<u>Alternative Fuels for Air Transport</u>

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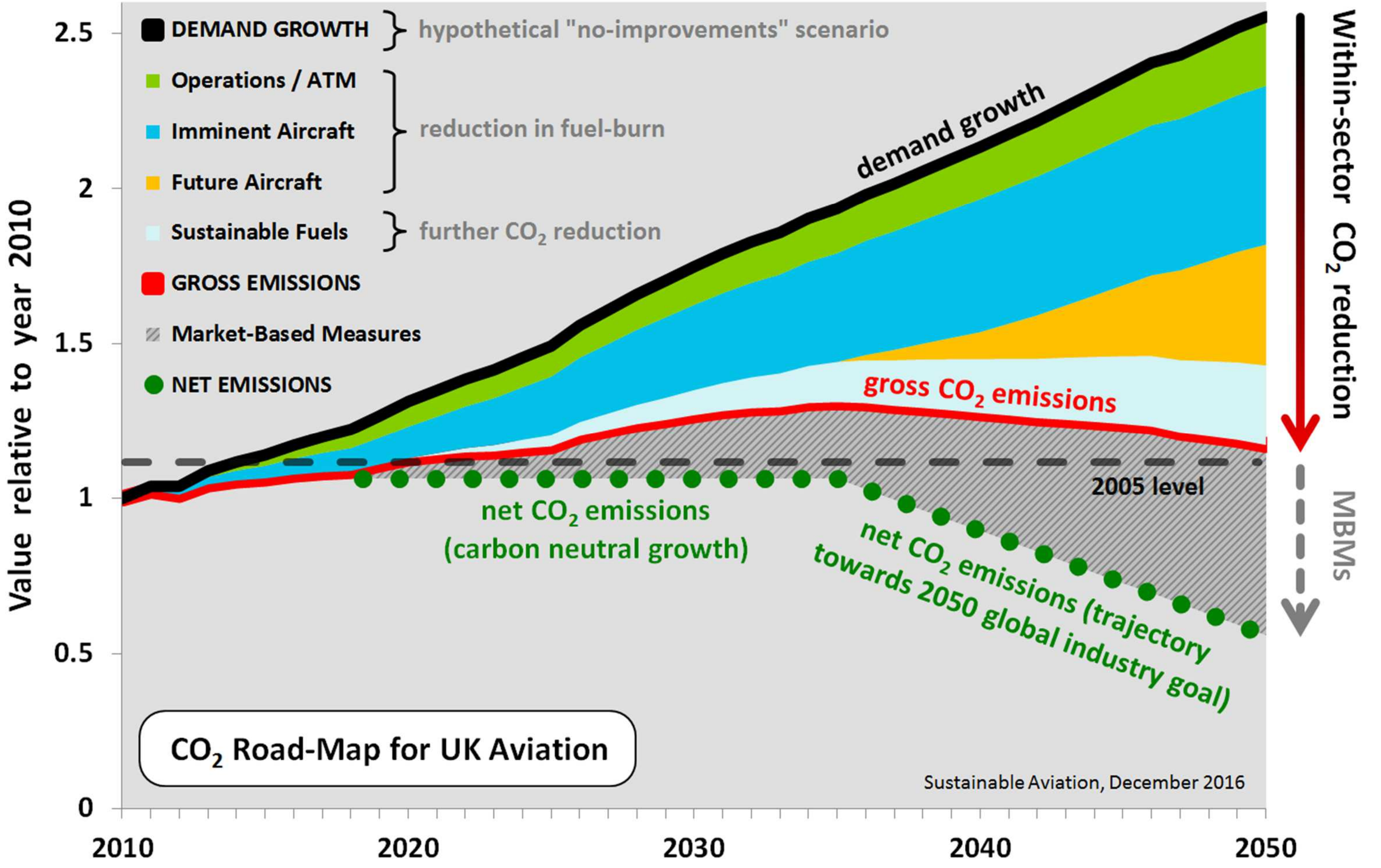
Sustainable Aviation CO2 Road Map (UK)



Requirements for an Aviation Fuel

- High energy content (per unit weight and volume) - to minimise fuel burn, operating costs and CO_2 emissions
- Low freeze point - to ensure fuel does not freeze at altitude
- Excellent thermal stability – to provide required heat sink capability
- Suitable flash point – to ensure the fuel will ignite (or not) in air as required
- Good storage stability – to ensure quality of the fuel is maintained with time
- Compatibility with materials in the fuel system

Equals a “Drop in” Kerosene replacement

Alternative Fuels for Aviation

	Mass	Volume
	MJ/kg	MJ/litre
Kerosene	43.2	34.9
Liquid Hydrogen	120	8.4
Methane	50	21.2
Ethanol/Methanol*	27.2/19.9	

* Hygroscopic

A “Drop-in” synthetic Kerosene can be produced from biomass by the Fischer-Tropsch process or by hydrogenation of vegetable oils.

What about Bio-fuels?

- It is fundamental that production must be sustainable, without prejudice to land and water resources for food production

Aviation Biofuel Sustainable Feedstocks under active consideration:-

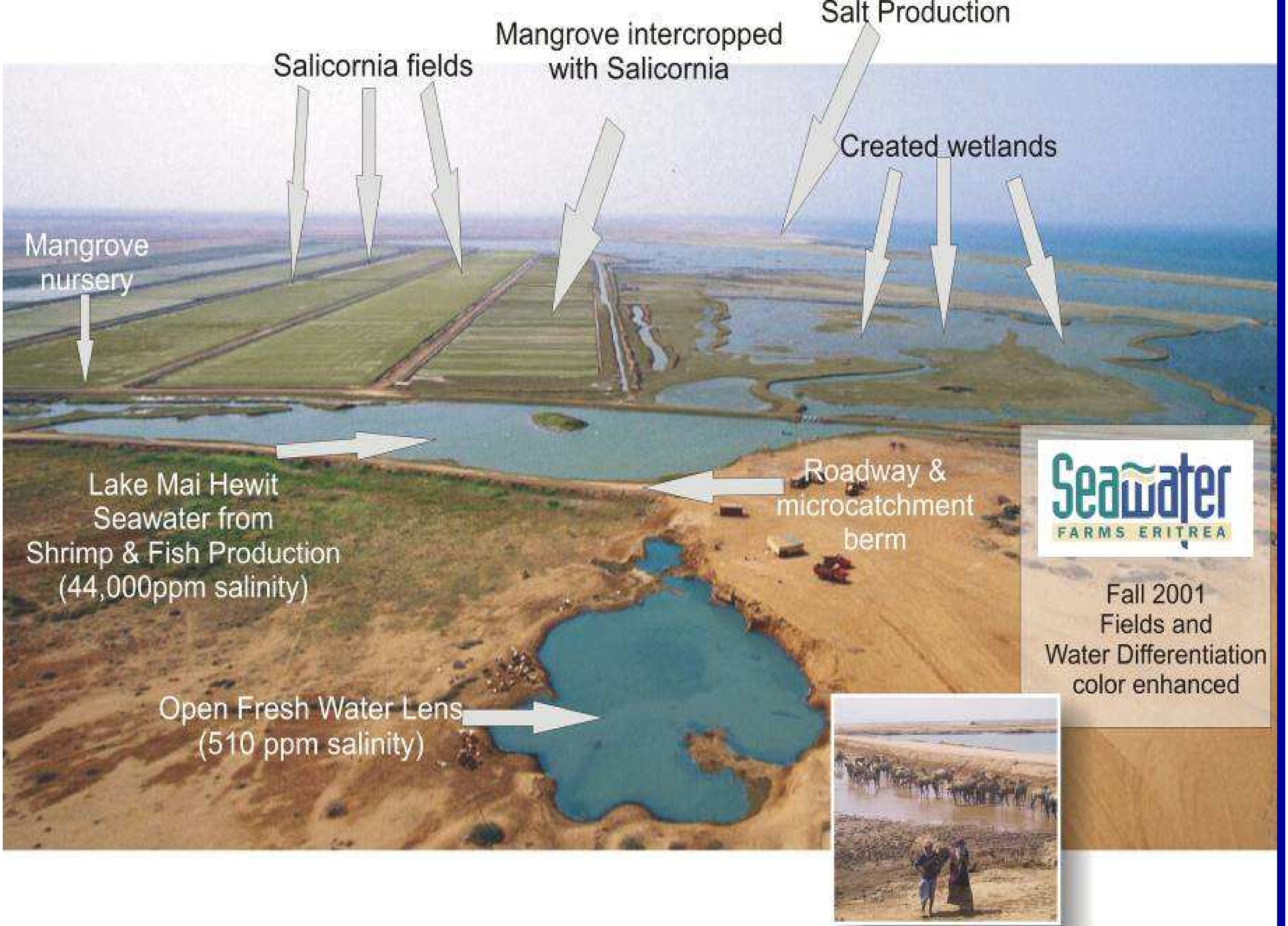
- Camelina - Ready now
- Jatropha - Ready in 2-4 years
- Halophytes (eg Salicornia) - Ready in 2-4 years
- Algae - Ready in 8-10 years

Several R&T consortia established; output has now reached “large scale demonstration quantities” (of order 250,000 gallons)

Camelina Placement Trials

Manchester Metropolitan University

Mihailesti Trial: from seeding to oil 3 varieties / 2 periods for sowing ➔ Austria- *Calena* ; Germany - GP202; Romania - *Camelia*


Salt Production
Mangrove intercropped with Salicornia
Salicornia fields
Created wetlands
Mangrove nursery
Lake Mai Hewit Seawater from Shrimp & Fish Production (44,000ppm salinity)
Roadway & microcatchment berm
Seawater FARMS ERITREA
Fall 2001 Fields and Water Differentiation color enhanced
Open Fresh Water Lens (510 ppm salinity)

BioFuels As An Alternative Fuel Source For Aviation

GreenLab Research Facility

Salicornia europea / Salicornia virginica

Seashore mallow in Delaware bay

➔GreenLab Research Facility designed to optimize saltwater algal, halophytes and other biomass species for potential use as aviation biofuels. Contains seven unique ecosystems representing various soil/water salinities, several states of climatic adaptation total life cycle system laboratory and field trial data.

➔Over 800 GreenLab visitors in 2009 including three congressional visits , including State Department International Visitor Leadership Program (IVLP) delgation (2009).

➔ Identified three optimal halophytes species (S. virginica, S. europea, S. bigelovii) out of 26 potential candidates worldwide using high throughput screening that do not use freshwater, arable land or compete with food crops.

➔Collaborations with Boeing, Evogene, DOE, Seambiotic The University of Arizona and The University of Delaware to optimize lipid extraction for saltwater algae ,halophytes and other oil-seed plants..

Seashore mallow

Indoor biofuels lab

Salicornia bigelovii

Collaboration with the University of Delaware field study to demonstrate the feasibility of salinitizing *Kosteletzkya virginica* – Seashore mallow as an alternative biofuel biomass source.

Certification of “drop-in” biofuel kerosene replacements

(Energy content, freeze point, thermal stability etc.)

•Many flights have taken place over the last 3 years, typically one engine fed with a blend of kerosene and biofuel. All have been very successful.

•Properties have been shown to be at least as good as fossil fuel kerosene (although additives for lubrication etc may be required above 50-50)

•A 50/50 blend has already been certificated.

•Worldwide Certification standards are being agreed.

Suggested time line for Bio-fuel Introduction

• Certification for commercial use	2011
•10 plus pilot plants in production	2013-15
•1% of total fuel used is Biofuel	2015-20
•20% Biofuel	2030- 50
•100% Biofuel	2050 + ?

European Commission

The European Biofuels FlightPath

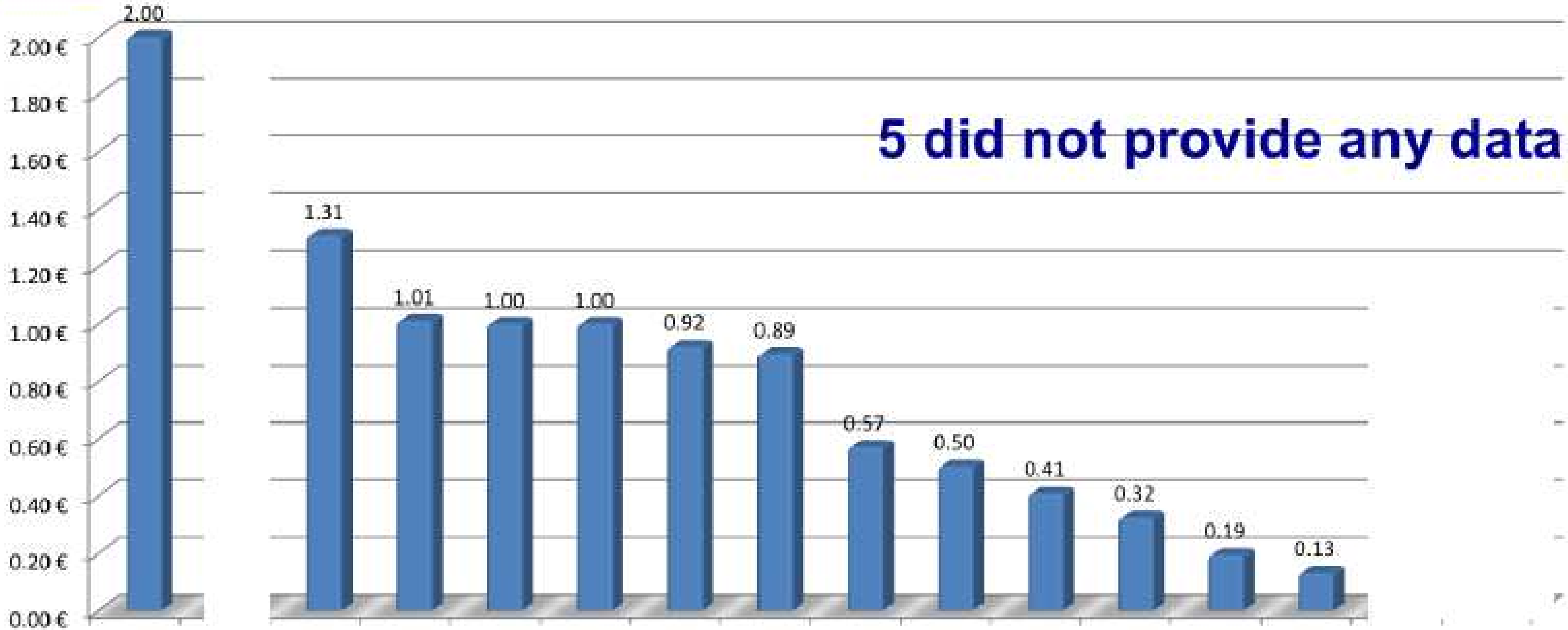
2 MTons of Aviation BioFuels in 2020 = 4% of EU fuel consumption

Cross Industry & government collaboration and consensus

AIRBUS
AIRFRANCE
Lufthansa
BRITISH AIRWAYS
KLM
DG Energy
btg business technology group
CHEMTEX ITALIA
UPM
NESTE OIL
uop A Honeywell Company

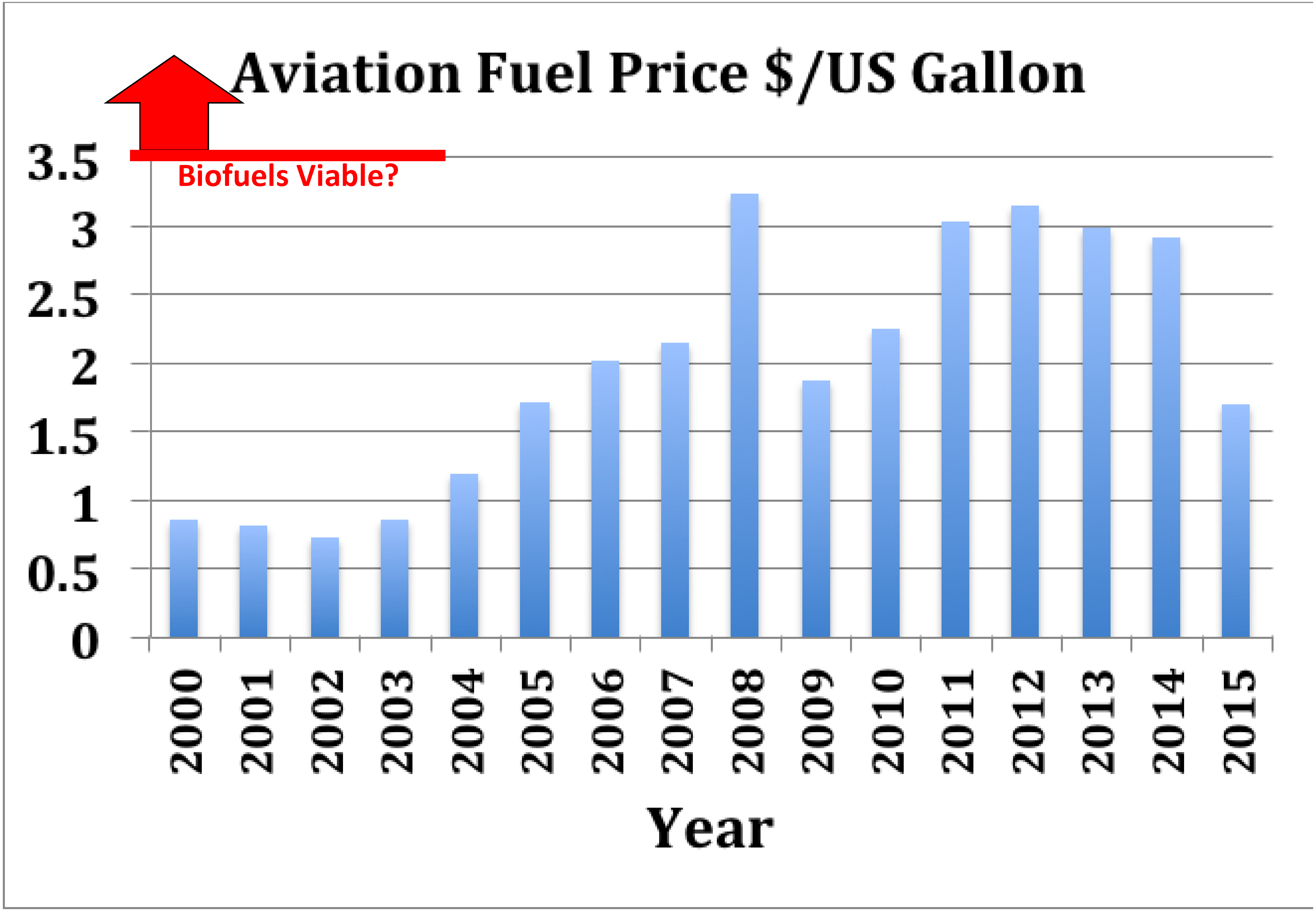
By 2015:	By 2018:	By 2020:
• Set-up financial mechanisms • Secure sustainable feedstock production to feed 3 refineries • Construct 3 new refineries and launch Biofuel production • Manage communication strategy	• Regular commercial flights using bio-jet fuel blends • Construct 4 additional refineries • Construct 2 additional refineries producing algal & microbial oil based aviation Biofuels	• Full deployment of at least 2 million tons of biofuels per annum for EU aviation
Objective → 3 Refineries Cost → 1.300 M€	Objective → 6 Refineries Cost → 1.700 M€	9 Refineries and 3.000 M€ total Cost

Cost of aviation biofuel production €/lt



Arithmetic mean value: 0.77 €/lt

Midrange value: 1.06 €/lt


Aviation Fuel Price $/US Gallon
Biofuels Viable?
3.5
3
2.5
2
1.5
1
0.5
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year

Other Fuel Possibilities

Other feed stocks

- Use of waste cooking oil etc.
- Wood waste
- Direct production of hydrocarbons without photo synthesis in plants eg focused solar power. eg $2CO_2 + 3H_2O$ (+ Energy) = $C_2H_6O + 3O_2$

Other Propulsion systems

- Cryogenic Liquid Hydrogen
- Electric Propulsion
- Nuclear Fission

British Airways – Solena Fuels (2014) “Fuel from Garbage”

Solena Fuels has gone bankrupt and the above proposal is dead. However, British Airways have recently (2017) announced a new partnership with “Velocys” for a similar proposal. Velocys are registered in the UK (at Harwell) and in the USA (Ohio). A first plant is targeted at producing 20,000 tons of “drop-in” kerosene per annum

“If we could use all the world’s garbage it would provide 25% of Aviation’s fuel needs”

(Old) “Breaking News!”

Southwest Airlines has entered into an agreement with Colorado-based Red Rock Biofuels (RRB) to purchase around three million gallons per year of renewable jet biofuel.

First deliveries are due to start in 2016 and RRB says it will be able to provide its product at cost parity with conventional jet fuel.

RRB has just secured a $70 million federal grant to help fund the building of a $200 million refinery that will produce jet fuel, diesel and naphtha from forestry residues sourced from timber operations. Around 140,000 dry tons of woody biomass feedstock will be converted into at least 12 million gallons annually of the three products.

Should bio-fuels go to Aviation or Ground Transport?

Ground Transport:-

- Easier certification requirements
- Cheaper to produce
- But other possibilities – Fuel Cells etc.

Aviation:-

- There is no other alternative to a "drop-in" synthetic kerosene in the medium term (possibly liquid hydrogen very long term).
- Stringent certification requirements.
- Straight forward distribution logistics.
- Motivated Industry due to current "environmental pressures".

Electricity as a Fuel?
Battery power densities etc.

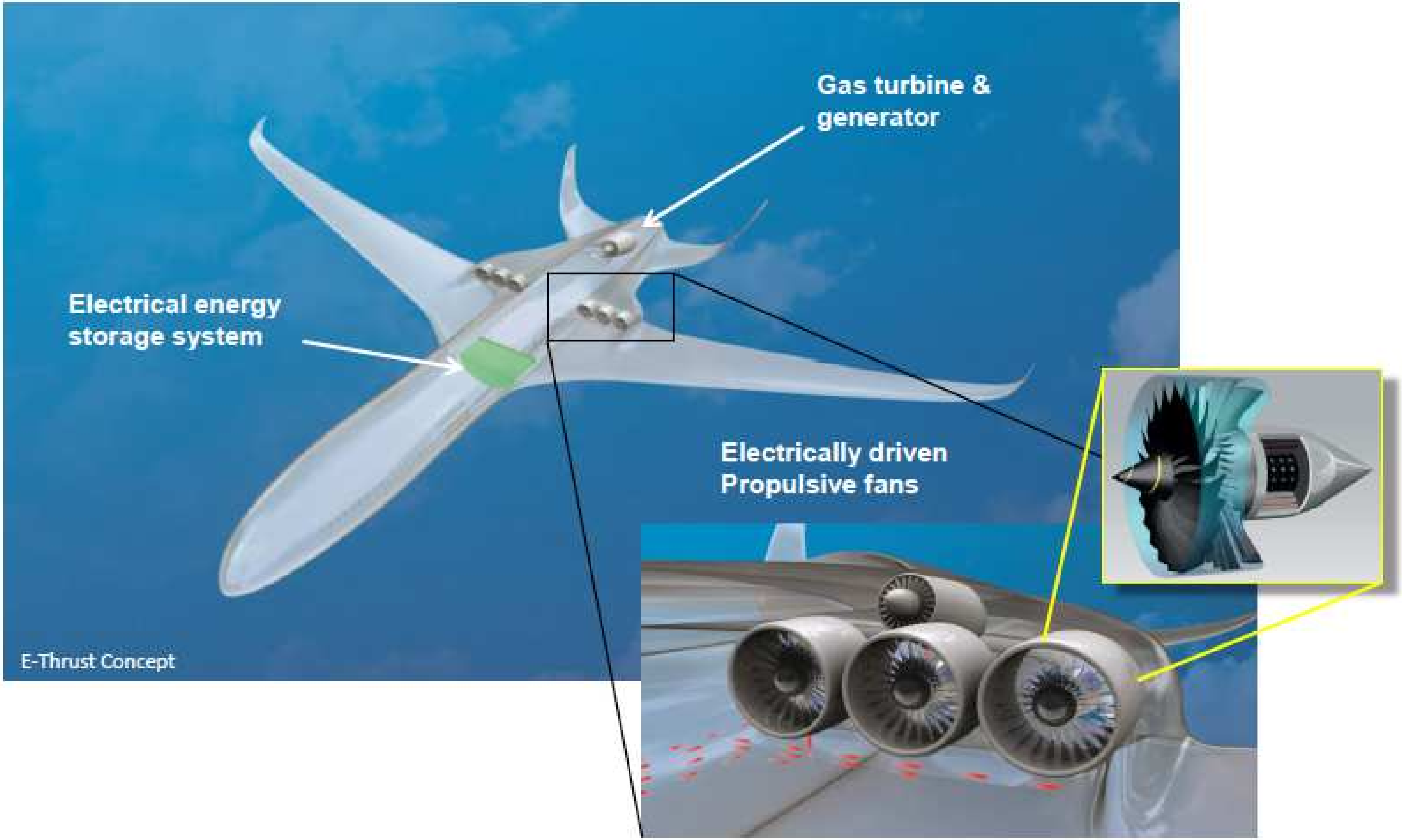
	Achieved	Theoretical Limit
Today		
lithium-ion	200 – 250KWh/Kg	400-450 KWh/Kg
The Future		
Lithium-Sulphur	400KWh/Kg	2600KWh/Kg
Lithium-Air	800KWh/Kg	11000KWh/Kg

Compared with Gasoline 12000KWh/Kg

Other Issues:
Refueling time
Increased landing weight cf take-off weight

Electric Propulsion?
Boeing “SUGAR” Concept

Hybrid turbo-electric propulsion



Rolls-Royce

Skunk Works Reveals
Compact Fusion Reactor Details

Lockheed Martin aims to develop compact reactor prototype in five years, production unit in ten.

The device is conceptually safer, cleaner and more powerful than much larger, current nuclear systems that rely on fission.

Lockheed believes its scalable concept will also be small and practical enough for applications ranging from interplanetary spacecraft and commercial ships to city power stations.

It may even revive the concept of large, nuclear-powered aircraft that virtually never require refueling—ideas of which were largely abandoned more than 50 years ago because of the dangers and complexities involved with nuclear fission reactors.

Aviation Week, 20th October 2014

The Ultimate “Green” Nuclear Fusion Powered aircraft?

Feasable? Lockheed Martin are a very respectable company – we shall see!