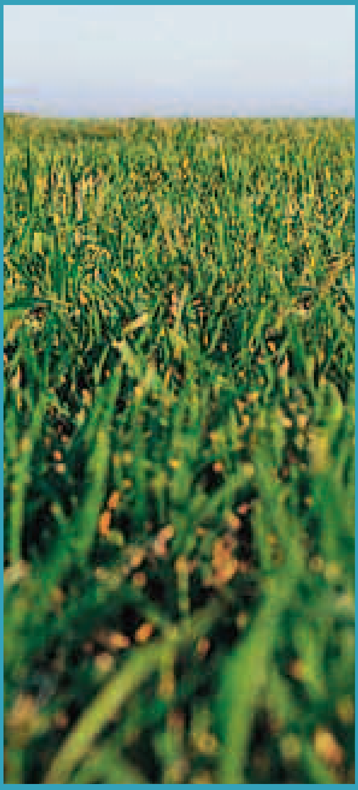
Second Generation Biofuels - A Greenergy perspective

In this Perspective Green*ergy* addresses some of the opportunities and issues associated with second generation biofuels.



Summary

Green*ergy* is a significant producer and supplier of petroleum and biofuels into the UK transport fuels market, supplying over 15% of the UK's overall petrol and diesel market and approximately one third of the biofuels market. The company has extensive worldwide sourcing experience, with manufacturing operations in the UK and a blending facility in Rotterdam from which we supply customers across Europe.

Green*ergy* is not a developer of second generation biofuel technology but intends to supply second generation biofuels once these become commercially available and assuming they offer genuine environmental and carbon benefit.

In this Perspective, Green*ergy* presents the following:

- First generation biofuels are generally derived from crop based feedstocks, while second generation biofuels can be derived from a broader range of feedstocks, such as grasses, wood, landfill waste and potentially algae.
- The new technologies for second generation biofuel are being developed, but very few are yet viable in commercial scale production.
- Comparing the benefits of first and second generation biofuels is complex and the advantages and disadvantages of second generation biofuels are not yet fully understood.
- The energy density of feedstocks is important to the practicality of second generation biofuels. Some second generation biofuels which are derived from feedstocks with a low energy density may face logistical issues and land use efficiency questions and these may present as big a barrier to their uptake as the development of the core technology.
- To help determine which second generation feedstocks are most attractive Green*ergy* uses a 'Product Process Value' formula which considers economic, environmental, carbon and productivity factors.

The arguments for and against first and second generation biofuels can be split into cost, carbon benefit, land use yield and logistics.

In general:

Issue	First Generation	Second Generation
Capital cost	Low per tonne	High per tonne
Feedstock cost	High per tonne	Low per tonne
Operating cost	Low per tonne	High per tonne
Carbon benefit per tonne	Variable (poor to excellent)	Variable (poor to excellent)
Carbon benefit per hectare	Variable (poor to excellent)	Good to best
Energy yield	High	Low
Logistics	Low cost and practical	Generally high cost, impractical
Land resources	Possible to implement within existing long term arrangements	Difficult to see how most can be developed without significant land use change

An overview of the different second generation biofuels under development is included in the Appendix.

1 Defining first and second generation biofuels

Perspective
In general first generation biofuels are derived from crop based feedstocks, while second generation biofuels are derived from a broader range of feedstocks, such as grasses, wood, landfill waste and potentially microalgae.

There is no simple and broadly agreed definition of what constitutes first and second generation biofuels.

First generation biofuels are generally considered to be fuels made from traditional crop based feedstocks that are primary energy sources and produced in low intensity[1] production processes to defined quality parameters - for example vegetable oil for biodiesel (via esterification) and sugar crops for bioethanol (via fermentation). The resultant fuels are distinctive and high quality.

Second generation biofuel processes are complex and designed to convert a broader range of feedstocks using complex, high intensity[2] manufacturing plants to produce fuels that may be indistinguishable from the petroleum fuels they seek to replace.

In particular second generation fuels seek to use lower cost feedstocks that are perceived to be more widely available or give higher tonnage yields per hectare. The promoters of such technologies argue that such feedstocks could offer energy and sustainability benefits compared to the more traditional crops used for first generation biofuel production[3].

1 Low capital expenditure, low internal energy consumption / loss, simple processing schemes
2 High capital expenditure, high internal energy consumption/loss, complex processing schemes
3 Shell http://www.shell.com/home/content/aboutshell-en/what_we_do/refining_selling/fuels/biofuels.html

2 About second generation biofuel technologies

Perspective
Most of the effort taking place by second generation technology developers is to make the uneconomic economic, both financially and environmentally.

Whilst being promoted as second generation, most of the underlying chemical and thermal processes inherent in second generation biofuels are long standing - for example pyrolysis for biomass to liquids technology. Therefore in many cases the technological issue is not one of invention but rather one of improvement, novel application or, in the case of the more complex processes, economics. The gross margin that can be generated from second generation biofuel production does not currently cover the capital and operating costs and therefore currently no second generation biofuels are in commercial production.

A list of second generation biofuels under development is included in the Appendix.

3 Green*ergy* plans for second generation biofuels

Perspective

As a biofuel supplier rather than a technology developer, Green*ergy*'s role is to develop market access for second generation biofuels. Green*ergy* intends to supply second-generation biofuels once these are commercially available, on the condition that they offer genuine environmental benefits and are price competitive.

Green*ergy* is committed to supplying sustainably produced biofuels which offer genuine carbon savings. It is seeking to expand its production of biofuel and will do so by licensing biofuel production technology from the technology innovators. For example, the technology used at Green*ergy*'s biodiesel plant in Immingham is licensed from Desmet Ballestra.

Large amounts of capital are being invested in the development of second generation biofuel technologies and some solutions can be expected over the years ahead. If or when these technologies deliver appropriate environmental and financial benefits and are reliable, Green*ergy* will adopt them.

For example Green*ergy* has an exclusive UK license over one particular solid waste to biofuel technology which it expects to announce and start commercialising in 2008 / 09. This will be announced in due course.

The following table describes some technologies that Green*ergy* is monitoring with interest.

Table 1. Some interesting technologies

Technology	Why watch it
Bioethanol from wood as a co-product from timber	Large quantity of relatively low cost feedstock. High carbon:nitrogen ratio. Can be combined with afforestation.
Bioethanol from cellulosic (Switchgrass)	High yield per hectare of feedstock creates a potentially good use of US grasslands, if combined with first generation fuels for commercial scale
Biodiesel and bioethanol from algae	Not strictly a biofuel, more an efficiency improver of existing power stations. Nevertheless, by using waste heat from existing power stations it has potential to achieve the highest production density per hectare, so is particularly suited to developed countries
Bioethanol from landfill waste	Potential to capitalise on existing waste supply chain. Alternative solutions to landfill are critically required in many developed countries.

4 The broader aims of biofuels generation

Perspective
All biofuels, both first and second generation, convert the sun's energy into vehicle energy. The most effective biofuels will be those that do so using the least amount of land and fossil fuel inputs[4].

Biofuels aim to be low carbon to reduce the effect of climate change, sustainable so that there are no unexpected negatives to offset the low carbon, and a financially viable alternative to petroleum fuels.

Fundamentally the source of all biofuels and virtually all forms of energy including the food we eat is the sun and the land. Biofuels capture the sun's energy through photosynthesis in plants which is released through combustion in vehicle engines. In this respect we are all solar powered and even fossil fuels are "solar energy delayed" since they are formed from plants growing on the earth many millions of years ago.

Therefore the most effective biofuels and biofuel technologies will be those that convert the greatest amount of the sun's energy per hectare to vehicle energy. Calculating this is a complex matter and needs to take account of land use issues and the practical thermodynamic limitations of energy processing.

The importance of the laws of thermodynamics

Perspective: It is helpful to consider supply chains in their most fundamental form when considering alternatives forms of biofuel feedstocks.

The laws of thermodynamics are particularly useful when ranking different types of biofuel processing routes. The laws are:

- First Law - Energy is conserved; it cannot be created or destroyed[5].
  The first law tells us that there is only so much potential energy available from a given crop or feedstock source, irrespective of the kind of technology used to make a fuel.

- Second Law - Entropy (unusable disorder) increases with all activity[6].
  So, every time we do something involving energy processing some useful energy is lost forever into low grade unusable energy. A car for example, is only 40% efficient because unrecoverable heat is lost to the environment through the radiator, exhaust and friction.

- The Second Law tells us that to get the best benefit from a given crop of feedstock we must minimise the number of energy changes of state to the feedstock within the processing route i.e. burning primary biomass as a wood or straw creates less entropy than gasifying, condensing into a liquid and then burning it as a biomass to liquid fuel.

It is interesting that whilst first generation fuels (e.g. biodiesel) are often referred to as inefficient because they use crops, they are in fact the most efficient according to the Second Law. This is because they require relatively little process energy changes of state as nature has already pre-prepared the feedstock into the liquid form (nature being a far more efficient processor than man).

4 Fossil fuel inputs = fertiliser + energy in transport and processing
5 http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEner1.html
6 http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEner1.html

5 Comparing the benefits of different biofuels production methods and generations

Perspective

Green*ergy* uses a formula which it calls "Product Process Value" to rank different biofuel production methods.

When assessing the relative merits of different biofuel production methods and generations we need to consider the following:

- Source and type of biomass;
- Yield per hectare per year, taking into account land value and water requirements;
- Efficiency and complexity of conversion of the energy to vehicle fuel (the process route);
- Net effect on carbon emissions;
- Any other factors or weaknesses such as water consumption, process energy consumption, biodiversity or logistics etc (called here "hygiene factors");
- Additionality and the alternative uses of the feedstock - does the biofuel production method give genuinely additional benefits and would the feedstock or land have produced greater benefits if used for another purpose; and
- Financial and environmental economics.

In simple terms different biofuels can be assessed in the following way:

- (Energy per hectare per year) x (process route efficiency) – (hygiene factors) – (additionality considerations) = benefit
- Benefit / costs = "Product Process Value".

Green*ergy* believes "Product Process Value" is the key test of the value of a biofuel, whether first or second generation. Brazilian first generation bioethanol scores well because it has very good carbon efficiency, and is therefore used by Green*ergy* in preference to other first generation sources of bioethanol such as bioethanol derived from US corn, which Green*ergy* chooses not to supply.

6 Land use, fundamental energy availability and energy density

Perspective

The logistical requirements for second generation feedstocks, energy density, land use change and production location are as big a barrier to the development of second generation biofuels as the core technology.

In the developed world, particularly in Western Europe, much of the land has been intensively managed for a long period of time, so there is little opportunity to find hidden land resources. Within agronomic restraints such as crop rotations, crops are optimised for the location in which they are grown. So in the UK, arable crops predominate in the East and grass for milk and beef cattle in the wetter West.

In the developed world very little land is unproductive. Thus, in northern Europe, if a second generation biofuel requires a feedstock which is not currently grown it may be difficult, and probably in terms of the yield per hectare per year be dis-optimal, to substantially change land use.

Most of the novel crops (grasses, woody biomass) required for second generation biofuels are of low energy density and low value. This means that distribution costs dominate the economics, and in many cases it will be economically and environmentally preferable to utilise the biomass locally for heat rather than as a feedstock for transport fuels.

Table 2. Energy density of different crops used for energy

Crop	Energy per tonne (GJ/tonne)	Density (tonnes/m^2)	Tonnes per truck load (22 tonnes or 45 cbm max)	Energy per truck load (22 tonnes or 40 cbm) GJ	Value of crop per tonne £	Value of crops per truck £	Value per 'Fundamental' £/GJ
Rapeseed	18[7]	0.669[8]	22,000	396	230	5,060	22
Rapeseed oil	37[9]	0.915[10]	22,000	814	650	14,300	22
Wheat	17[11]	0.772[12]	22,000	374	120	2,640	22
Switch grass	13[13]	0.160[14]	5,400	70.2	40	216	5.4
SRC	18[15]	0.396[16]	6,750	121.5	40	270	6.75

Sources: Various

7 Derived from Energy Power Resources
8 Handbook of Industrial Drying
9 Austrian Biofuels Institute
10 DIN EN ISO 3675 Quality standard for Vegetable Oil
11 FAO
12 Handbook of Industrial Drying
13 Biomass Energy Centre
14 Centre for Renewable Energy and Sustainable Technology
15 ibid
16 (assumed willow) ECCM forestry models

Table 1 shows how the financial value and energy value of different feedstock truck loads vary. The low energy content of grasses per truck means a lot more trucking and handling is required to transport such feedstocks to the production plant than for 1st generation feedstocks. Switchgrass for example has only 20% of the truck energy value of wheat or rapeseed, meaning about 5 times more trucks are required at a given energy output. At the same time the value of grasses or wood is much lower per truck substantially reducing the range that the feedstocks can be moved economically.

It is worth noting that five tonnes of biomass on a truck is the equivalent of only one tonne of final fuel. To put this into context a normal fuel tanker used by Green*ergy* will carry 28 tonnes of product fuel and a normal road tanker has at least a 600kg fuel tank for own use. These logistics are very inefficient and unless they can be substantially improved will be detrimental to the development and progress into market of second generation biofuels.

The substantial land use changes needed in the developed world in order to yield novel[17] crops for second generation biofuels will require enormous changes in world agricultural trade patterns. This will also mean more “high value and dense” food crops being grown outside Europe in tropical areas and imported, and more “low value and low density” novel energy crops grown in Europe to supply 2nd generation fuels. At the same time the use of the novel feedstocks will have to be close to the farm in order to support the distribution costs and this may lead to many small inefficient production plants rather than few larger.

Given that second generation technologies are inherently more expensive (3 to 10 times per tonne of production), they would logically need fewer bigger production facilities to support the investment rather than a larger number of smaller ones. This contradiction between the need for very local feedstock logistics and large “mega” factories to cover the high technology costs appears to substantially undermine many of the potential second generation feedstocks and technology benefits.

An alternative solution to this problem is to produce second generation fuels in tropical areas.

17 Novel is used here in the context of growing, for example, SRC where wheat or rape or sheep may currently be grown. In south east Scotland for the Lockerbie biomass plant SRC is being established on former sheep grazing land.

7 Product Process Value energy

Perspective

If these logistical issues can be solved, second generation feedstocks appear to be attractive on a per hectare basis compared to first generation feedstocks.

Table 3 shows that on a benefit per hectare basis some second generation crops (notably switchgrass grass) are more attractive compared to first generation technologies but do not compare well with to tropical first generation feedstocks.

Table 3. Energy density and carbon saving of different crops

Crop	Tonnes per hectare per year	Generation	Use	Tonnes of product per tonne of feed	Energy per tonne of product (GJ)	Energy per hectare per year (GJ)	% carbon saving per tonne of product	Carbon saving per hectare per year te C
Rapeseed	1.8[18]	1st	biodiesel	0.430	34.0	26	50%	0.30
Rapeseed oil	0.8[19]	1st	biodiesel	0.980	34.0	25	50%	0.30
Palm oil	3.6[20]	1st	biodiesel	0.960	34.0	118	80%	2.21
Wheat	2.3[21]	1st	bioethanol	0.336	26.5	21	20%	0.12
Sugar cane	16.9[22]	1st	bioethanol	0.150	26.5	67	90%	1.82
Switch grass	13.1[23]	2nd (celulosic)	bioethanol	0.200	26.5	69	80%	1.67
Tropical trees	4.8	2nd (celulosic)	bioethanol	0.200	26.5	24	90%	0.65
Northern trees (SRC)	18[24]	2nd (celulosic)	bioethanol	0.200	26.5	10	80%	0.25

18 Derived from FAOSTAT 2008
19 ibid
20 RFA 2008
21 Derived from FAOSTAT 2008
22 ibid
23 Biomass Energy Centre
24 DEFRA

8 “Waste” crops verses conventional crops

Perspective
Nothing is actually a waste (even landfill dumping creates landfill gas to generate electricity); at best biomass can be considered a commercial feedstock “not yet fully valued”.

There is a tendency for promoters of second generation (or alternative feedstock sources) to focus on “waste” as having benefits over primary crops. Such a claim needs to be carefully considered. As an example, so called “wastes” such as the left over stalks from wheat or rape production are currently ploughed back into the ground as a fertiliser and if the whole of crop is removed from the ground, these “wastes” may need to be replaced by fossil fuel based fertilisers.

So when looking at whether a feedstock can actually be considered as a waste we need to consider:

- That alternative uses of all energy feedstocks exist;
- Additionality of co-products should not be overlooked;
- Everything at the margin comes from the land;
- In the longer-term, waste producers may cease to pay “gate-fees” for waste disposal since waste will increasingly have alternative uses and value. This will affect the commercial viability of waste-to-energy or waste-to-biofuel production projects;
- The extent to which the collection of fallen waste (forests) will affect biodiversity and carbon sinks.

Technology name	Player for more info	Alternative to	Generation	Feedstock	Typical energy per hectare per year	Typical process yield	Capital expenditure / operating expenditure	Additionality / carbon benefit	General considerations	Value
Esterification	Desmet Ballestra or Lurgi	Diesel	1st	Vegetable oil	26-118	ca 100%	Low	Variable, moderate to excellent	Very simple and portable process, valuable co products, feedstock selection is key	Good
Direct use of vegetable oil in refineries	Conoco Phillips (Fat) Nesté NextBL	Diesel	1st (Nesté say 2nd but without justification)	Vegetable oil or animal fats	< 21	< 80%	High	Depends on feedstock can be ok / low or maybe negative	Too much biomass energy wasted as heat in the process, which would be better generated from a wood crop, H2 consumption in process is issue, hits additionality hard	Poor
Bioethanol sugar fermentation	Various, notably in Brazil	Petrol	1st	Sugar cane	67	15%	Medium	Excellent	Excellent use of co-products, often +ve social benefits	Indispensible
Bioethanol starch fermentation	Abengoa	Petrol	1st	Corn or wheat or beet	21	30%	High	Poor	Too many fossil inputs	Indifferent to useless
ETBE	Dow	Petrol	1st	Bioethanol from sugar cane or other	67 - 21	15%	Medium +	Depends source of bio	A refinery process to ‘bind’ premade bioethanol into a bigger molecule	Depends on bioethanol source
Cellulosic bioethanol	Shell / Logen	Petrol	2nd	Grasses or wood	69	20%	High	Good	Potential holy grail, but taking a long time to commercialise which sets off alarm bells, concerns about trucking logistics	Potentially excellent, but maybe impractical
Biobutanol	BP / Dupont	Petrol	1st	Sugars or starches	< 21	< 30%	High	Unknown (worse than bioethanol due 2nd law)	Mysterious	Unknown / poor due 2nd law
Biomass (cellulosic) gas to liquid	Chloren	Petrol or diesel	2nd	Grasses or wood	depends on feed	unknown		2nd law gets you, so probably poor	Astounding expensive. Better to use the wood as heat and displace coal. Also feedstock scale issues re logistics	Poor due 2nd law
Algae	Algoil / others	Diesel or petrol	2nd	CO2 from power stations	Very high	> 100% as no feed	unknown	Unknown, expected excellent	Potential fantastic, but limited to locations where power generation is already taking place	possibly number 1
Biomass acid hydrolysis	Masada	Petrol	2nd	Cellulosic waste / grasses or wood	Na as based on waste	low	unknown	Unknown, expected good	Large scale municipal waste to fuel, success will depend on waste logistics vs power generation	Unknown maybe good
Biomass / algae to hydrogen					???			Unknown	Very little known about this technology, doubts about the point of hydrogen distribution	Maybe very interesting