Biofuels, Technologies, Transportation and Societies

Biofuels are liquids, solids or gases derived from sustainable renewable sources of biomass (see fig 1.)

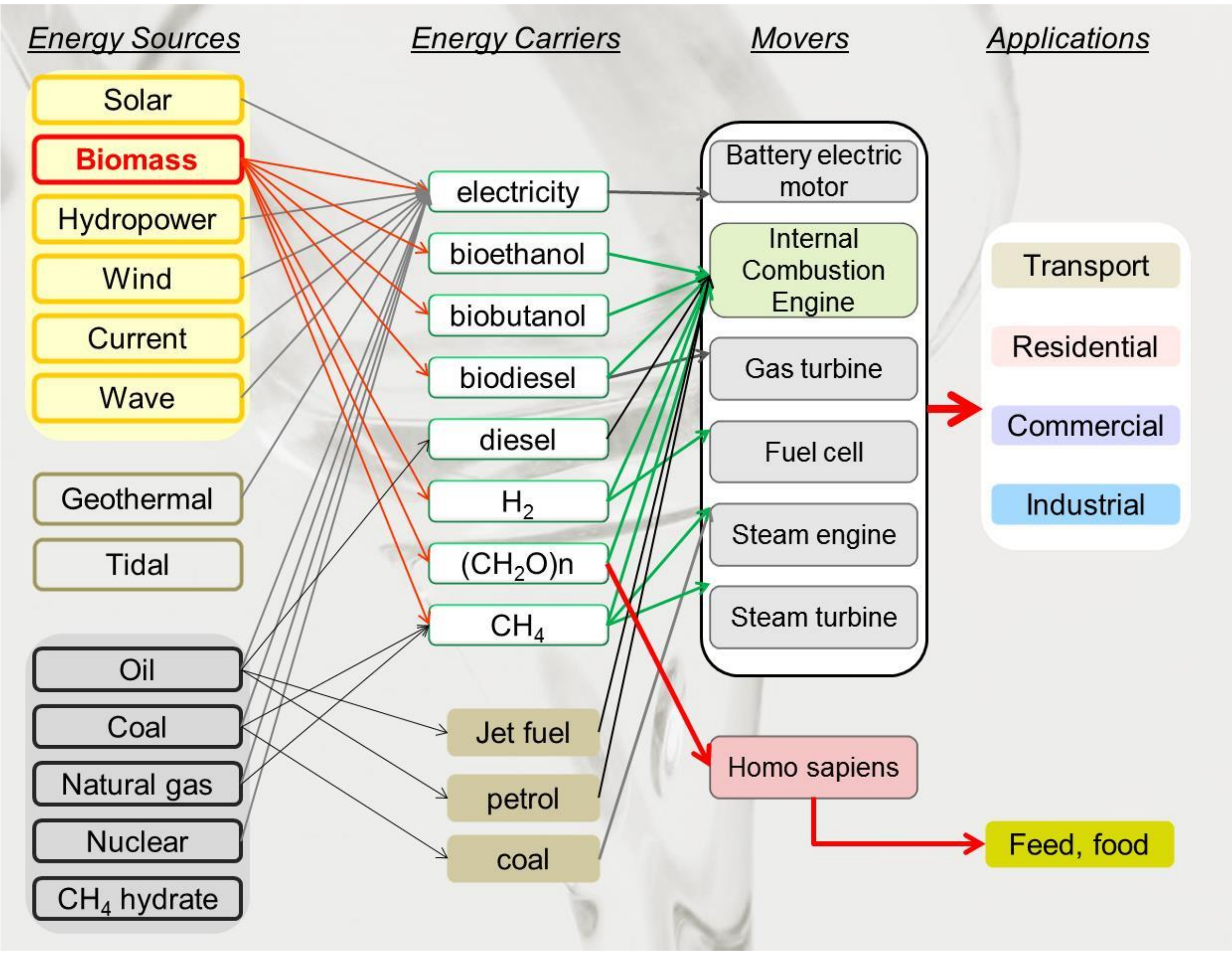


Fig. 1 Summary of energy sources, energy carriers, 'movers' and applications Energy sources today comprise: Geothermal, Tidal, Solar and its six transformations, and non-renewable

The use of biomass –derived fuels instead of fossil-based fuel is seen as an important route by which to achieve major gains in the reduction of carbon emissions. This is particularly so when they are used to fuel Combined Heat and Power (CHP) systems. The biofuels portfolio includes

- Ethanol (from carbohydrates),
- Biodiesel (from oils),
- Biomethane (from anaerobic digestion of biomass)
- lignocellulosic biomass
- biobutanol (from carbohydrates),
- glycerol.

Amongst renewable energy sources, only biofuels can be used to efficiently produce both heat and power in CHP systems.

Approaches to establish biofuel resources have been developed on the back of long-established farming practices aimed at providing food (so-called **first generation biofuels (Fig. 2)**, but new technologies based on the exploitation of industrial by-products such as glycerol, as well as food and agricultural wastes and the cultivation of algae (**second generation biofuels (Fig. 3)** are paving a way forward to ensure food production is not compromised and renewable resources are not wasted.

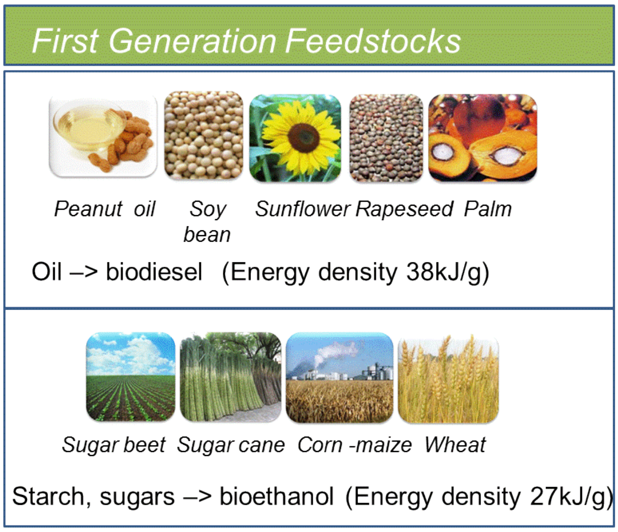


Fig. 2 First generation biomass feedstocks

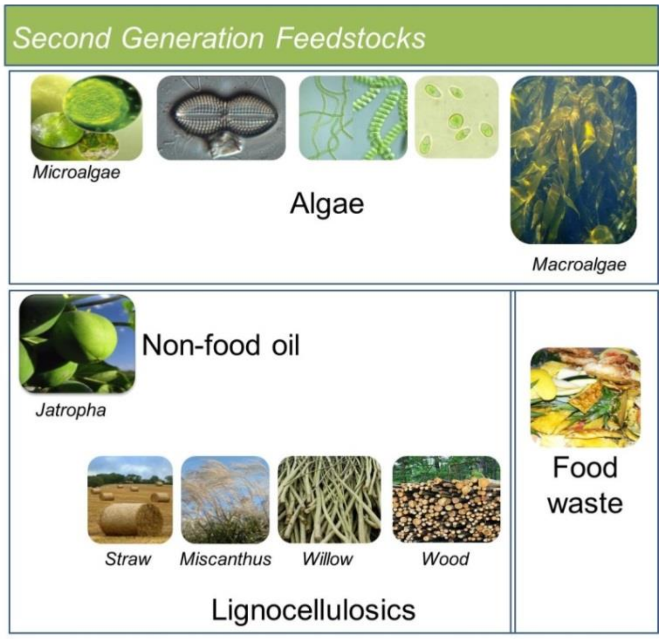


Fig. 3 Second generation biomass feedstocks

<u>Anaerobic digestion (AD) to produce biomethane</u>

One of the most efficient ways to sustainably process heterogeneous food waste and plant by-product streams is by anaerobic digestion (AD) to produce biomethane. The technology has been in existence for treating waste waters for more than a century, but take-up at an industrial scale has only recently been stimulated by rising oil prices; the need to divert organic wastes from landfill; and political incentives such as the availability of Carbon Credits and of Feed-in Tariffs, the latter of which are paving the way for gas supply to grid systems in Europe and parts of Africa such as Kenya.

The UK produces close to 500 million tonnes of waste each year, the majority of which ends up in landfill sites. As biodegradable waste breaks down in landfill sites, it naturally produces methane and carbon dioxide, which can continue being released into the atmosphere for anything up to several hundred years after a site has been closed. Both of these gases play a major role in global warming, climate change and damage to the ozone layer. Additionally, landfill sites bring the risk of water and noise pollution and of course the attraction of vermin.

In an attempt to significantly reduce the amount of waste going to landfill, the EU has issued a set of directives which will see biodegradable waste being recycled by processes such as Anaerobic Digestion. By 2013, the UK aims to have reduced waste going to landfill by up to 8 million tonnes - municipal and commercial waste account for well over 100m tonnes and the remainder is made up of agricultural and controlled wastes. .

The Proximity principle proposes that waste should be recycled/treated/disposed of as close to its place of origin as possible to reduce emissions energy use from transportation.

In South Africa, lack of enabling legislation has slowed the development of CHP programmes and in turn, industrial-scale take-up of biogas production.

<u>AD and Integrated Algal Pond Systems (IAPS)</u>

AD produces biogas not pure biomethane, and impurities of CO2 (20-50% v/v) and other minor gases need to be removed to meet gas quality specifications for grid connection. As a result innovative processes are required to capture and use the CO2 in biogas to cultivate microalgae in AD effluents, offering the potential for simultaneous carbon recovery, energy capture, and gas purification, as well as nutrient sequestration and cleaning of AD effluent water. One such technology is the Integrated Algal Pond System (IAPS)

The Integrated Algal Pond System uses algae in a waste water management system to clean the effluent water from anaerobic digestion of wastes with a high water content. The algae also capture solar energy and support the growth of the natural waste water bacterial communities to produce biogas from waste water organic matter.

Algae growing in a facultative pond (See Fig 4) in the surface layers of waste water above the bacteria from anaerobic fermentation of waste, clean up the biogas by removing the CO2 from the biogas through the process of photosynthesis. The resulting gas is methane, which can be harvested and piped from the ponds as an energy source to power a generator and produce electricity and heat in CHP.   A powerful means of trapping solar energy, the algae also sequester nitrogen and phosphorus from the wastewater and can be cultivated in downstream high rate algal ponds. Go to Training resources: Algae systems in wastewater treatment for more information.

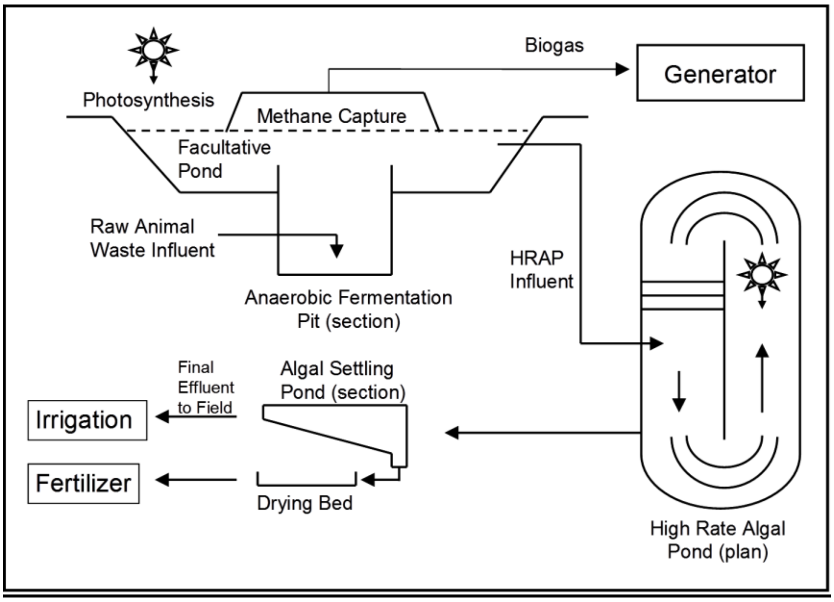


Fig. 4. Scheme of an Integrated Algal Pond System (Rhodes University – go to Algae systems in wastewater treatment*)*

Biodiesel

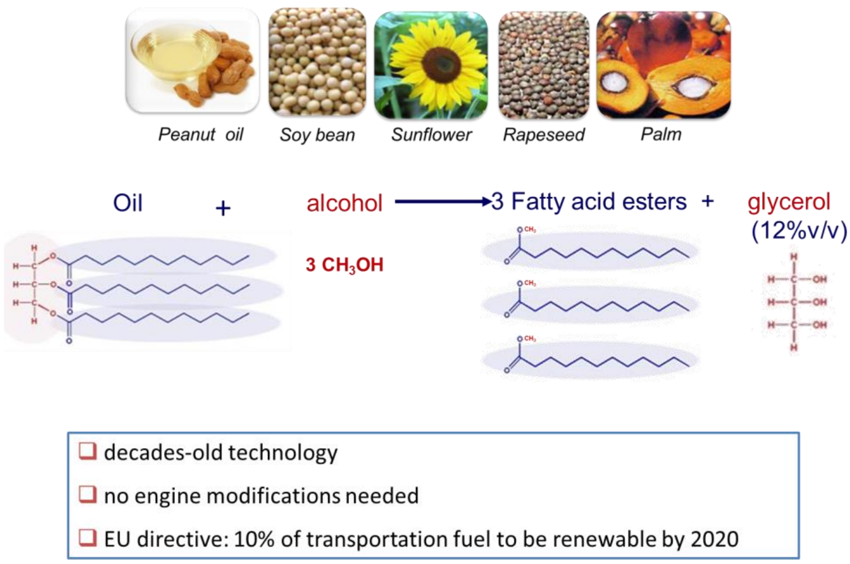


Fig.5. Overview of oil esterification to make biodiesel

In the biodiesel industry sector, technologies to make biodiesel esters and glycerol from plant oil have been in existence since the 1920's and are now widespread because biodiesel can be used in place of fossil fuel in standard diesel engines without engine modification. Although the demand in Africa has thus far been driven purely by economics and fossil-fuel availability, in Europe, the EU Biofuels Directive of May 2003 stipulated that member states must replace 5.75% of all transport fossil fuels with biofuels by 2010.

2008 witnessed dramatically increased world food prices, fuelled in part by the demand for biofuels in developed countries but also by agricultural subsidies in developed nations, which impacted negatively on agriculture practice in developing nations; commodity market speculation, changing eating habits in China and India in favour of more resource intensive beef and dairy food ; and climate change. These factors coupled with rainforest destruction to clear land for agriculture, and the decline in fossil fuel prices in 2009, resulted in a rethink of the biofuel programme. This has in turn resulted in capacity targets not being realised and many biodiesel producers going out of business.

Glycerol

The by-product of biodiesel production, glycerol, will provide heat and electricity at very high efficiency (>90%) without chemical alteration or the addition of combustion enhancers thanks to the discovery of a novel compression ignition cycle in CHP systems (the McNeil cycle). In fact, the combustion of glycerol is more energy efficient than any known fossil, bio or synthetic fuel. No detectable combustion particulate is produced and it can deliver the lowest possible exhaust emissions. It also has the safest handling properties of all known fuels - it is water soluble, bio-degradable, non-odorous, non-volatile, non-toxic and has low flammability. The higher the energy density of the fuel, the more energy may be stored or transported for the same amount of volume. Glycerol has a relatively high density, so on a volumetric basis its energy content is better than that of e.g. methanol (See Fig 6).

Glycerol also has a high boiling point and heat capacity and extremely low volatility, so glycerol fuel tanks can be safely used as thermal batteries, storing heat for CHP applications.

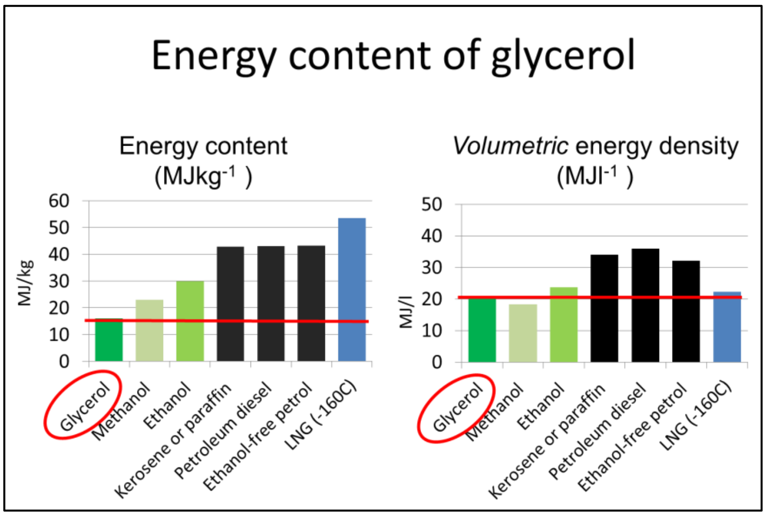
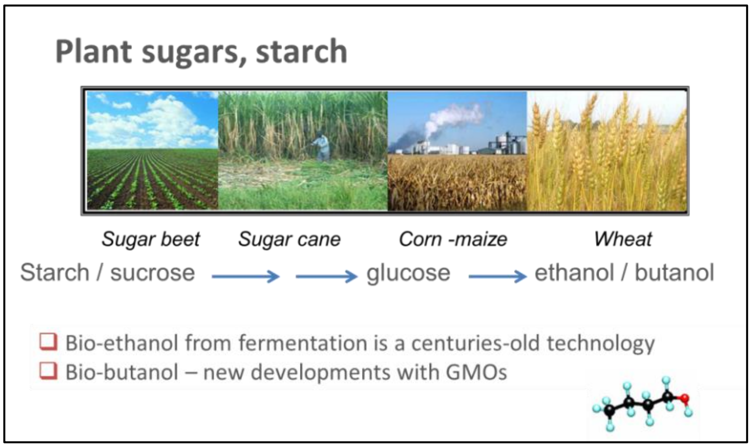


Fig 6

Co-development of a glycerol biofuel market is predicted to completely overhaul the biodiesel industry sector, providing the necessary timelines to establish alternative new sources of glycerol, ultimately a better fuel than biodiesel. In this regard, significant attention is being paid to halophytic microalgae that generate up to 80% of their mass as glycerol in highly saline environments. Even so, industrial-scale production of glycerol from algae still needs fundamental research to find economical ways to deliver microalgal glycerol from saline waters to CHP systems. The EU-Africa Caribbean Pacific (ACP) Science and Technology programme has established a new project for 2009-2012 aimed at capacity building to create sustainable non-food biofuel supply chains for CHP in Africa, such as those based on glycerol and biogas.

Bioethanol and Biobutanol



Bioethanol and biobutanol are both sourced from the fermentation of sugars in crops such as wheat or sugar-cane.

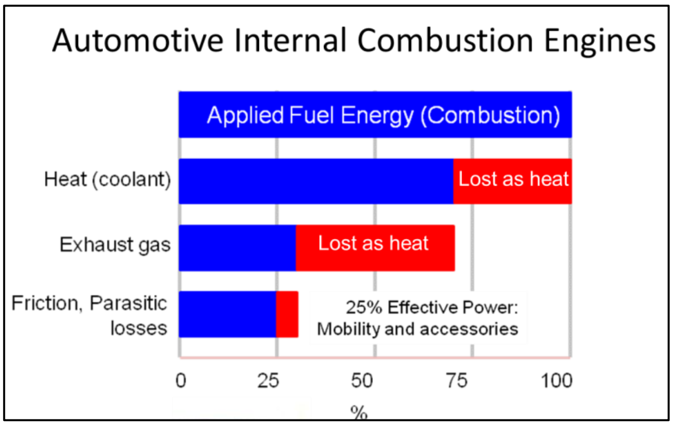
Biobutanol is a 4-carbon alcohol (butyl alcohol). Historically, up until about the mid-50s, biobutanol was fermented from simple sugars in a process that produced acetone and ethanol, in addition to the butanol component. The process is known as ABE (Acetone Butanol Ethanol) and has used unsophisticated microbes such as Clostridium acetobutylicum. The problem with this type of microbe is that it is poisoned by the butanol it produces once the alcohol concentration rises above approximately 2%. GMOs have obviated these problems.

Biofuels and Transport

The efficiency of an internal combustion engine refers to the percentage of the energy resulting from the combustion that actually is applied to moving the car or running the accessories. Of the 100% energy available from combustion, ~ 25% is used to produce mechanical energy that turns the wheels of the car or running the accessories (+5% for the parasitic and friction losses). Diesel engines and lean combustion gasoline engines are somewhat better: 35% of the energy flows to mobility and accessories.

The energy content of biobutanol is closer to that of petrol than ethanol and so offers better fuel economy than petrol/ethanol blends. It is easily blended with conventional grades of petrol, so can be readily incorporated into an existing fuel infrastructure. Vehicles can also be fuelled with high concentrations of biobutanol—up to 100%—with minor or no vehicle modifications, unlike bioethanol.

Bioethanol is a superior fuel for spark ignition internal combustion engines compared to petrol, but only if the engine is optimized to run on bioethanol. If petrol is used in a bioethanol engine it would cause knocking, which would damage the engine. Because of the compression limitation required to prevent “engine knock”, a typical petrol engine can only deliver about 25% efficiency: the other 75% is lost in waste heat.



Energy conversion efficiencies

Conversion	Efficiency %	Input
Electrical motor	90-97	Electricity through grid
Small electric motor	60-75%	Electricity in battery
Steam turbine 40-45%	40-45%	Steam
Gas turbine	35 - 40%	Gas
Diesel ICE	30-35%	Diesel
Petrol ICE	15-25%	Petrol
Mammalian muscle	15-20%	Glucose

Zhang (2011): Process Biochemistry 46, 2091-2110

A bioethanol engine can deliver about 40% efficiency, more comparable to that of a diesel engine.

Hybrid electric vehicles (HEVs) combine the internal combustion engine of a conventional vehicle with the high-voltage battery and electric motor of an electric vehicle. As a result, HEVs can achieve twice the fuel economy of conventional vehicles.

In **2005 the US DOE announced** $87.5 million in co-funding to support 12 projects developing advanced combustion engine and waste heat recovery technologies. The projects, with a total value of $175 million (50%, or $87.5 million, of which is contributed by industry) focus on increasing engine efficiency while maintaining low emissions.

The Administration has set of goal of improving engine efficiency from 30% (the 2004 baseline) to 45% by 2012 for passenger vehicles and from 40% (2002 baseline) to 55% by 2013 for commercial vehicles. Such increases in thermal efficiency would result in a projected concomitant reduction in engine fuel consumption of 10%–15%.

In **2011 the European Commission adopted a roadmap** of 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050.

In the White paper 2011: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, by 2050, key goals will include:

- No more conventionally-fuelled cars in cities.
- 40% use of sustainable low carbon fuels in aviation; at least 40% cut in shipping emissions.
- A 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.
- All of which will contribute to a 60% cut in transport emissions by the middle of the century.