Shell Global Solutions

'The Role of Alternative Fuels in Air Transport - Options and Challenges'

UTIAS-MITACS International Workshop on Aviation and Climate Change, Toronto 28-29th May 2008

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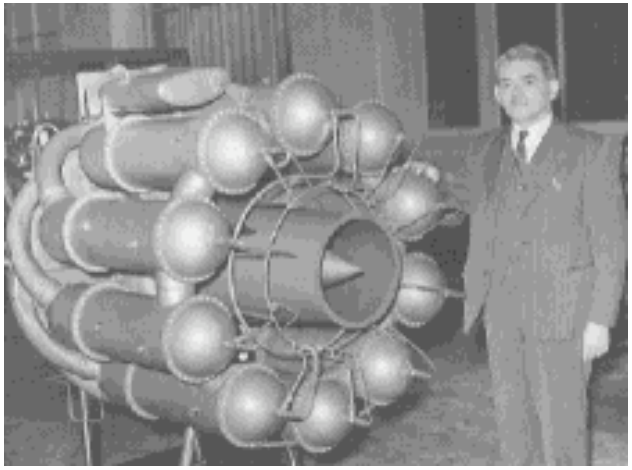
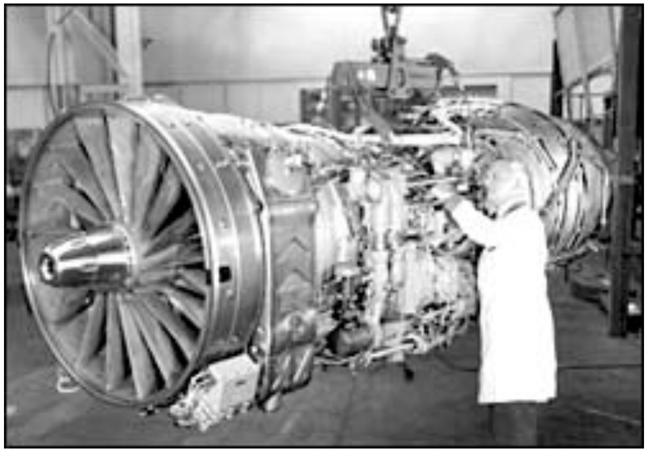
Shell Global Solutions UK - Thornton

A History of Shell 'Firsts'

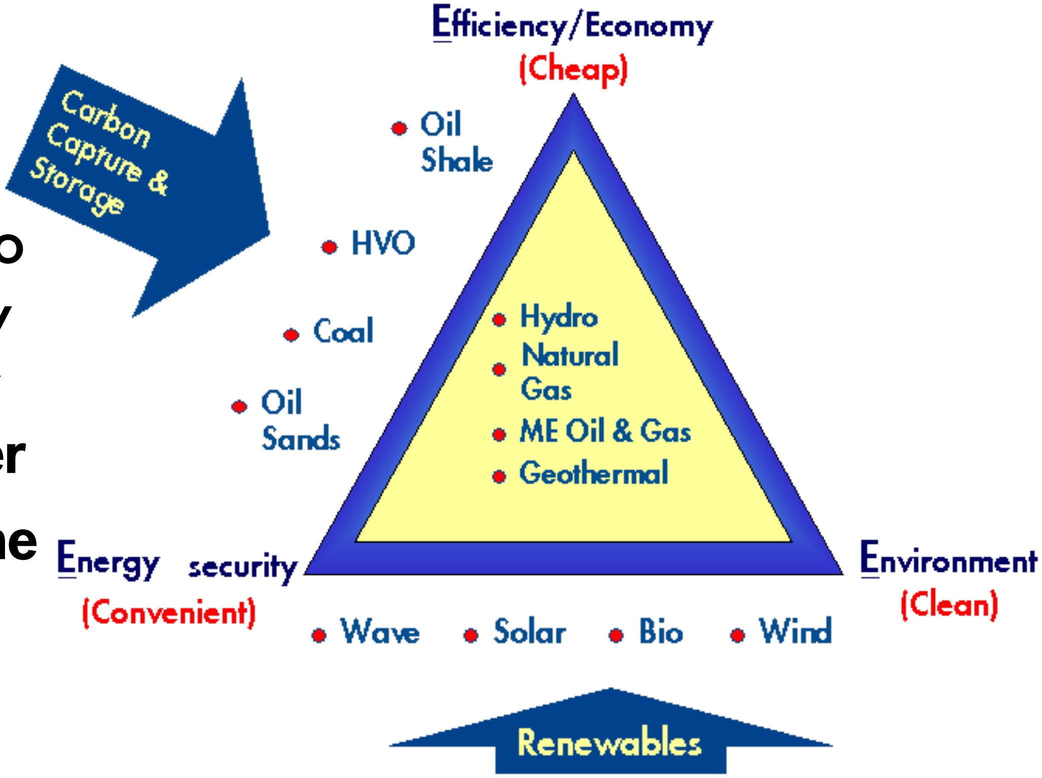




- **1930s** Shell develops a way to synthesise 100 Octane aviation gasoline
- **1940s** Shell helps develop the early pre-mixing gas turbine combustion system
- Late **1950s**. Shell is first to develop aviation piston engine oils with additives 'W oils'
- **1970s.** Shell develops a new generation turbine oil lubricant for Olympus & Concorde
- **1984**. Shell is the first to develop a semi-synthetic multigrade oil for aviation use.
- **1996.** Shell launches *Aero*Shell Grease 33 world-leading multi-purpose airframe grease
- **2008**. Shell, RR and Airbus conduct the first GTL jet fuel powered flight with the Airbus A380

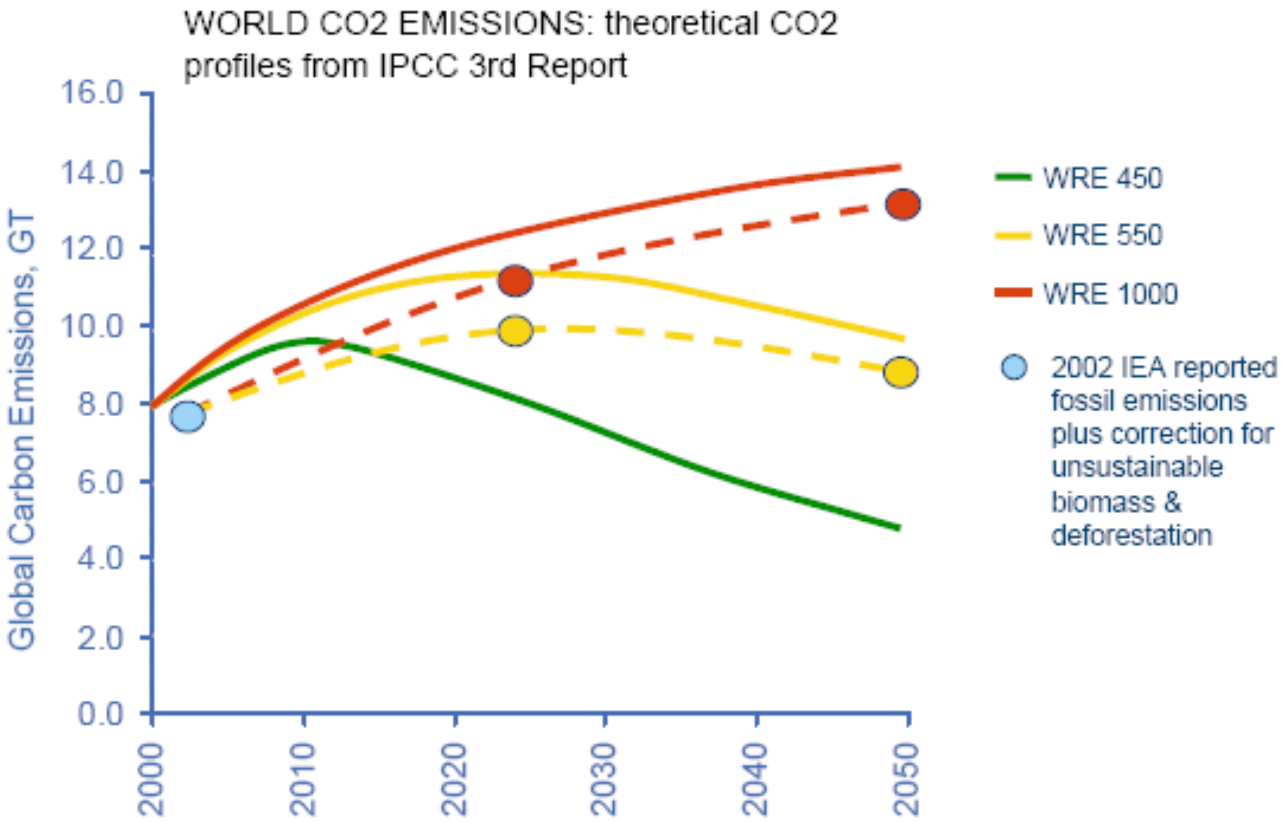
'Three Hard Truths'

- Energy demand could more than **double by 2050**, as population rises and developing countries expand economies
- Hydrocarbons will continue to provide foundation of energy supply for rest of this century but the **age of 'easy oil' is over**
- As a result, **management of the CO_2 footprint** is a priority
- Shell 2050 Scenarios paint possible futures of '**Scramble**' or '**Blueprint**' (preferred)



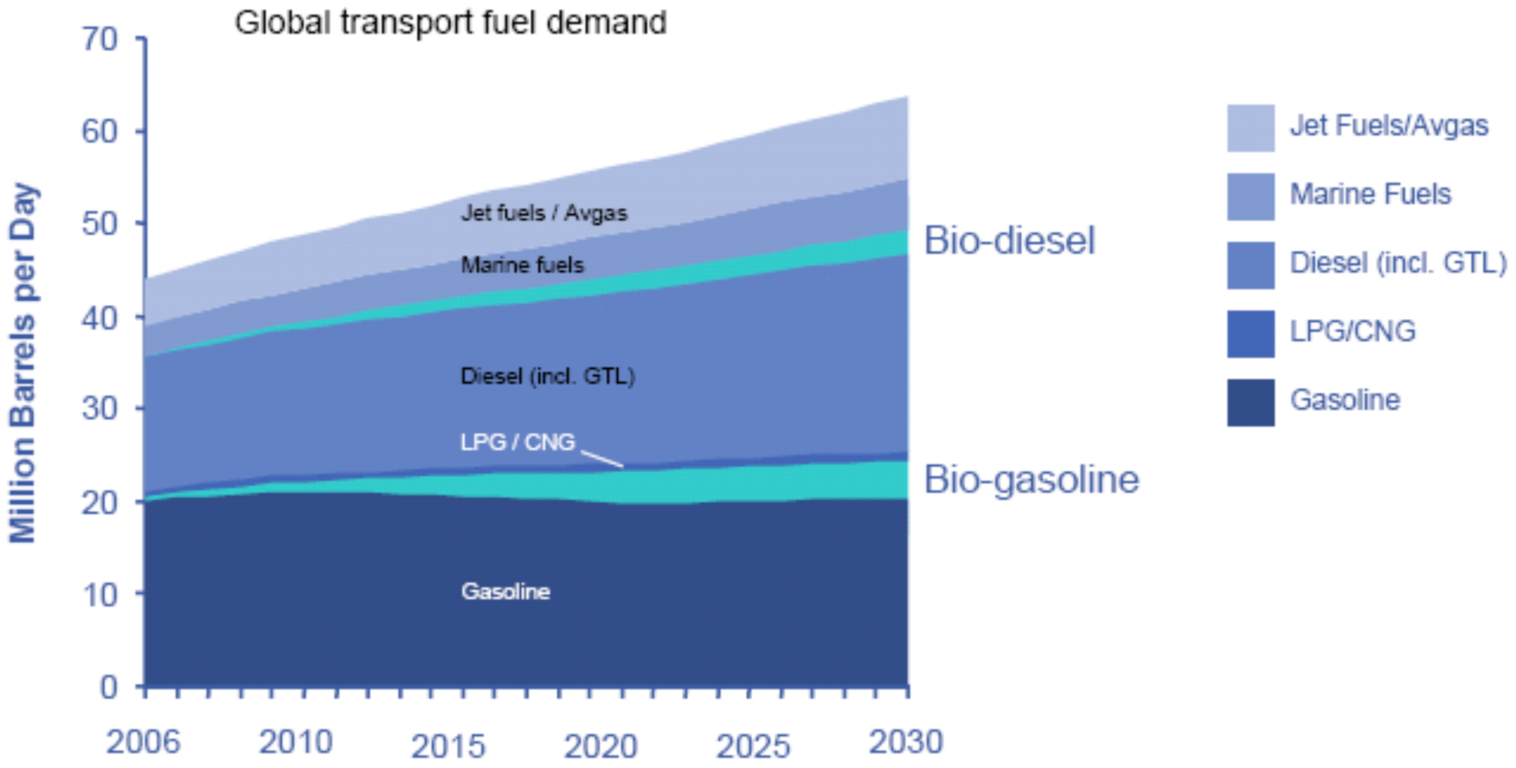
Climate Change

- Between now and 2050 the world has to provide double its current energy supply whilst halving the CO_2 emissions



Transport energy has to diversify

- Global transport fuel demand forecast to rise by 45% from 2006 to 2030
- Biofuels represent 1% of global transport fuel demand today but estimated to increase to 7% by 2030



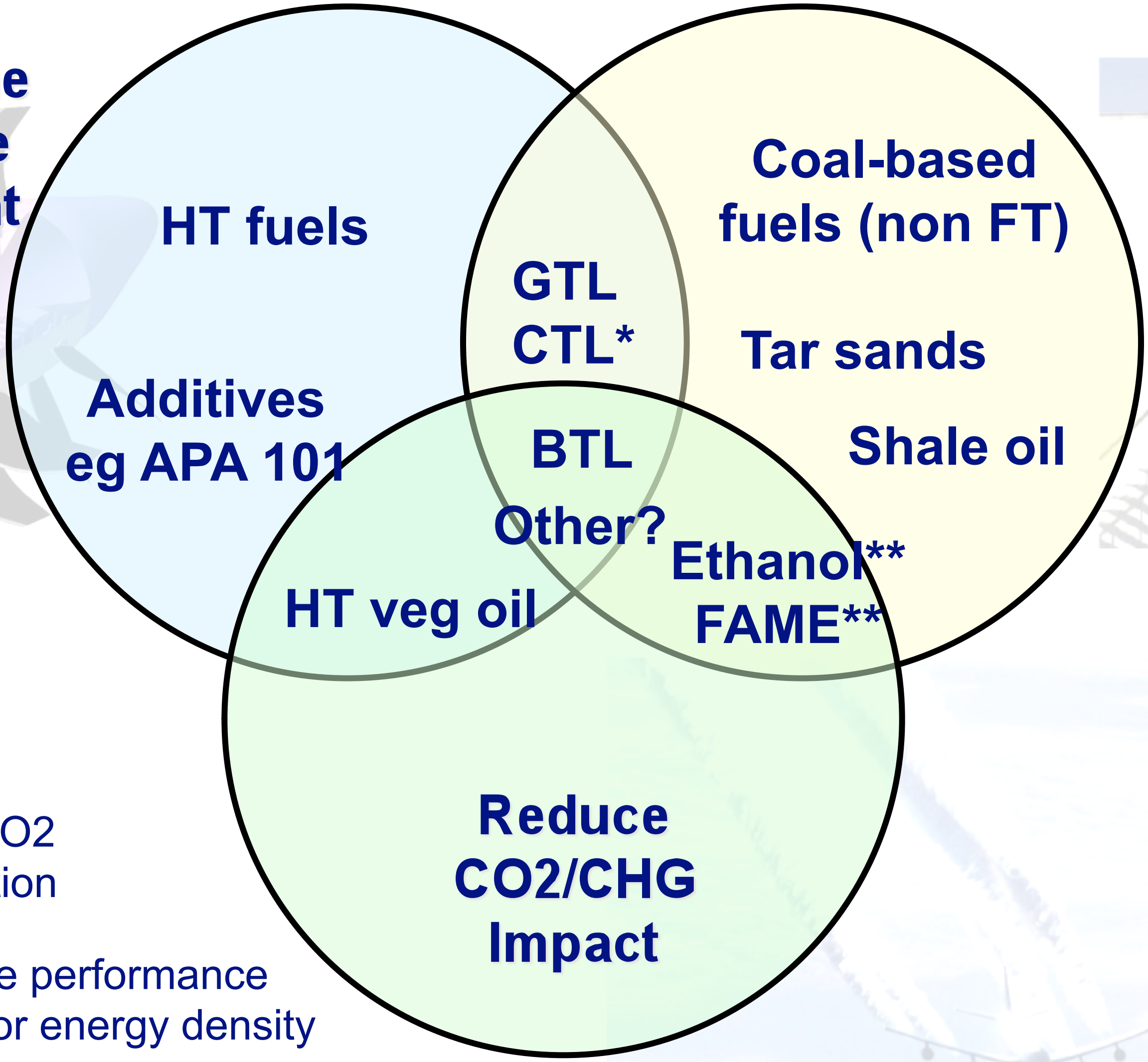
Source: Shell calculations based on IEA and PIRA data

In Aviation fuel options are limited – not much scope for special fuels

- Long lifetime and high capital cost of aircraft – kerosine is preferred jet fuel for next 30 years
- Focus on safety means lead times for fuel or additive development are long (~10 years)
- Airlines don't like aircraft that need special fuel
- Little incentive for OEMs to develop aircraft/engines running on a special high performance or alternative fuel
- Local alternative fuel solutions common in ground transportation fuels only applicable to General Aviation
- Hydrogen would need completely new aircraft and infrastructure

Current wisdom says
Any new or alternative aviation fuel
for the short to medium term
must be a drop-in replacement

The Fuel Options Map



Enable engine performance enhancement

Increase or diversify supply

Reduce CO2/CHG Impact

HT fuels

Additives
eg APA 101

GTL
CTL*

BTL

Other?

HT veg oil

Coal-based fuels (non FT)

Tar sands

Shale oil

Ethanol**
FAME**

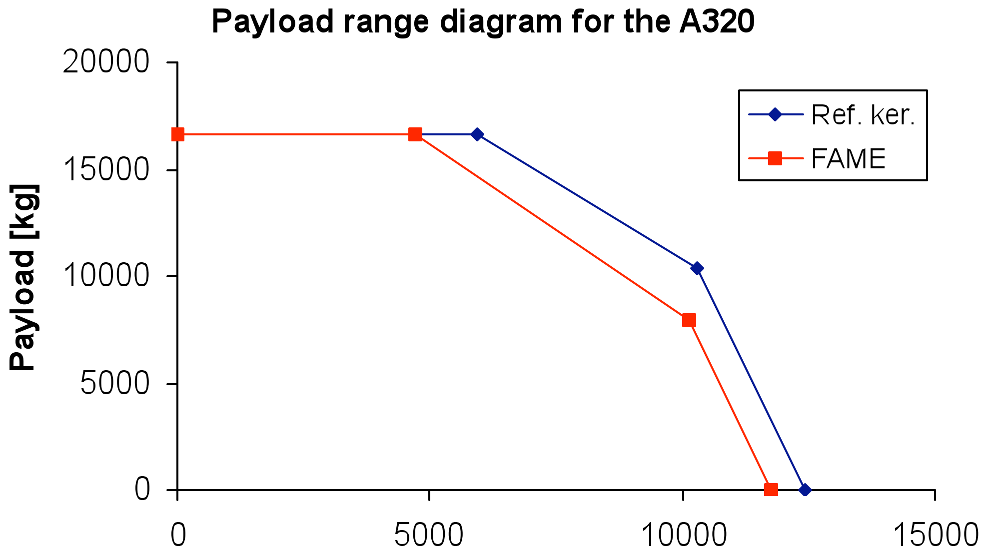
* Needs CO2 sequestration

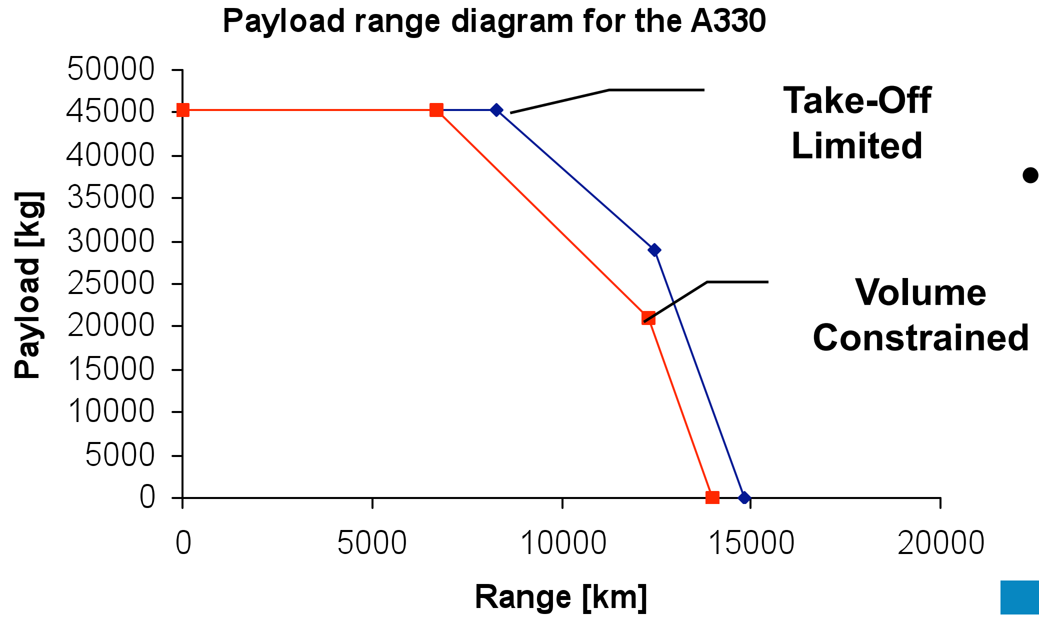
** negative performance due to poor energy density

The numbers say it all ...

Fuel	Density kg/m3	Energy MJ/kg	Energy MJ/L	Freeze pt, °C
Jet A-1	800	43.2	34.8	<-47
Ethanol	790	27.7	22.0	<-115
FAME	880	37.5	33.0	-5
GTL kero	740	44.0	32.5	<-50
Hydrogen	70	120	8.4	-259!

FAME impact on Aircraft Performance

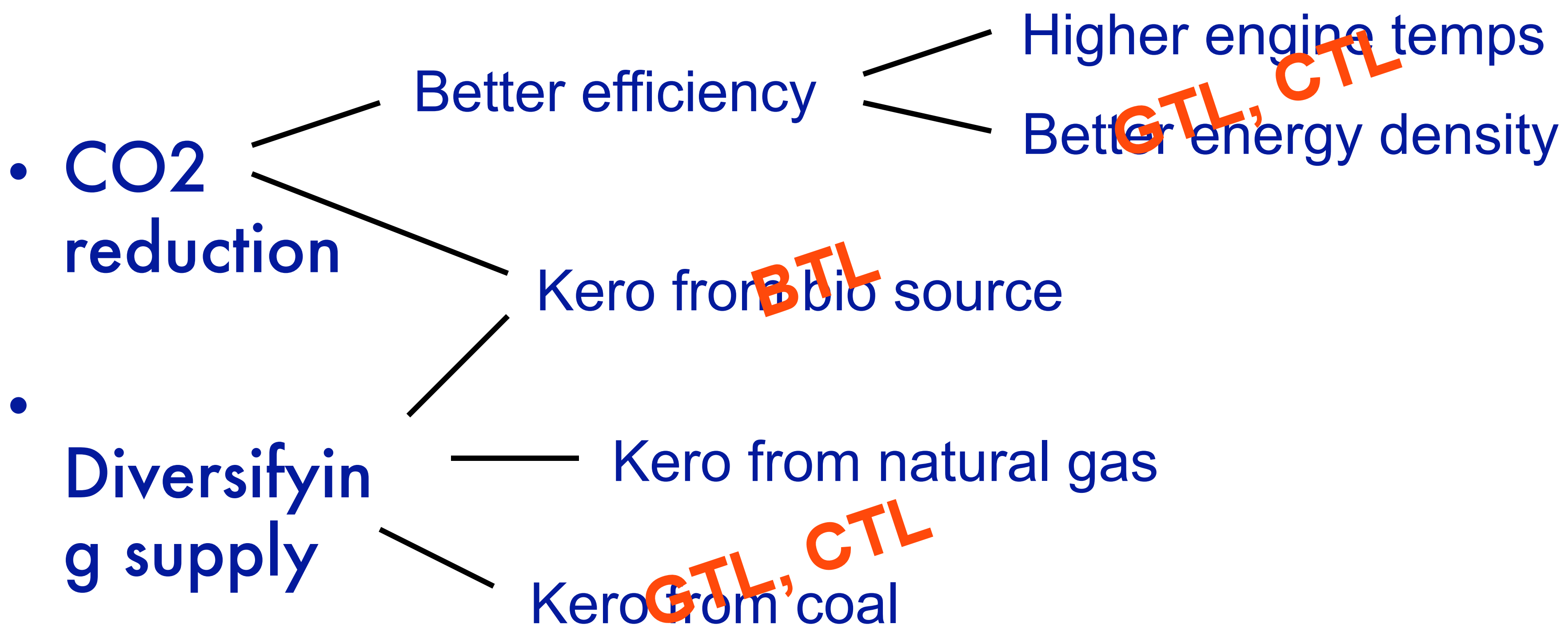




- Oxygenate fuels severely limit aircraft operations
- Opposite for high H/C ratio synthetic fuels although not when volume-constrained
- Effects more severe for smaller/short range aircraft (business jets)

Source: TU Delft modelling

The Fischer-Tropsch process offers great opportunity for diversifying supply



- CO2 reduction
- Diversifying supply

Better efficiency

Higher engine temps

Better energy density

GTL, CTL

Kero from bio source

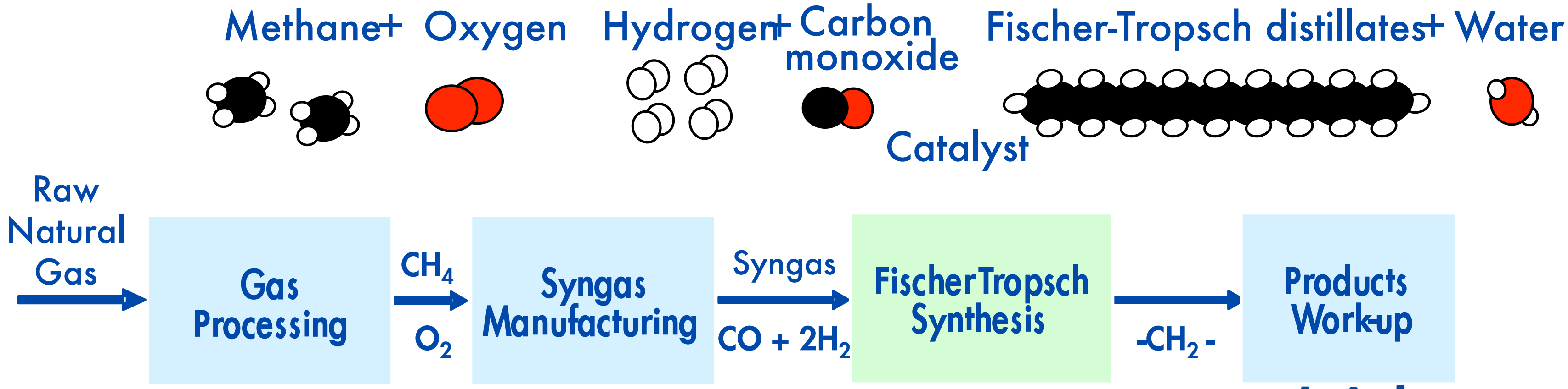
BTL

Kero from natural gas

Kero from coal

GTL, CTL

Gas-to-Liquids synthesis process



Methane + Oxygen

Hydrogen + Carbon monoxide

Fischer-Tropsch distillates + Water

Catalyst

Raw Natural Gas

Gas Processing

CH_4

O_2

Syngas Manufacturing

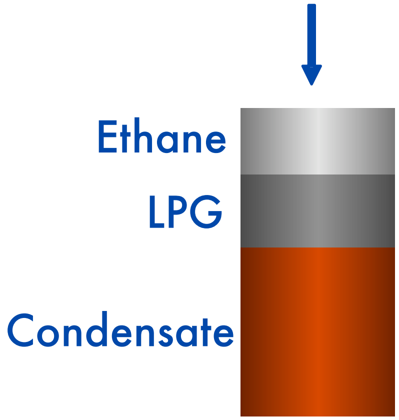
Syngas

$CO + 2H_2$

Fischer Tropsch Synthesis

$-CH_2-$

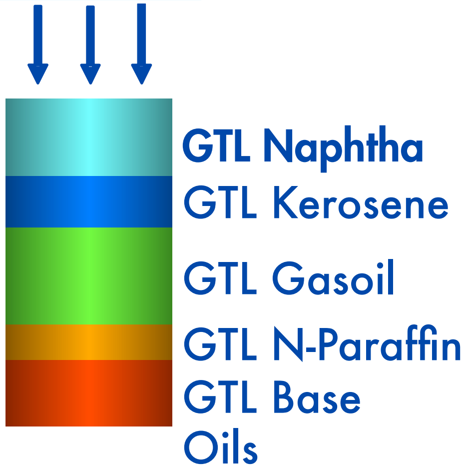
Products Work-up



Ethane

LPG

Condensate



GTL Naphtha

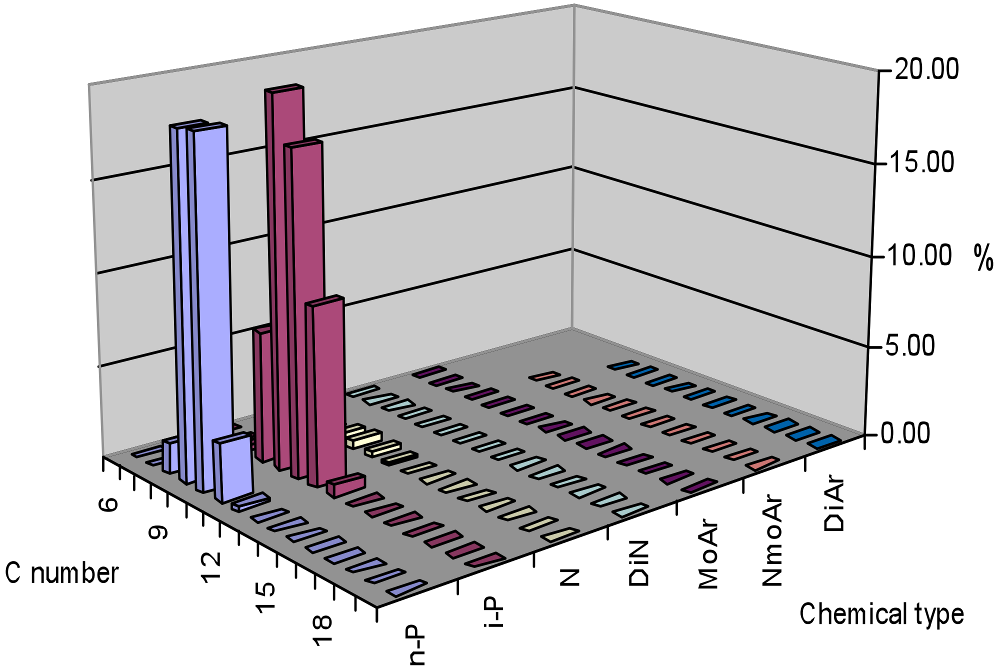
GTL Kerosene

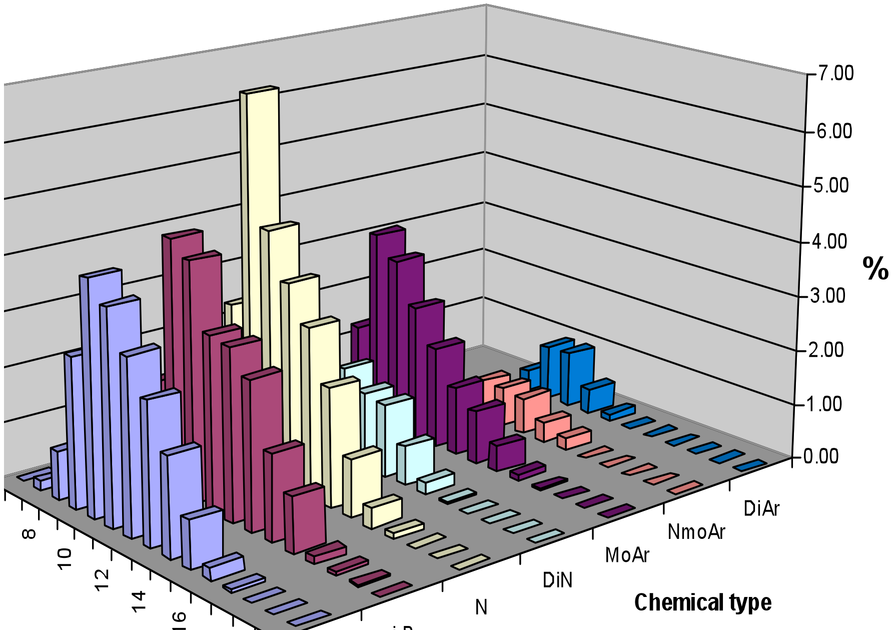
GTL Gasoil

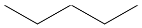
GTL N-Paraffin

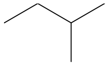
GTL Base Oils

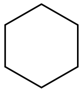
Fuel Composition

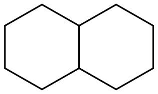

Gas-to-Liquids Jet

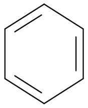

Typical UK Jet A1

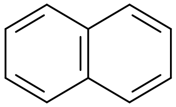

n-paraffinic

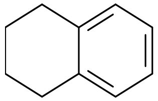

iso-
paraffinic

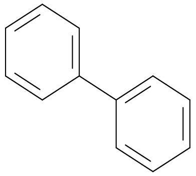

naphthene


di-naphthene


aromatic


di-aromatic


naphthenic mono-
aromatic

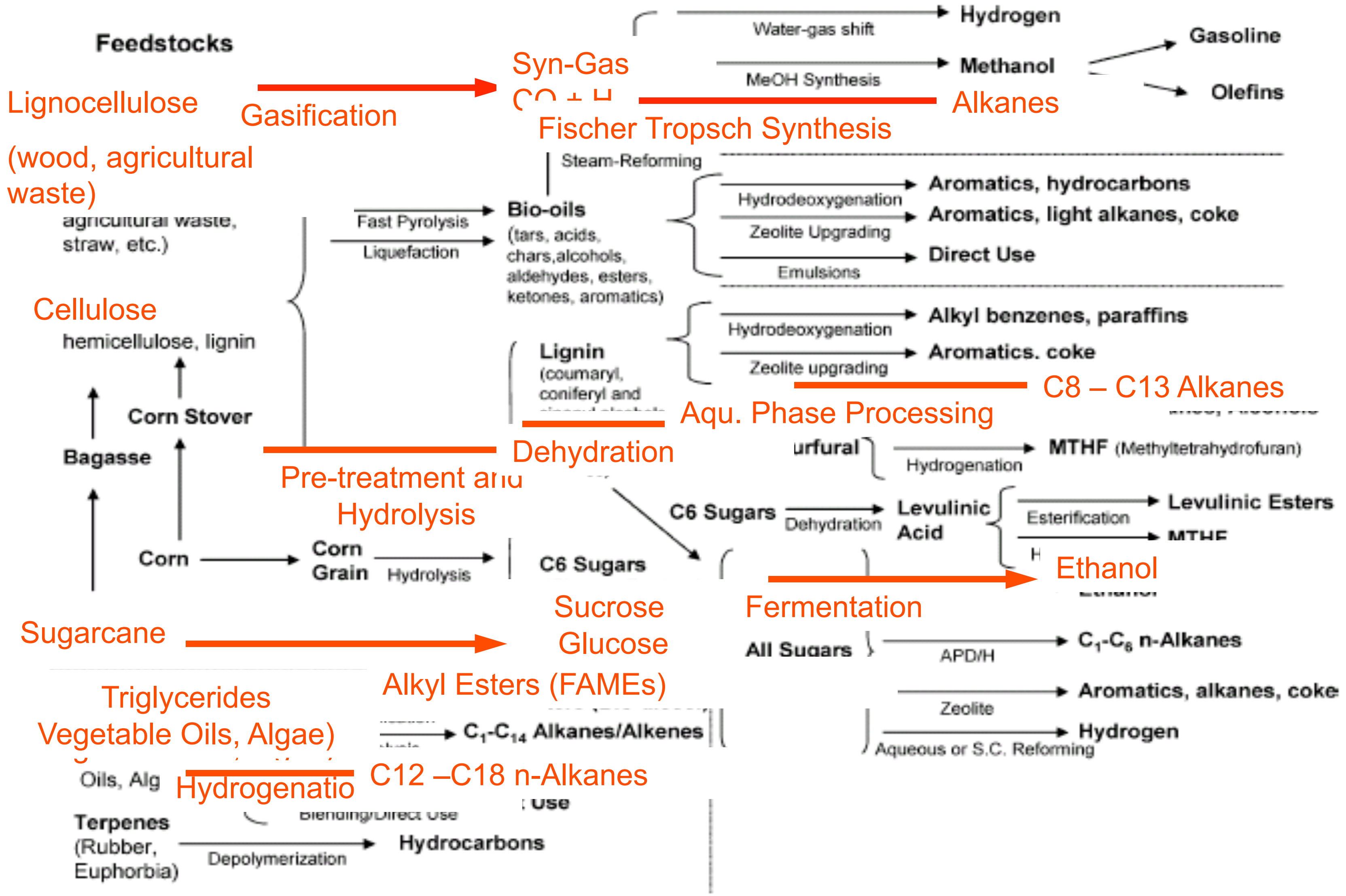

di-aromatic

Airbus A380 GTL flight - Feb. 1st, 2008

Producing a quick bio-jet fuel is difficult as 1st generation biofuels aren’t suitable for aviation

- Oxygen content gives weight penalty with no benefit
- FAME characteristics depend on original vegetable oil – certification is more complicated
- Significant engine and airframe issues – eg thermal stability and freeze point (+ corrosion for alcohols)
- May have applicability in bespoke local solutions, such as ethanol in piston engined crop dusters in Brazil but are not “drop-in” replacements for conventional fuels.

Fortunately there are many other options …



Feedstocks

Lignocellulose

(wood, agricultural waste)

agricultural waste, straw, etc.)

Gasification

Syn-Gas

CO + H

Water-gas shift → Hydrogen

MeOH Synthesis → Methanol → Gasoline, Olefins

Fischer Tropsch Synthesis → Alkanes

Steam-Reforming

Fast Pyrolysis, Liquefaction → Bio-oils (tars, acids, chars, alcohols, aldehydes, esters, ketones, aromatics)

Hydrodeoxygenation → Aromatics, hydrocarbons

Zeolite Upgrading → Aromatics, light alkanes, coke

Emulsions → Direct Use

Lignin (coumaryl, coniferyl and

Hydrodeoxygenation → Alkyl benzenes, paraffins

Zeolite upgrading → Aromatics, coke

Aqu. Phase Processing → C8 – C13 Alkanes

Cellulose

hemicellulose, lignin

Corn Stover

Bagasse

Corn

Pre-treatment and Hydrolysis

Dehydration

urfural → Hydrogenation → MTHF (Methyltetrahydrofuran)

C6 Sugars → Dehydration → Levulinic Acid

Esterification → Levulinic Esters

MTHF

Corn → Corn Grain → Hydrolysis → C6 Sugars

Fermentation → Ethanol

Sugarcane → Sucrose Glucose

All Sugars → APD/H → C_1-C_6 n-Alkanes

Zeolite → Aromatics, alkanes, coke

Aqueous or S.C. Reforming → Hydrogen

Triglycerides

Vegetable Oils, Algae)

Alkyl Esters (FAMEs)

→ C_1-C_{14} Alkanes/Alkenes

Oils, Alg

Hydrogenatio → C12 –C18 n-Alkanes

Blending/Direct Use

Terpenes (Rubber, Euphorbia) → Depolymerization → Hydrocarbons

Source: Huber

BTL kerosene – one route to green skies?

Better thermal stability – **potential for hotter, more efficient engines?**
Zero aromatics – **reduced soot emissions,**
Low luminosity flame – **longer engine life**
New molecules – **Improved supply**
Renewable – **Reduced CO_2 footprint (94% reduction)**

WORLD'S FIRST BTL DEMONSTRATION PLANT (Shell/Choren) WILL START UP 2008/9, PRODUCING CUTS FROM NAPHTHA TO DIESEL

BUT IS THIS THE WAY TO BIOJET ?

Very high cost of production plants
Availability of biomass ?
Cost of transport of biomass

Hydrotreating vegetable oils - A better option for aviation than FAME

- Uses conventional type hydrotreating technology
- Removes oxygen, hence good energy density
- Kerosine produced is very similar to GTL Kerosene (low S, low aromatics)
- Process is cheaper than BTL but feedstock more expensive
- Need to find suitable carbon chain oils
- Principal issue for aviation is the availability and cost of a suitable vegetable oil – are algae the answer ?

Some crops are better than others..

Crop	Yield (dry tonnes/ha/year
Wheat	4
Cereal straw	5
Corn	16
Cornstover	5
Temperate Willow	15
Miscanthus/switchgrass	15
Tropical Eucalyptus	20
Whole sugarcane	20
Sugar beet	21
Algae	100
Microalgae	200

Sustainability – the issues

- A number of issues are linked to the production of ethanol and FAME, particularly in developing countries & in tropical climates
- Safeguards are needed:
  - Social: migrant & child labour, human rights, local community land rights
  - Environmental: rare habitats & species, soil & water, CO_2 emissions
- Achieving safeguards is challenging in this new area
  - Complex, indirect impacts of agricultural practices and land use
  - Traceability from a traded commodity
  - Prohibitive cost of a fully segregated supply chain

METRO

Wednesday, May 9, 2007 www.metro.co.uk

Biofuels ‘a threat not our saviour’

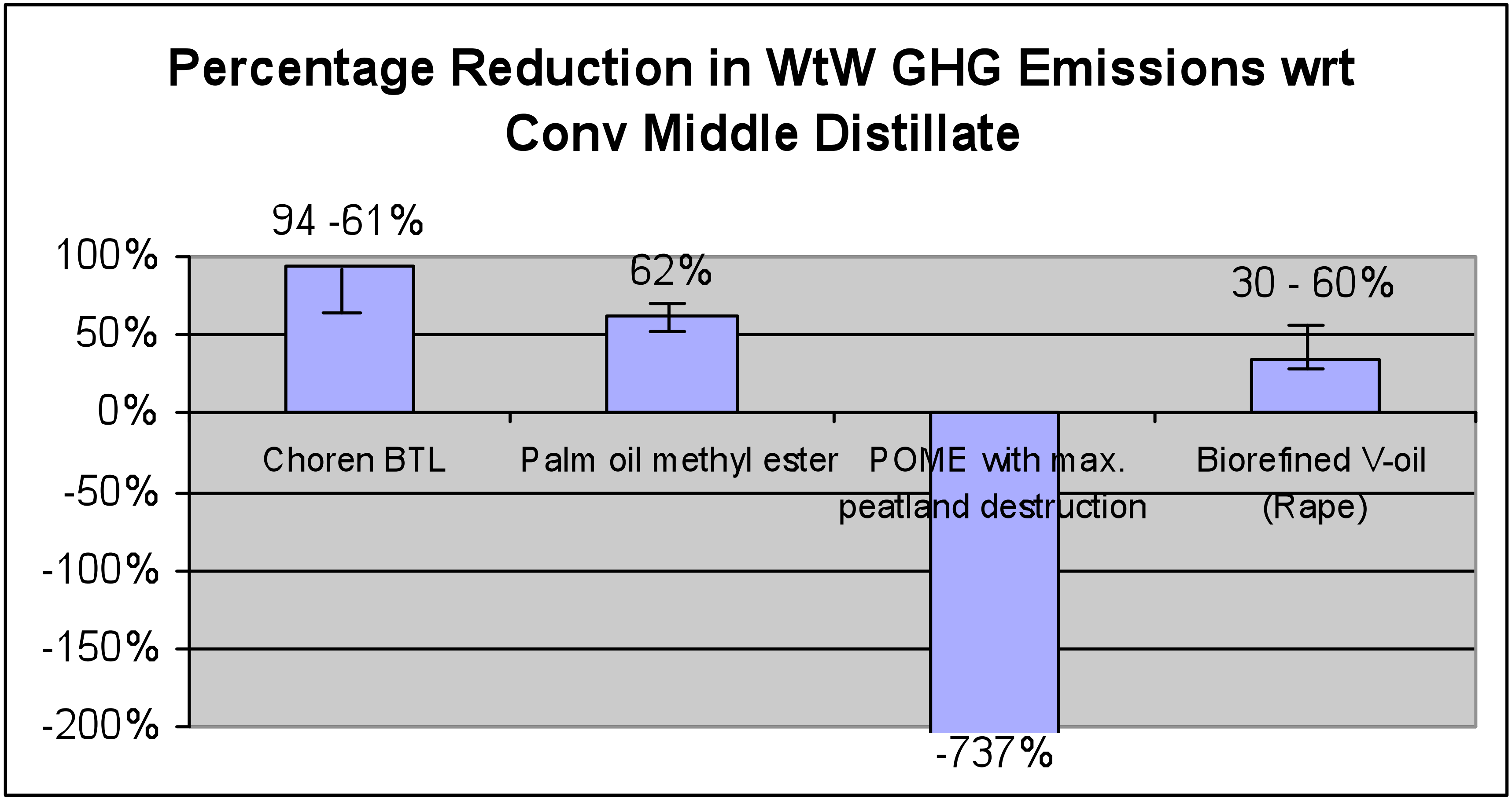
BIOFUELS will cause serious environmental and social damage instead of saving the planet, a UN report is warning.

BY OLIVER STALLWOOD

Algae: One of the Potential Feeds
Shell's Cellana Partnership

- Shell's collaborative partnership in Hawaii is constructing a pilot plant to grow marine algae in saline ponds.
- Facility will screen and cultivate microalgae for the production of vegetable oils.
- Microalgae produce at least 15 times more oil per hectare than alternatives such as Rape, Palm, Soy and Jatropha.
- Work is also being carried out to explore the potential for algae to capture waste CO2 from other industrial facilities.
- Aviation will have to compete with bio diesel.

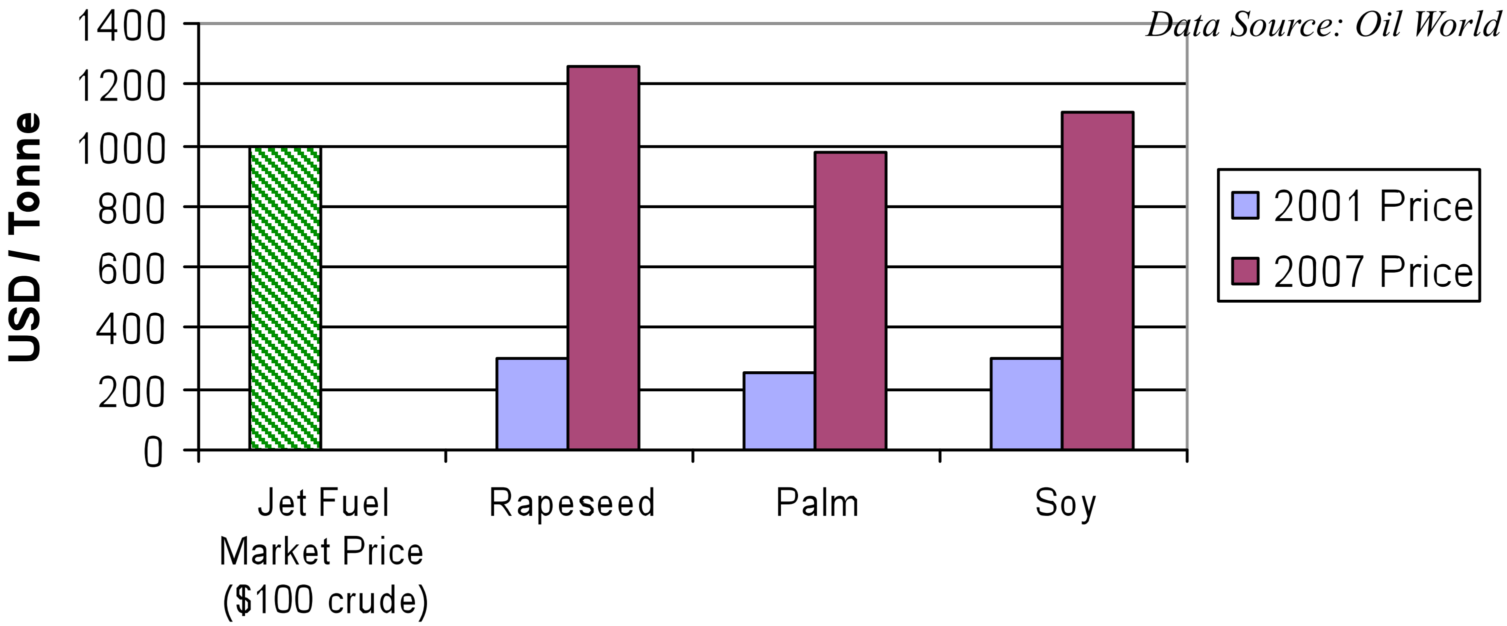
Each potential Pathway and Biomass Source has a different Well-to-Wake impact



Various sources.

Impact of legislation: driving markets short

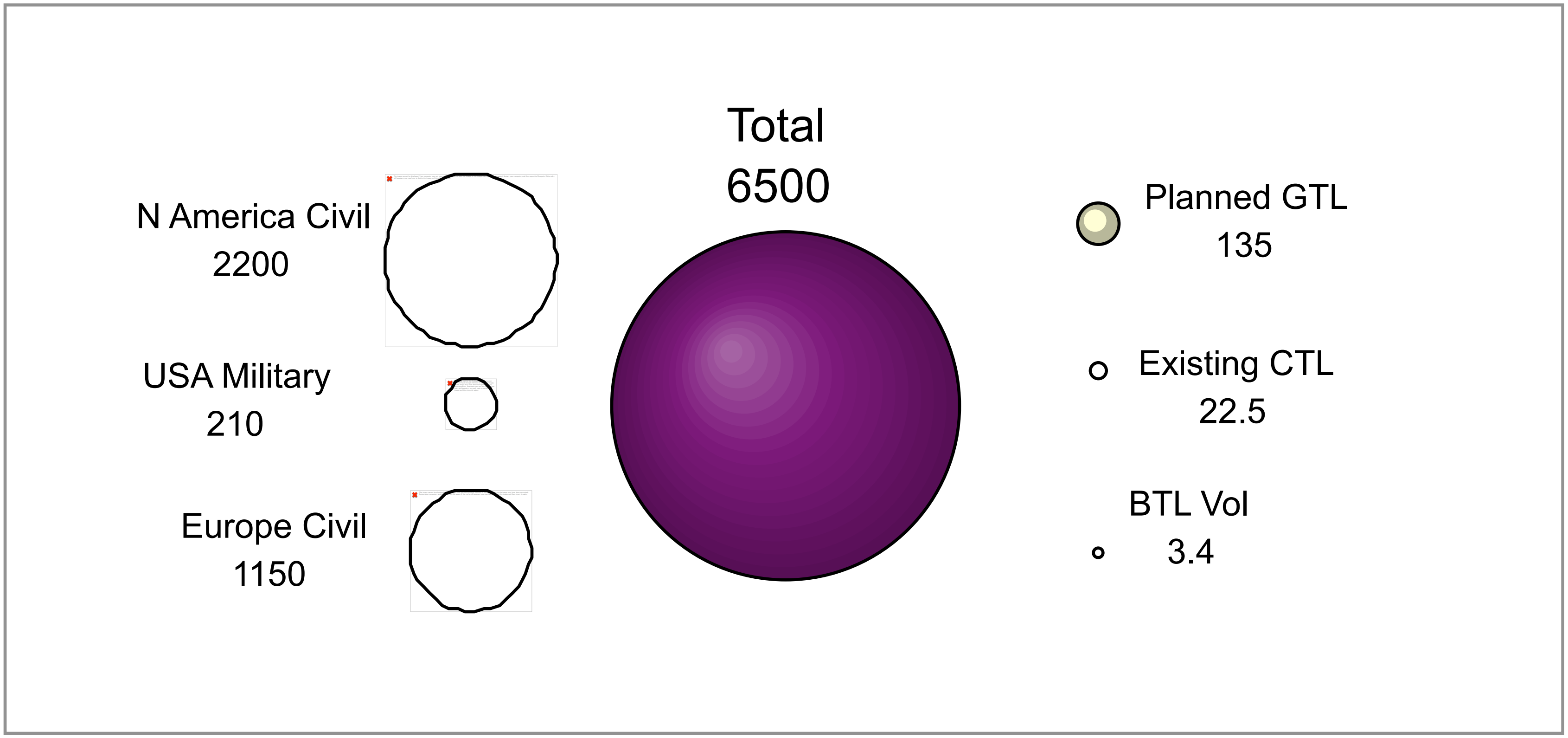
Change in traditional bio feed costs



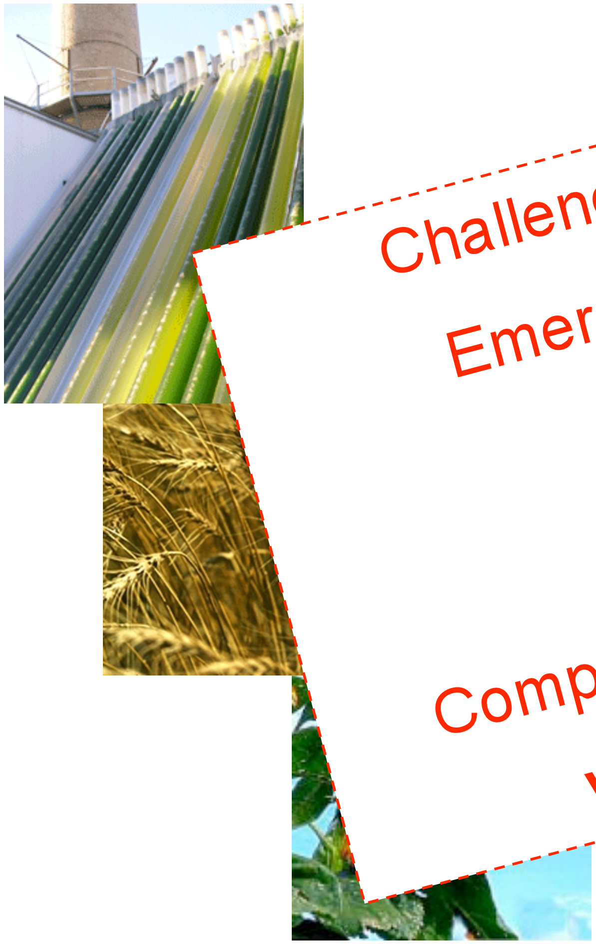
- "No single pathway offers a short-term route to high volumes of low carbon fuel" (Concawe Report).
- Contributions from a number of technologies is needed giving a wider variety of fuels, meaning niche applications need to be considered.

Estimated Picture for Jet in 2017

2017 Jet fuel Picture
Optimistic Forecasts for Alternatives (kbbl/day)



The Future and 'Bio Jet' challenges



Economic

- Large capita
- C

es.

pprovals

versity.

as.

rate

w production and cultivation costs
    - has the right natural carbon chain length
- Algae widely seen as having the greatest potential, but commercial-scale is some years away.
- Find low-cost and low-energy processing routes.

Challenges for alternative jet fuels?

Emerging/Unclear Business Case

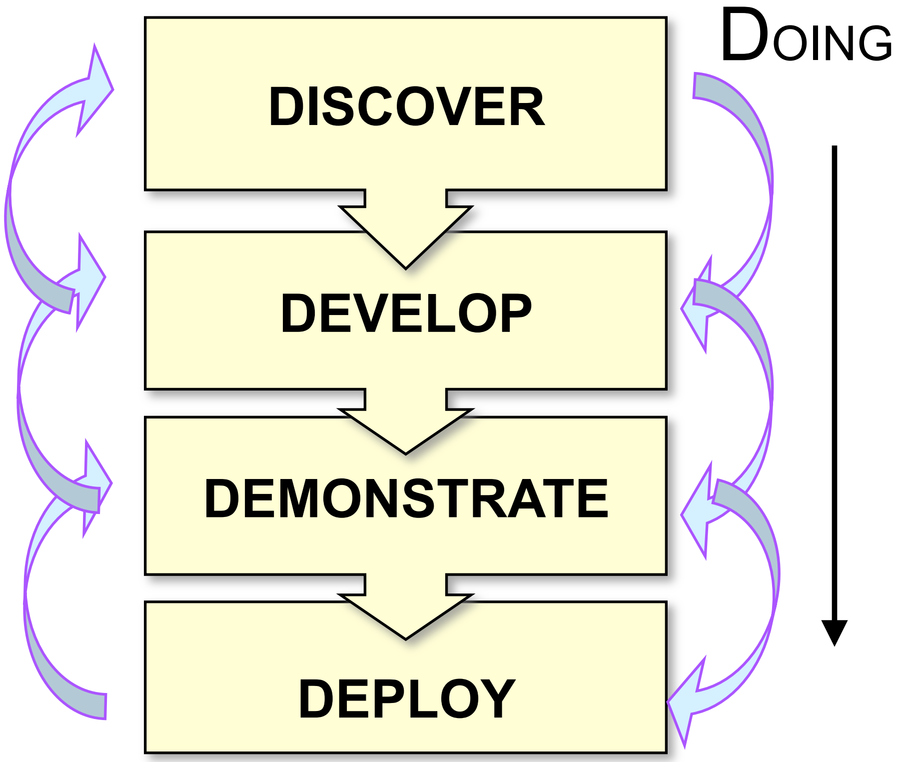
Capital

Product Cost

Competition with other transport sectors

Work continues despite this.

Shell's Technology Approach 'the 4 D'S'



DISCOVER

DEVELOP

DEMONSTRATE

DEPLOY

DOING

- Ongoing research programmes exploring feasibility of wide range of pathways
- Participation in CAAFI (FAA-led), IATA and several EU research consortia
- Demonstration projects in F-T fuels domain – 'Synthetic Fuel Continuum'
- Using portfolio approach: 'and-and' rather than 'or-or'

Shell welcomes interdisciplinary & international cooperation with OEMs, Academia & Governments to investigate options for Alternative Aviation fuels

What are your Questions?

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