An Economic Analysis of Non-fossil Energy Carriers in Aviation

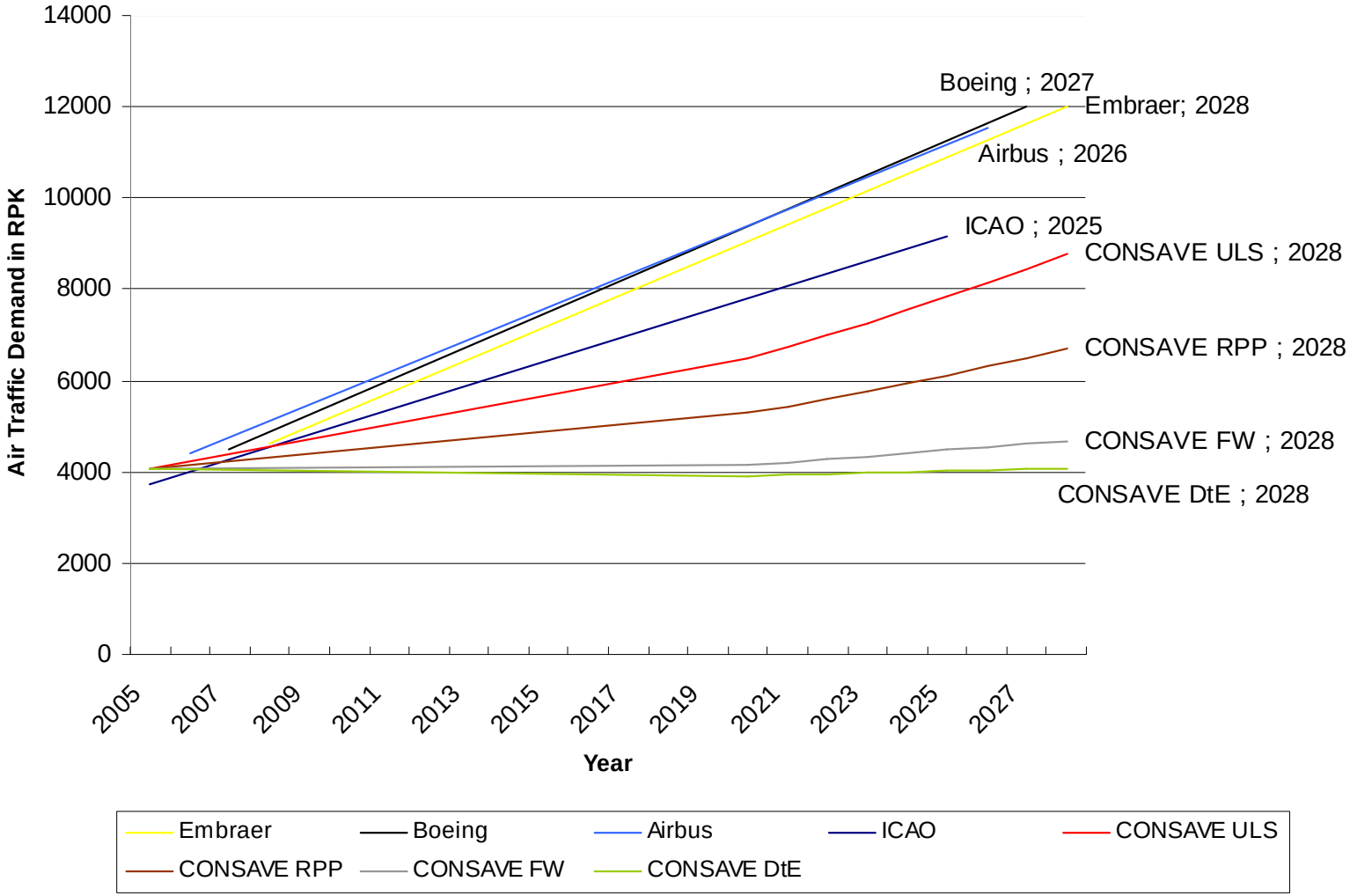
Context

- Summer 2008
  - oil prices
  - extensive press coverage of test flights with new fuels
- Environmental policies e.g. EU-ETS or blending of fuel for ground transportation

Content

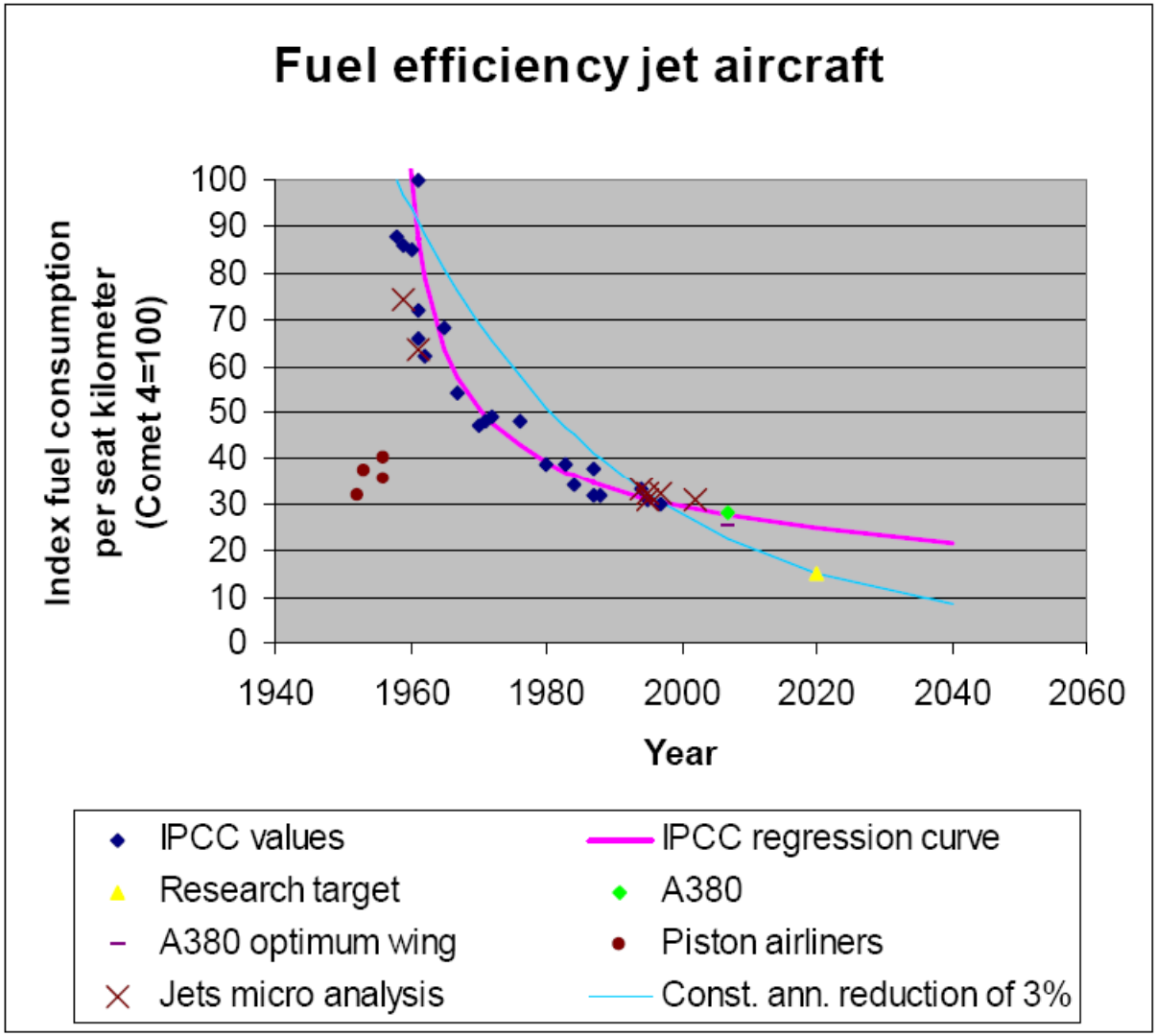
- Market determinants
  - Air traffic development
  - Fuel efficiency trends
  - Crude oil price
- Political determinants
- Possible new non-fossil energy carriers
  - Biofuels with jet-fuel properties
  - Alcohols
  - Cryogenic fuels
  - Electricity
  - Nuclear energy carriers

Market Determinant Air Traffic Development



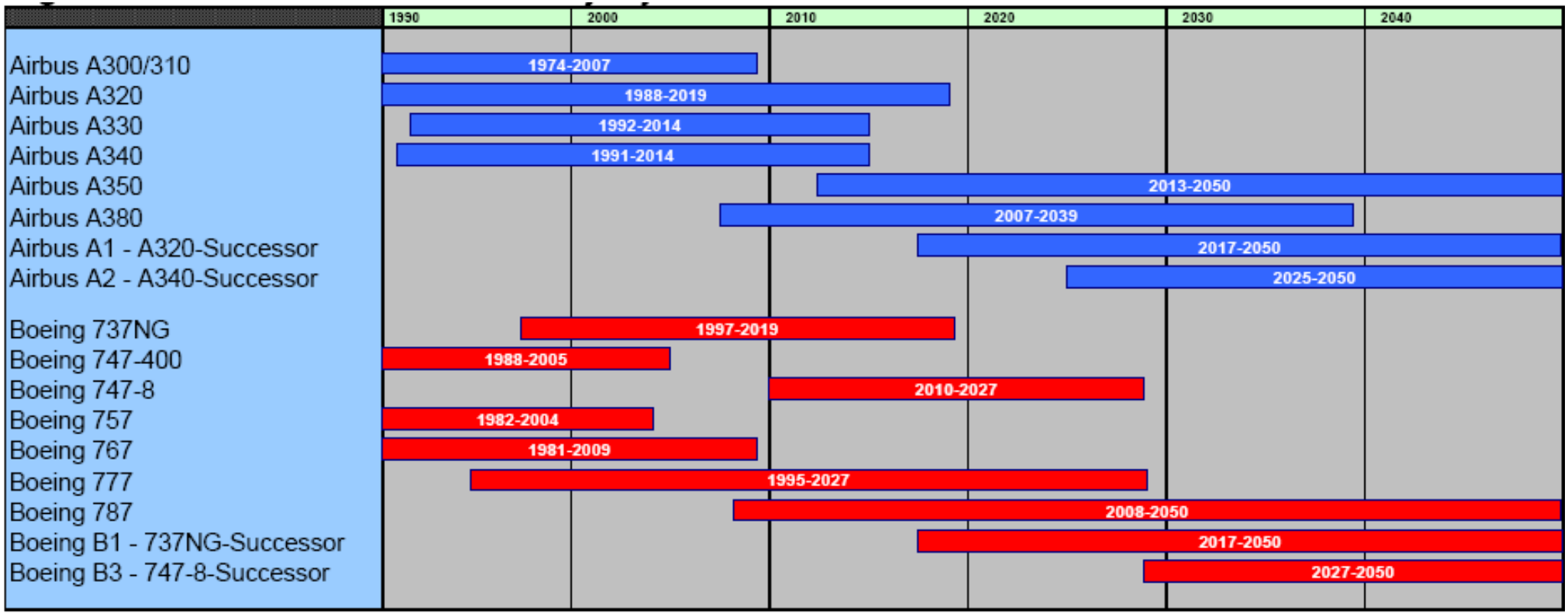
Datasource: Airbus (2006), Boeing (2007), CONSAVE 2050 (2005), Embraer (2008), ICAO (2005)

Market Determinant Fuel Efficiency Development



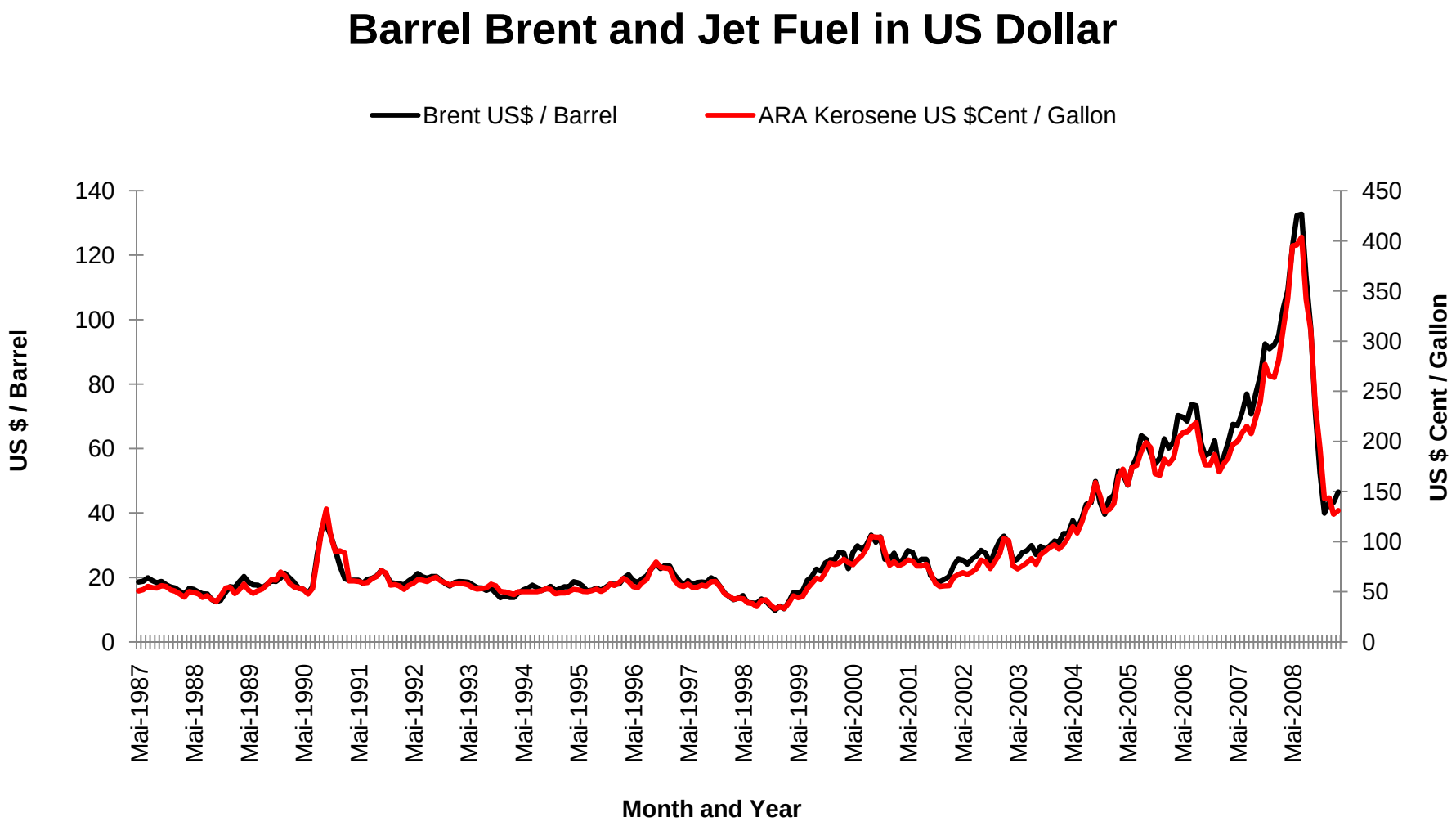
Source: Peeters et al. (2005)

Market Determinant Fuel Efficiency: Production dates of aircraft



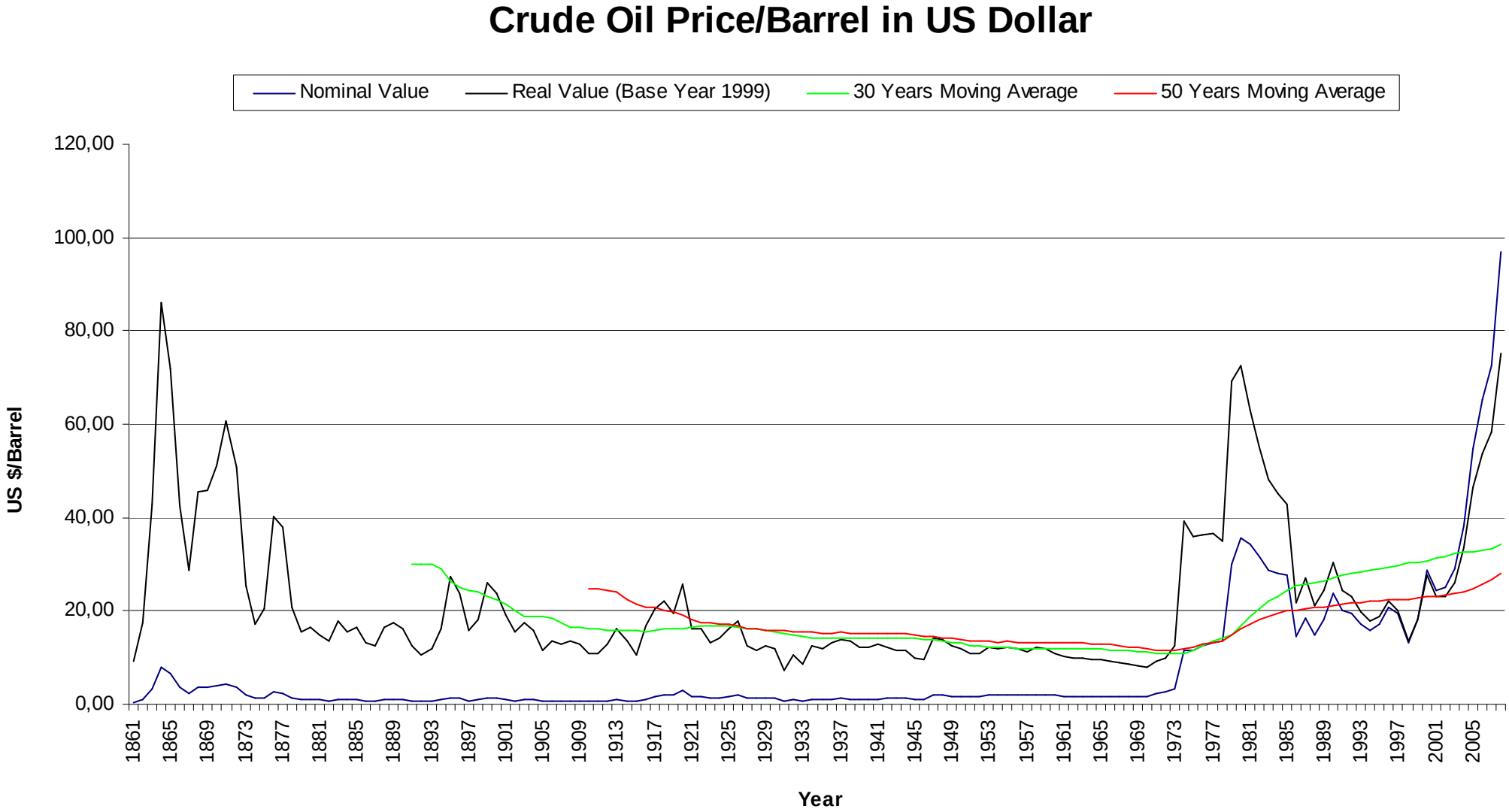
Source: Grimme (2008).

Market Determinant Oil: Relationship Oil and Jet Fuel



Datasource: EIA (2009).

Market Determinant Oil



Datasource: EIA (2009).

Political Determinant Emissions Trading Scheme

Directive 2008/101/EG in conjunction with Directive 2003/87/EG:

- Commercial aviation is included in the ETS
- The total amount of certificates is reduced to 97% of historical Aviation emissions by 2012.

Allocation:

- 15 % auctioned
- Special Reserve (~3%) for newcomer und small fast growing airlines.
- Free allocated allowances (technology benchmark)

Political Determinant Emissions Trading Scheme

Cost: (4th May 2009)

- Jet fuel: 460,90 US $ / t
- Emissions allowance (Carbix-Index): 14,29 € / t

- Total jet fuel cost: 520,93 US $ / t

Political Determinant Fuel Blending

What do stakeholders say?

- IATA: by 2017, 10% synthetic fuel should be used

- LH: by 2020 5 - 10% synthetic fuel should be used

Political Determinant Fuel Blending

Regulations in the EU (Directive 2003/30/EG):

- Blending requirement for gasoline and diesel fuels
- Minimum blending rate: 5,75% Biofuel

Regulations in the USA (Energy Policy Act of 2005):

- Fixed absolute quantity of biofuel for gasoline and diesel fuels
- EPA decides on the Renewable Fuel Standard (2009: 10,21%)

Regulations in Brasil (Roots in PROALCOOL 1975):

- Blending rate span of 15-25 %
- Mid 2007: Share of FFV of total new vehicles sold: 85 %

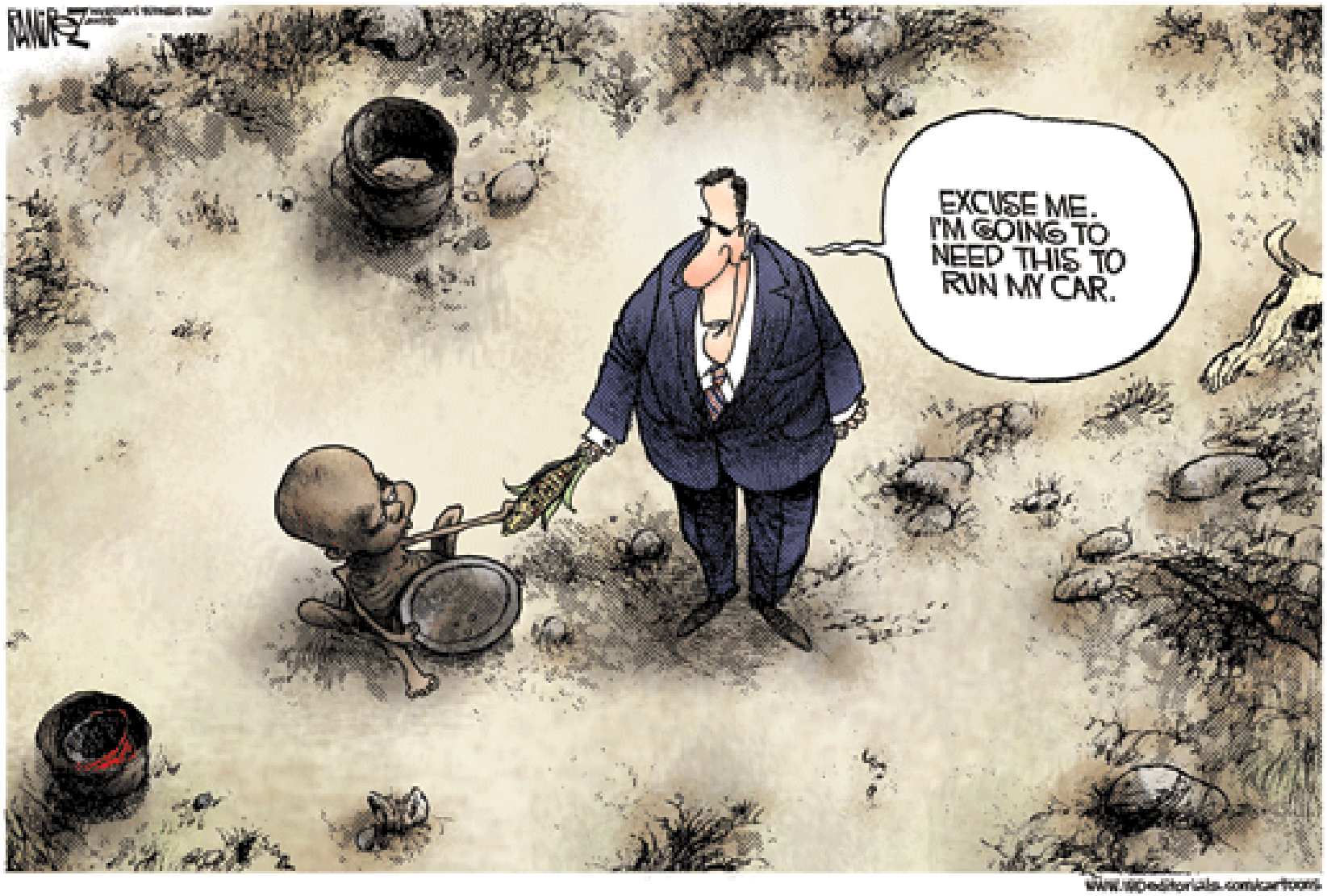
Political Determinant Energy Independence of Military

Projects of the Military of the USA:

- Air Force: „Office of the Secretary of Defense Assured Fuels Initiative“

- DARPA: Biomass derived jet fuels
  Supplement: cellulosic and algae

Possible New Energy Carriers



Important Jet Fuel Characteristics (Jet-A1)

Flash point	38 ℃
Boiling point	156 ℃
Freezing point	-47 ℃
Autoignition temperature	220 ℃
Density	0,804 kg/l (at 15 ℃)
Volumetric energy density	34,69 MJ/l
Gravimetric energy density	43,15 MJ/kg

Biofuels 1. Generation

Properties:

- Feed Material: Food Crops

  Sugar, starch, plant oil and fatty acids
- End-product:

  Biodiesel, Alcohols, Biogas, synthetic Diesel, ...
- Yields:

  Alcohols 2 - 6 t/ha/year

  Biodiesel 1 t/ha/year
- Cost (Barrel oil equivalent):

  Rapeseedoil: ~ $ 160

Biofuels 1. Generation

	Volumetric energy density	Gravimetric energy density	Freezing point
Jet fuel [a]	34.69 MJ/l	43.15 MJ/kg	- 47 °C
Methyl esters [b]	31,2 MJ/l	39 MJ/kg	-10 – 0 °C

Source: [a] Smith and Workman 2004; [b] see e.g. Saynor 2003

Alcohols:

Properties:

- Feed Material:

  Sugar
- Production process:

  Fermentation
- End-product:

  Methanol, Ethanol, Butanol
- Cost:

  Differs by region, competitive fuel in Brasil

Alcohols:

	Volumetric energy density	Gravimetric energy density	Freezing point	Flash point
Jet-A [a]	34.69 MJ/l	43.15 MJ/kg	- 47 °C	38 °C
Methanol	15.6 MJ/l	20 MJ/kg	- 97°C	11 °C
Ethanol	24.2 MJ/l	30.6 MJ/kg	-114.3 °C	13 °C
Butanol	29.71 MJ/l	36.68 MJ/kg	-90 °C	29 °C

Source: [a] Smith and Workman 2004, for alcohols see e.g. Sehra 2003

Biofuels 2. Generation (Advanced Biofuels)

Properties:

- Feed material (non-food): energy crops, wood, residues
  Problematic is high share of lignocellulose
- End-product:
  Hydrogen, Biodiesel, Alcohol, Dimethylfuran, ...
- Yields:
  Synthetic diesel 4 t/ha/year
  Alcohols (Methanol, Ethanol) 5 - 8 t/ha/year
- Cost (barrel oil equivalent):
  Synthetic jet fuel: ~ $ 35 - 85

Biofuels 3. Generation (Advanced biofuels, next generation feedstock and processing)

Properties:

- Feed Material: microalgae
- Processing methods:

  Hydrocracking, FT, hydrotreating
- End-product:

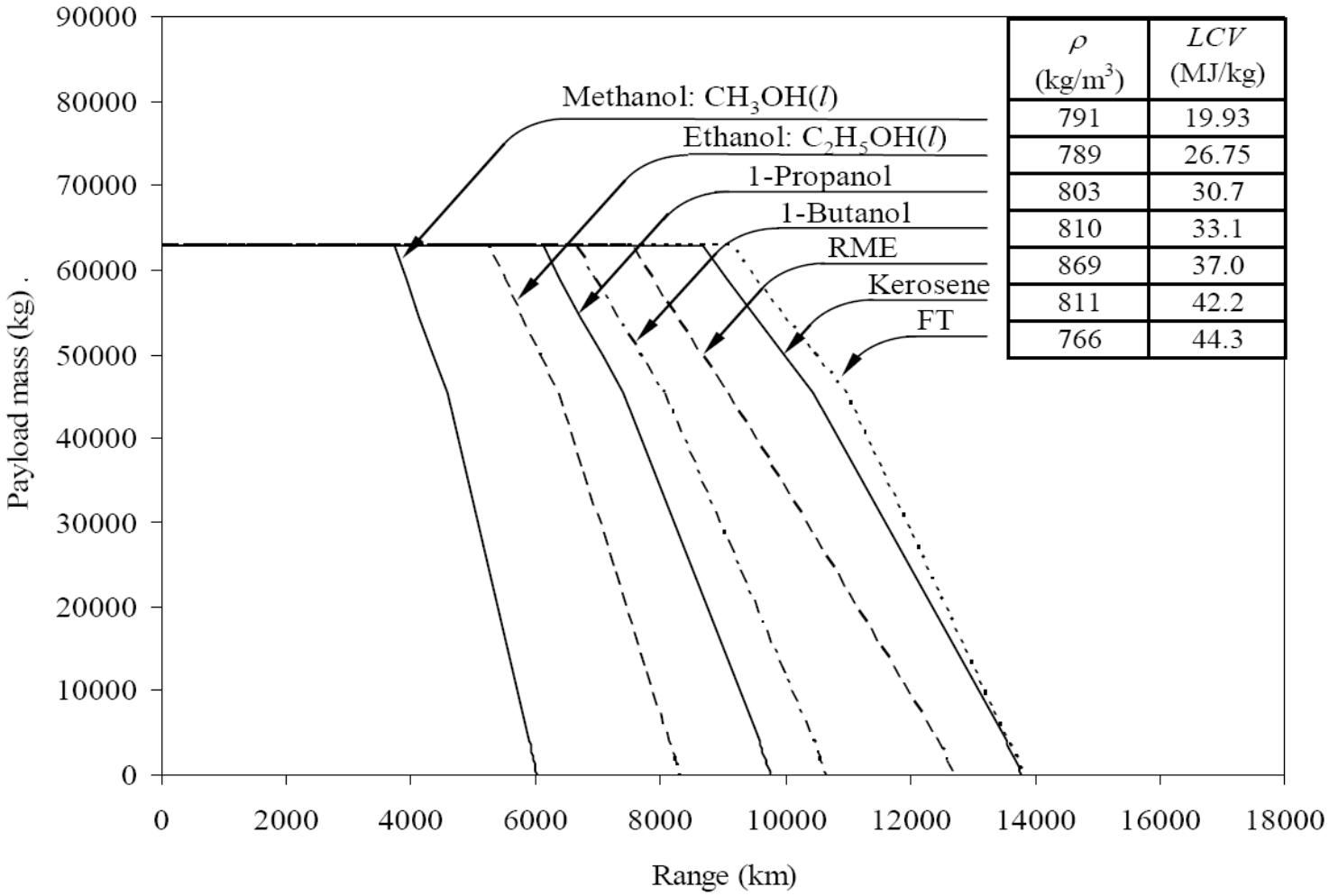
  „Bio“ crude oil, jet fuel
- Yields:

  theoretic barrier: 47 t/ha/Jahr
- Cost (Barrel oil equivalent):

  $ 120 – 700

  DARPA-goal: $1 – 2 / gallon = $ 42 - 84

Alternative Fuels and Range



ρ (kg/m^3)	LCV (MJ/kg)
791	19.93
789	26.75
803	30.7
810	33.1
869	37.0
811	42.2
766	44.3

Source: Wilson (2009).

Cryogenic Fuels: Liquid Hydrogen

Research Projects:

- Cryoplane (EU-Project)
- NASA
- Tupolev
- LAPCAT A2

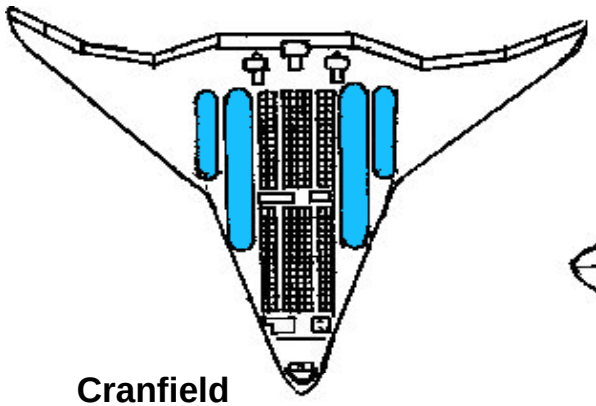
Supersonic Aircraft (EU- Project)

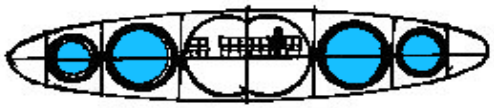
Important Cryogenic Fuels Properties

	Volumetric energy density	Gravimetric energy density	Operating temperature
Jet fuel	34.69 MJ/l	43.15 MJ/kg	
LH_2	8.49 MJ/l	119.5 MJ/kg	-252.8 °C
Biogas	24,12 MJ/l	55.45 MJ/kg	-161.65 °C

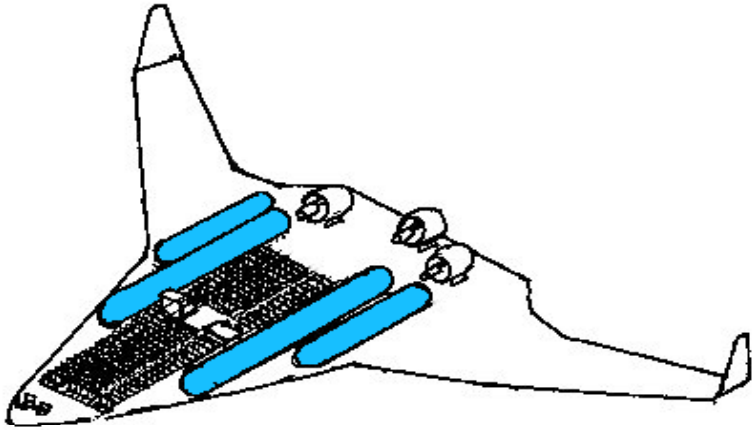
- Only limited infrastructure available, not a drop-in fuel
- Boil-off-losses: ~1% / day
- Main use: rocket propulsion
- Cooling potential may be an order of 21 – times that of jet fuel

Possible Aircraft Configurations





Cranfield



Electricity

Electricity storage has very low energy density (Li-Ion Battery):

		Jet Fuel
Volumetric energy density	0,972 MJ/l	34,69 MJ/l
Gravimetric energy density	0,576 MJ/kg	43,15 MJ/kg

- But: Electric motors have very high energy conversion efficiency
- Alternative energy carriers could be used for fuel cells
  e.g. Methanol (DMFC) or LH2 (possible super-conductivity motor)
- Demonstration projects with small aircraft

Nuclear Energy Carrier

- Main problems:
  - Weight of shielding
  - Risk of crash involving radiation
  - Test grounds for nuclear aircraft

- US-Military research between 1948 and 1961:
  Competing concepts (direct flow, heat exchanger)
  Reactor shielding poses a weight penalty
  47 test flights with reactor onboard

- No development at the moment

Cost Overview

Energy carrier	Cost in US $/GJ 2008	Cost in US $ 2008/kg jet fuel equivalent
Jet fuel	15,81	0,675
Rape methylester	38,18 – 59,95	1,65 – 2,59
Rapemethylester – Soy oil methylester	13,75 – 15,27	1,04 – 1,17
Fischer-Tropsch Fuel	6,78 – 42,71	0,29 – 1,85
Algae Fuel	152,50	6,58
DARPA-Goal, Algae Fuel	22,94	0,99
Ethanol	12,05 – 32,44	0,52 – 1,40
Methanol	10,77 – 14,36	0,60 – 0,81
Butanol	10,05 – 12,29	0,43 – 0,53
Hydrogen	10,4 – 185,36	0,45 – 8,8
Biogas	6,04 – 12,7	0,26 – 0,55

Conclusion

- Oil is a restricted source but will stay available for a long time
- High oil prices make non-fossil fuels more attractive
- In the short to medium run, no alternative fuel can be introduced due to aircraft service life and lack of infrastructure
- Airports, airlines and aircraft manufacterers are not interested in completely new fuel
- New generations of biofuels are being developed, biofuels available today have disadvantageous properties and do not solve problems of aviation adequate

Thank you!

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