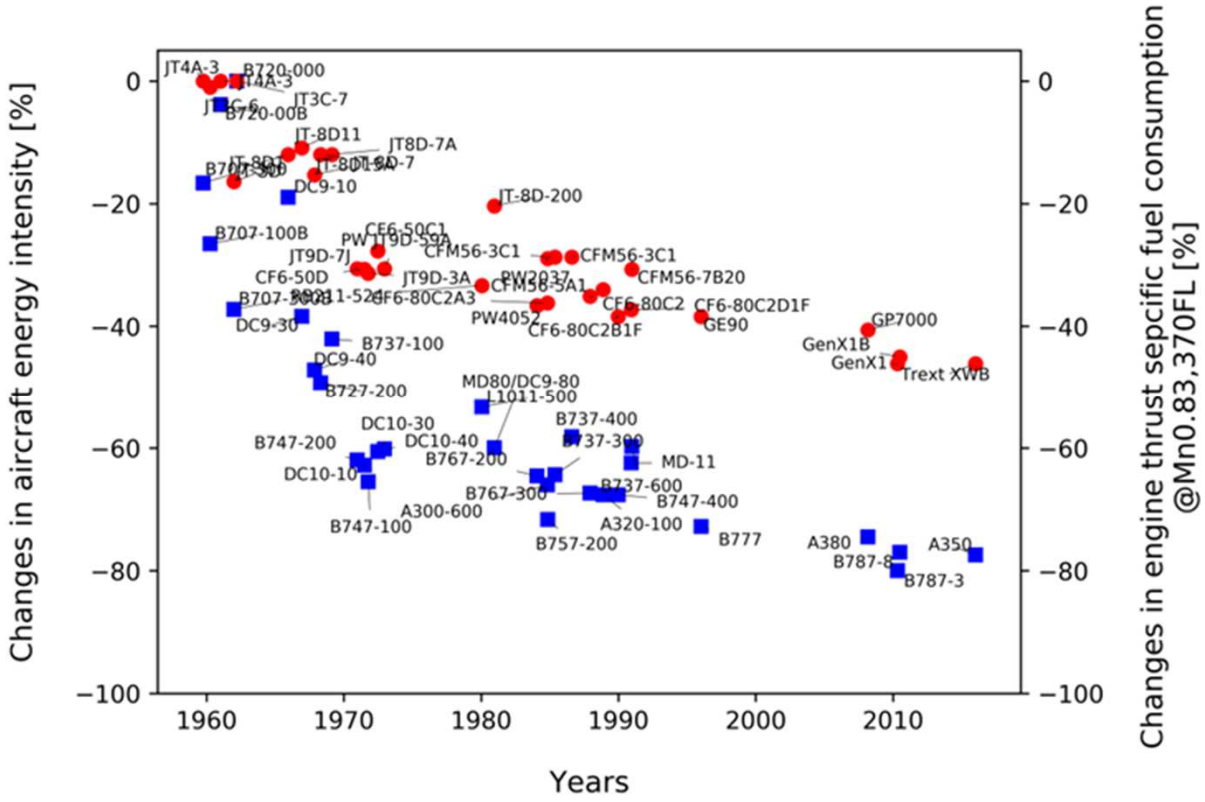
$$P = D \cdot U_\infty$$

Simplifying Assumption:

Thrust required is equal to the drag generated (no interactions!)

➢ T = D

Improvement in performance over the years



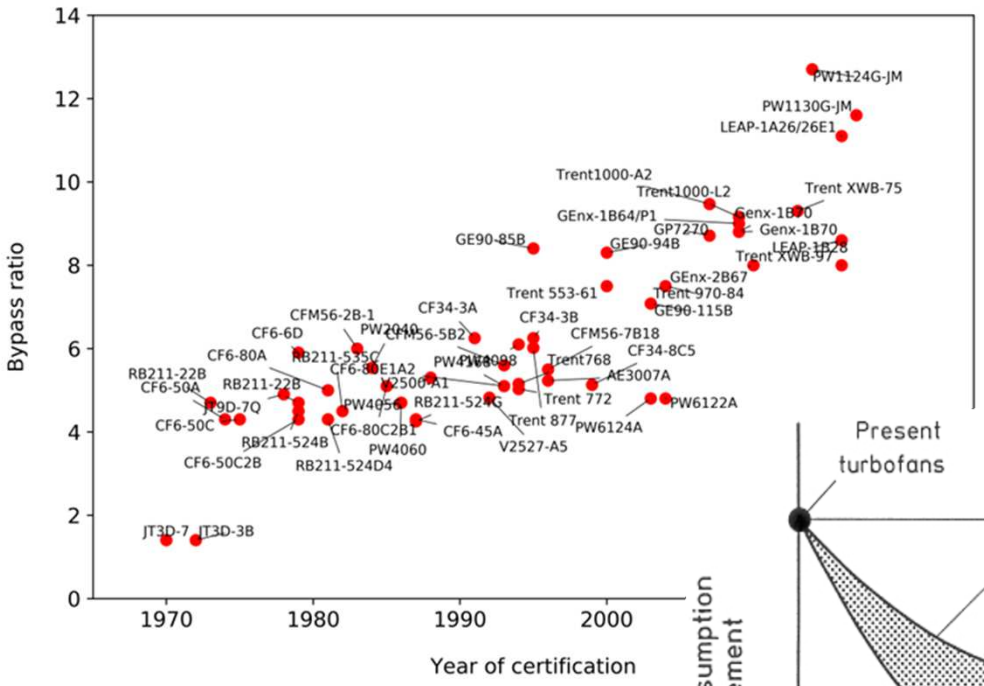
Engine and Aircraft

But:
Time does not heal all wounds.

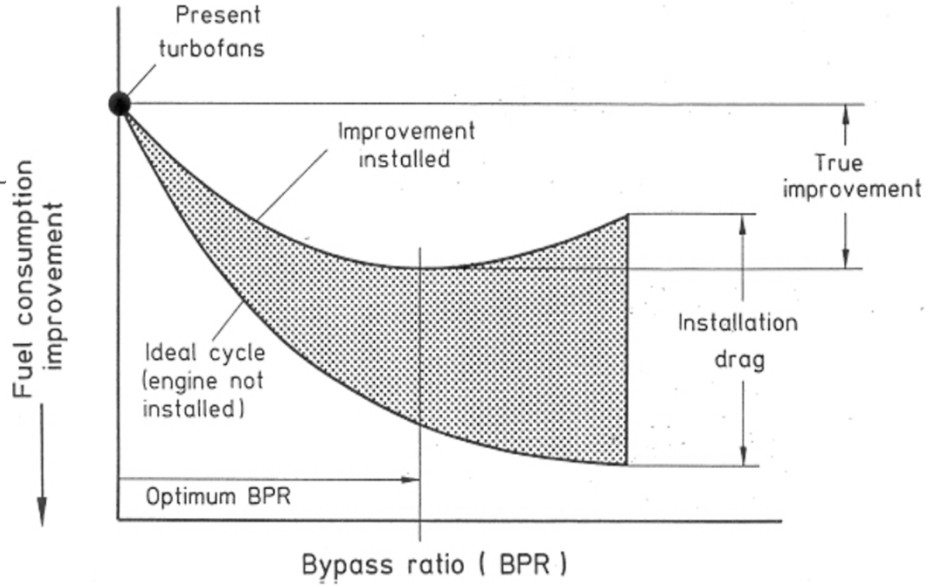
Thrust-specific fuel consumption and efficiency

- $\Pi_1 = \frac{\dot{m}_f}{T} * U_\infty$
  - With $T = \dot{m}_a \cdot (U_{Sl} - U_\infty)$
- $\Pi_1 = \frac{\dot{m}_f}{\rho_{air} U_\infty A \cdot (\frac{\Delta U}{U_\infty})}$
  - ➢ two ways to decrease.
- $\eta = \frac{U_\infty}{1/2(U_\infty + U_{Sl})} = \frac{1}{1 + \frac{\Delta U}{2 \cdot U_\infty}}$
  - ➢ only one beneficial.

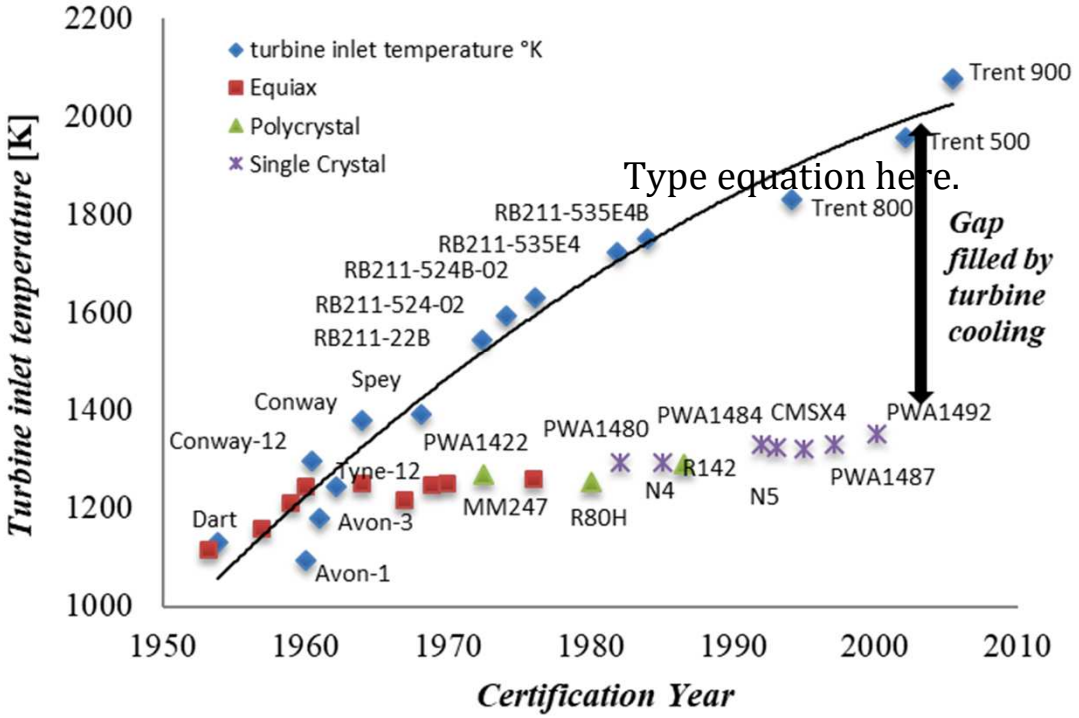
Development for the A/C already ordered



Benefit and pain



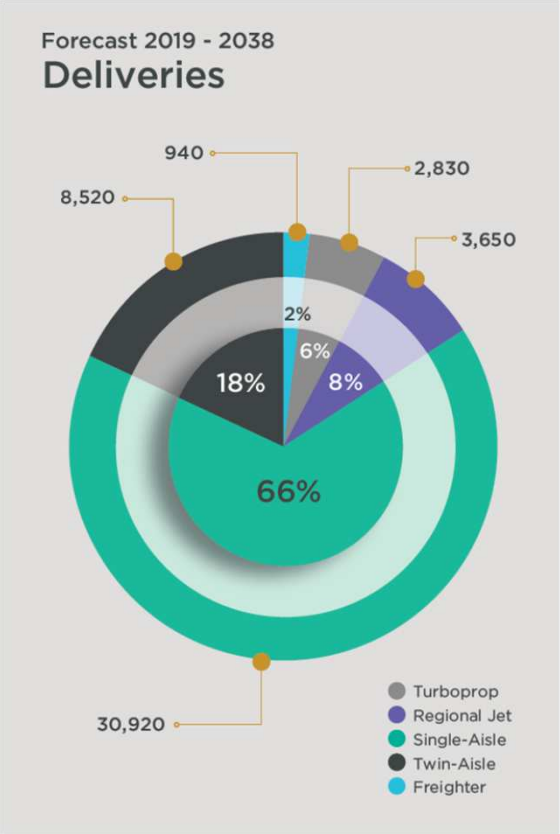
Developments in the past



Carnot: $\eta = \frac{T_i - T_o}{T_i}$

Gas turbine entrance temperature for increased thermal efficiency.
Note the importance of cooling of the structures

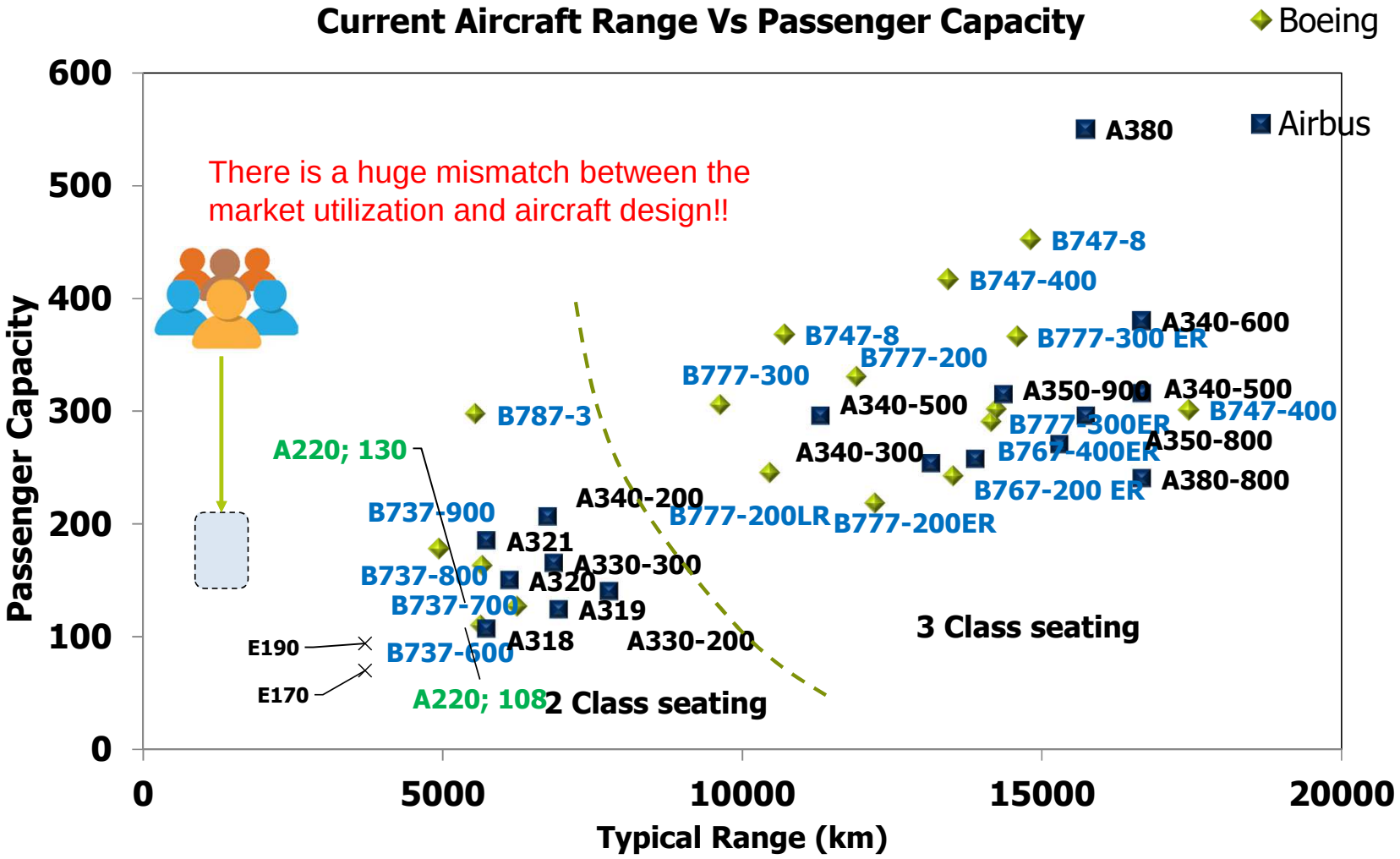
Developments in the future



- Of the total 66%+18% = 84% are large commercial civil transport aircraft.
- Approximately 15 000 are already ordered.
- At approximately 0.1 G€ per aircraft, 4T€ is a considerable amount.
- The rest is not a door opener.

Flight Global

Aircraft Seat & Range



Alternative shapes and engine integration?

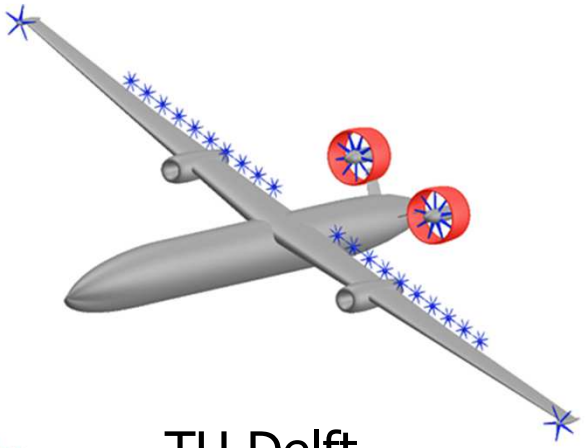
Figure 1. Conceptual illustration of fuel-efficient aircraft, including the truss-braced wing configuration (right), hybrid wing body configuration (center), and double-bubble configuration (left). Image credit: NASA.

Not among the 15 000 aircraft already ordered.

TUD

Propulsion concepts
Distributed propulsion

NASA



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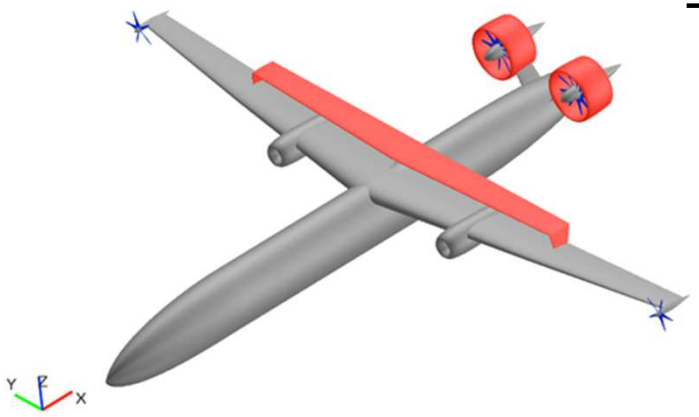
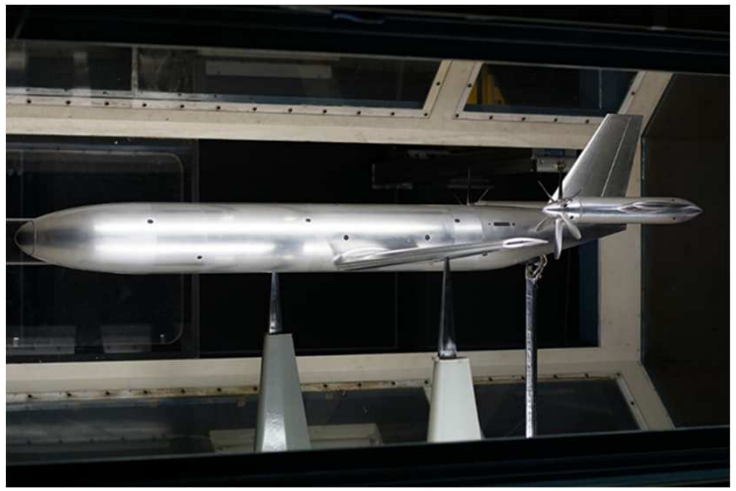


Open or shrouded?

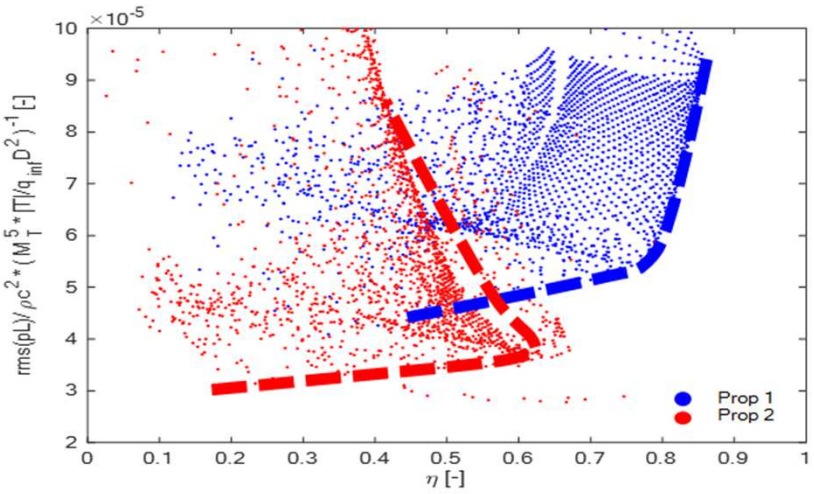
Return of the turboprops?

Currently about 6% in numbers of A/C



- Large propellers
- High propulsive efficiency
- Low weight
  - ➢ But …noise

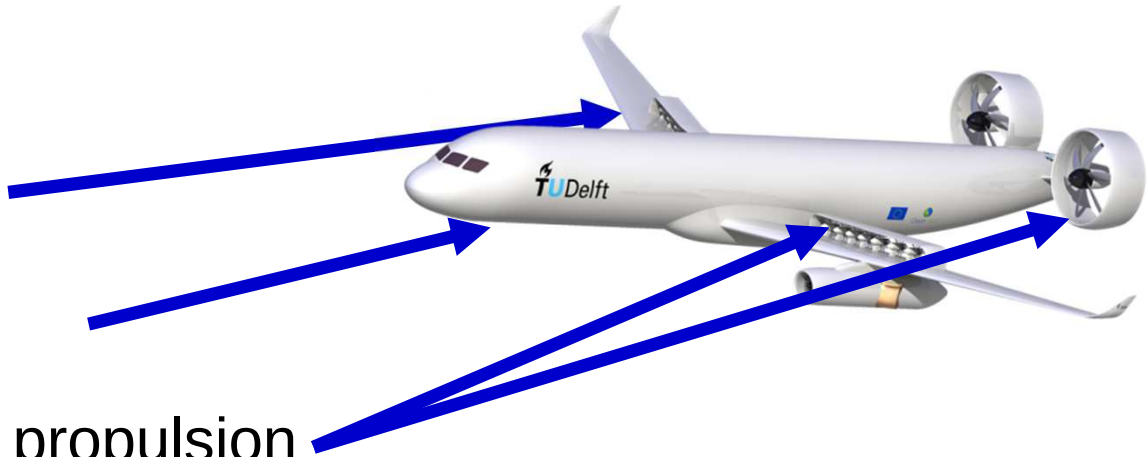
Thrust specific noise of propellers



Speculation about the price in noise
To be paid for fuel efficiency

Propulsion concepts
Hybrid electric

- Flexible drivetrain
- Innovative designs
- Distributed electric propulsion
- ***Boundary layer ingestion (BLI)***

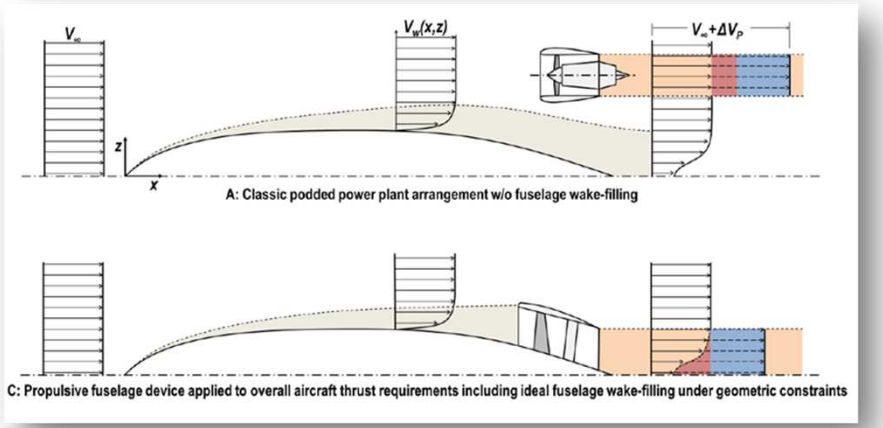


NOVAIR Project

Propulsion concepts

Engines in the wake or BL

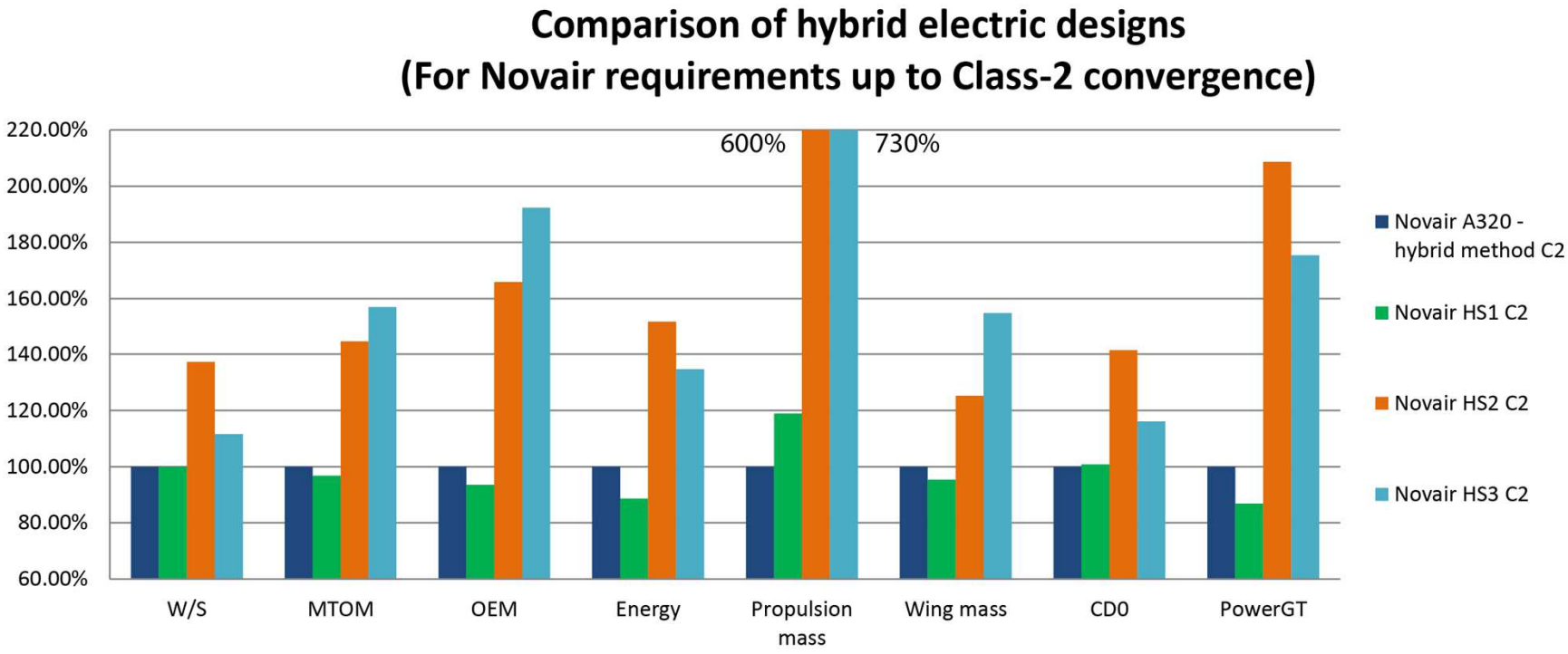
"Using momentum before it is dissipated"



Centreline – an EU research project

Baron von Munchhausen – a German fable

Evaluation of hybrid electric propulsion
Augmentation and distribution

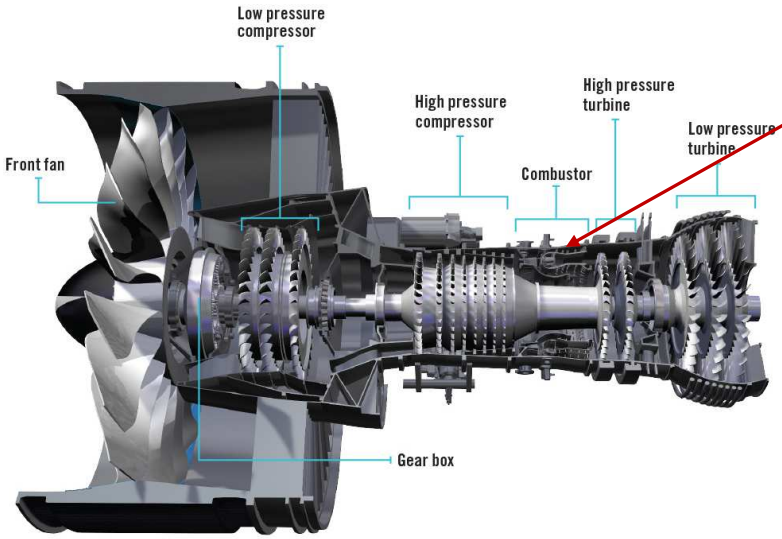


Only the boosted turbofan HS1 promises overall benefits

Back to the engines

Pratt & Whitney geared turbofan

A geared turbofan engine has a gearbox between the front fan and the shaft to the engine core, so that the speed of the front fan can be decoupled from the speed of the core. This way, the engine can safely drive a larger fan and push a larger volume of air, while the low-pressure compressor and turbine blades spin faster, boosting fuel efficiency.



Where is the fuel being burnt?

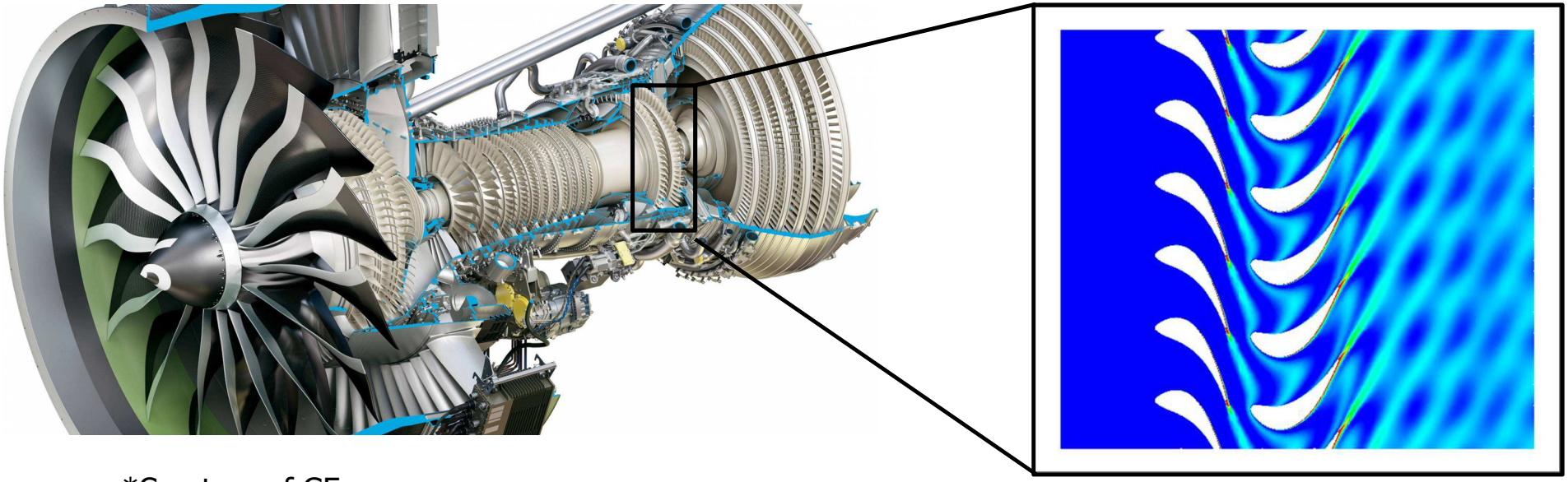
Rotating parts.

https://1l0044267psh26mr7fa57m09-wpengine.netdna-ssl.com/wp-content/uploads/2018/09/GTF-illo.jpg

Multi-row Interactions

Goal: Automated design of multi-row with unsteady flow models

Applications: LP/HP compressors/turbines



*Courtesy of GE

M. Pini

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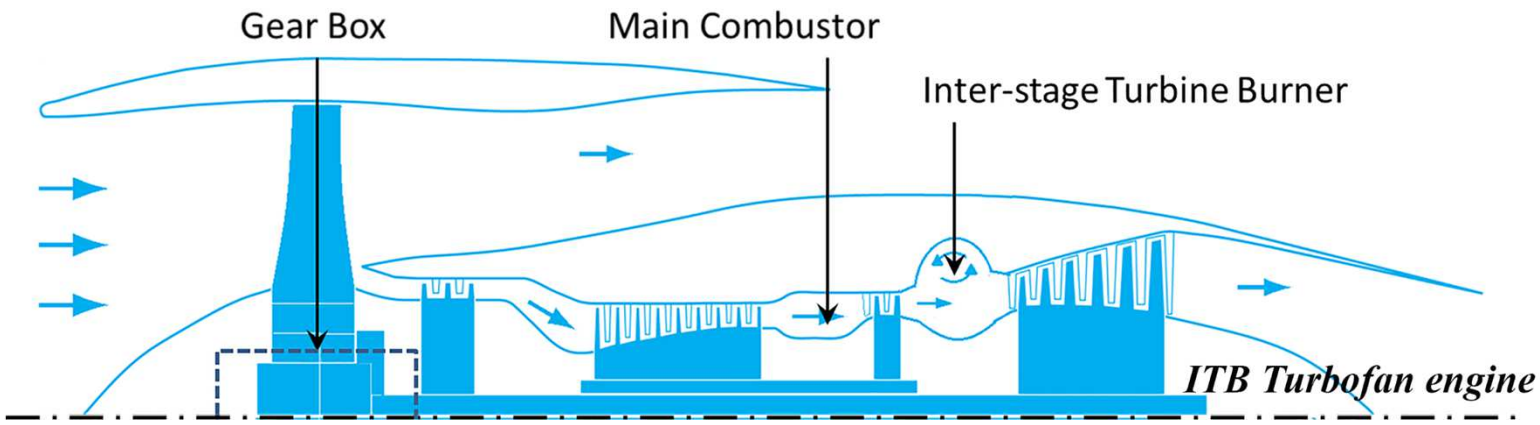
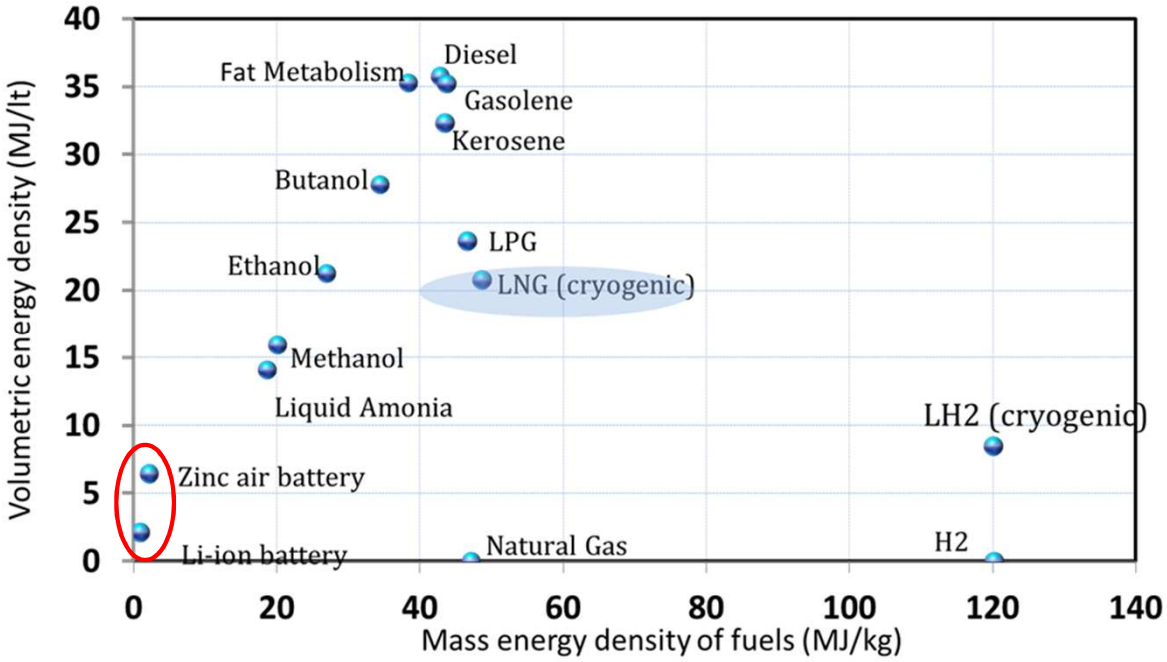
Propulsion & Power

Multiple combustion stages?



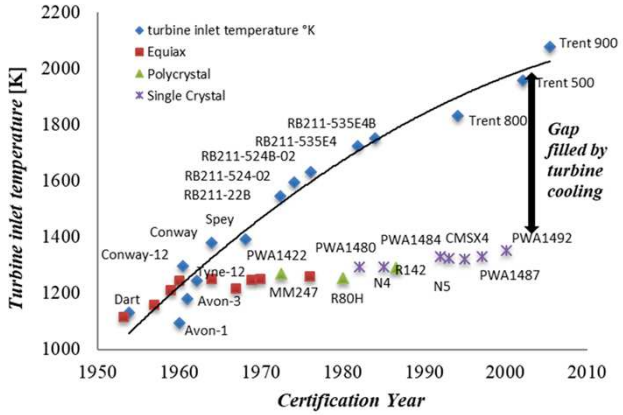
Where can we go from here?



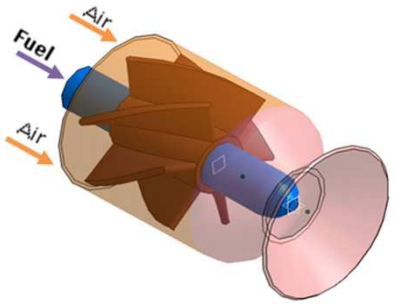
Choice of fuel

Can we find a
"thin end of the wedge"?

Mixing fuels?



Recall the increased temperature trend!

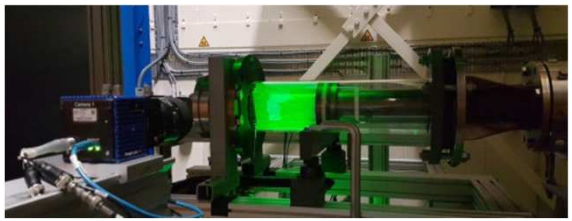


$CO + O_2 \rightarrow CO_2 + O$ (Initiation)

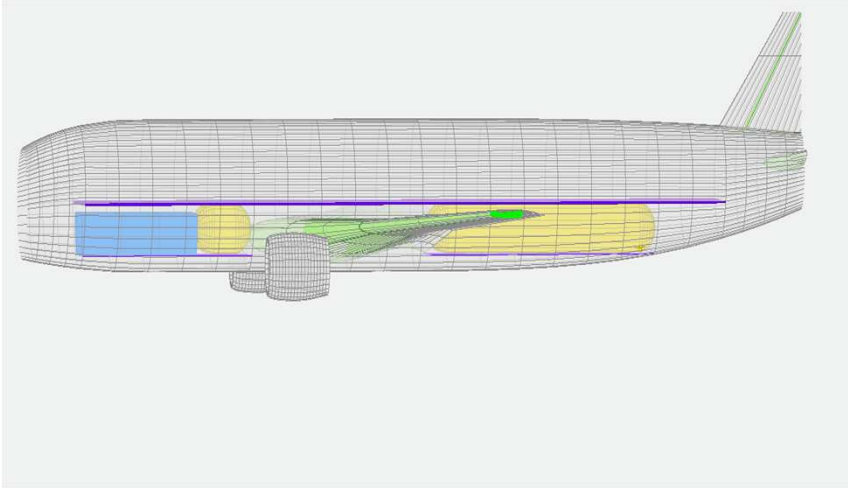
$O + H_2O \rightarrow OH + OH$ (branching)

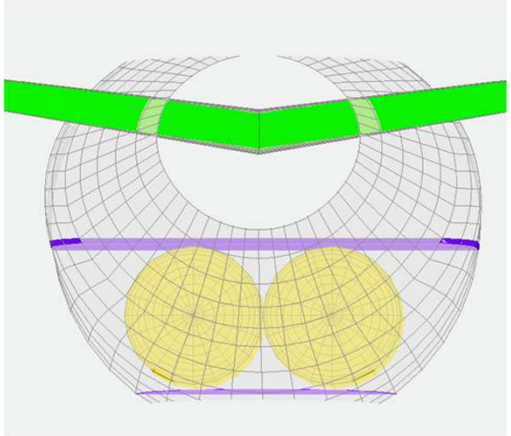
$CO + OH \rightarrow CO2 + H$ (propagation)

$H + O2 \rightarrow O + OH$ (propagation)



Room for alternative fuels, even cryogenized





Combustion chamber and combustion stability

Quality of combustion just as important as the increased temperature.

"Entropy and vorticity wave generation in realistic gas turbine combustors"
Bernhard Semlitsch, Tom Hynes, Ivan Langella, N. Swaminathan and A.P. Dowling

Summary/conclusions

- Hybrid fuels
  - Electric
  - Hydrogen
  - LNG

    Can be used for local optimization, i.e. keeping the airport surroundings clean.
- For long range, the chemically bonded carbohydrates are the clear favourite in terms of energy usage.
- No fuel is cheap, if you have to make it yourself.
- Enforce local cleaning as a thin end of the wedge!

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