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Energy crop potential in vegetable rotations

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Contents

1 Executive summary

Vegetable growers would like to decide if ‘energy crops’ offer new options that they can fit into their crop rotations. Information on the potential of energy crops in vegetable rotations would provide context to guide decision making during 2008 grant allocations made by the Fresh Vegetable Industry R & D Grants Committee of Horticulture New Zealand. There may be new markets for such crops if the strong interest in biofuels continues. Meeting on-farm energy needs is another attractive use for biofuels.

For the purposes of this review energy crops are defined as those which can serve as feedstocks for fuel production or can be used directly as fuel. The bioenergy science findings relevant to vegetable rotation crops reported here are divided into four categories: three portable types of biofuel (BF), which are biodiesel (BD), bioethanol (BE) and biogas (BG), and fuels for on-farm heating or electricity generation.

Recommendations in each area are summarised here.

1.1 Biodiesel

- The first action on BD crops is that efforts by arable crop growers to import seed of new rape cultivars so that variety trials can be run should be supported. The importation will be slowed by the fact that rape cultivars are the same species as canola oil so fall under the same regulations regarding risk of canola seed being mixed with GM cultivar seed.
- The follow-up trials with the best rape cultivars need to have life cycle assessments (LCA) done to establish the level of environmental benefit from displacing diesel with rapeseed BD.

1.2 Bioethanol

- The options for BE crops are more numerous than for BD and may include winter crops; in some cases these could also be crop residues from food/feed crops; choose the best using environmental and economic LCA analyses.
- I cannot recommend maize as a long-term BE feedstock due to the poor LCA results; however, it would be the quickest to get up and running; the arable industry should work with potential investors in BE processing plants to map out a contingency plan for a rapid deployment if the New Zealand petrol supply was suddenly reduced.
- Sorghum hybrids should be investigated for warm area production and sugarbeet for cooler areas because they, like maize, would be quick to get up and running.

1.3 Biogas

- Since anaerobic digesters for BG are very promising and efficient means to create bioenergy, efforts to develop smart cropping rotations should investigate silage-making and digester options.
- This is worth investigating at the farm scale, but it could also be viable to produce digester feedstocks for regional BG plants.

1.4 Fuel for heating/cogeneration

- I recommend that using energy crops and residues on-farm as fuels to generate heat or electricity be given full consideration; this would strongly apply to farms not well positioned on the electricity grid, where deregulated power prices after 2014 could greatly increase.
- In the short term, use of energy crops for direct combustion may have a place in meeting farm energy needs, prior to new cellulosic ethanol technology.
- Given the promise of anaerobic digesters for BG to create on-farm energy, the first BG recommendation above applies here as well.

2 Introduction

This quote from a recent overview of bioenergy provides some background terminology that has informed this review.

"Modern biomass can be used for the generation of electricity and heat. Bioethanol and biodiesel as well as diesel produced from biomass by Fischer-Tropsch synthesis are the most modern biomass-based transportation fuels. Bioethanol is a petrol additive/substitute. It is possible that wood, straw and even household wastes may be economically converted to bioethanol. Bioethanol is derived from alcoholic fermentation of sucrose or simple sugars, which are produced from biomass by hydrolysis processes. Currently crops generating starch, sugar or oil are the basis for transport fuel production. There has been renewed interest in the use of vegetable oils for making biodiesel due to its less polluting and renewable nature." (Demirbas 2007). Other good overviews are Wright (2006) and Hanna (2005).

The context for this review and analysis of research literature on energy crops includes the following issues:

- current challenges to profitable, sustainable vegetable growing create interest in finding new crops that can fit into rotations;
- the strong market interest in energy crops due to high fossil fuel prices and pressures to reduce use of these fuels; and
- the possibility of growing crops that can be used to meet on-farm energy needs.

This review of research findings on energy crops was designed with the following in mind:

- most of the emphasis should be on BFs that fall into the three main categories of BD, BE or BG. The other category is direct heating fuel;
- since the focus is New Zealand growing conditions, the selection of literature excludes tropical energy crops;
- perennial energy crops are excluded unless they can be grown successfully within 2 years of planting (the longest time likely to be suitable in a vegetable rotation); and
- two considerations in addition to agronomic potential of each energy crop are the environmental impacts and economics of its production.

3 Current state of knowledge

This section summarises the current situation for bioenergy crops in the context of the wider public discourse that has been going on in New Zealand for the past year. This has involved the energy sector, consultants who have provided reports on biofuels, and government policy makers, who have drafted the NZ Energy Strategy, the Sustainable Land Management & Climate Change initiative and legislation for a Biofuels Sales Obligation (see the websites of the Ministry of Economic Development, Ministry of Agriculture and Forestry and Ministry of Transport).

3.1 Biodiesel

Biodiesel fuel is a substitute for mineral diesel that is made from crop oils, animal fats, or waste cooking oils. In New Zealand there is a supply of sheep and beef tallow (currently exported) that would replace about 4% of current diesel use if processed into BD. Plant oil feedstocks will be needed if greater substitution for diesel is to occur after the 2012 production target in the pending legislation for a Biofuels Sales Obligation.

Most usage of BD is in Europe, where rapeseed oil is the principal feedstock, and in the USA, where soybean oil is the main feedstock. Soybean oil processes into BD fuel of slightly lower quality than rapeseed oil, but large quantities are available and are subsidised, so the USA choice is partly political. The EU countries are also importing BD derived from tropical crops such as oil palm.

The production costs of BD from rapeseed oil in the EU enable it to be marketed in competition with diesel. Some countries free it from the excise tax applied to diesel, making it cheaper than diesel and hastening the adoption of BD.

Oil crops grown for BD could possibly also be used unprocessed for direct farm fuel use.

3.2 Bioethanol

The alcohol category of BF usually refers to ethanol, so the term bioethanol (BE) is used. For convevience, I will use the term to apply to other alcohols such as methanol or butanol. Bioethanol is produced by the fermentation of sugars from plant sources (or milk) and used as a replacement for petrol, usually only as the minority part of a blend with petrol. This is because engine modification is required in order to use higher BE blends, in contrast to BD which can be used at high blends in most diesel engines.

The crops used to supply most current BE fuel are sugarcane and maize grain, with lesser amounts from sugarbeets and sweet sorghum. Bioethanol from sugarcane is economically viable in Brazil, but other BE only competes with petrol if subsidised.

Successful substitution of BE for petrol on a large scale from temperate crops will require cheaper sugars, obtained using new enzyme technologies to release sugars from crop residues or non-food crops. So the research findings surveyed here include many that focus on new ways to handle and process crops. However, only those reports that are testing such technology on crop feedstocks relevant to New Zealand vegetable growers are included.

3.3 Biogas

Biogas usually consists of methane, released when plant and animal matter decomposes, and captured in processes such as anaerobic digestion (composted with a low oxygen supply, favouring different micro-organisms). This has been most often used with animal manures and plant wastes, but sometimes using purpose-grown herbaceous crops to produce BG.

One relevant technological advance that seems likely is fuel tanks made from carbon with nanopores that store a volume of gas equal to 180 times their own volume and at one seventh the pressure of current gas cylinders. That could make BG a much more viable fuel (NSF 2007).

3.4 Fuels for heating/cogeneration

While this category does not involve an energy cash crop within the rotation, it is worth including for its potential to benefit a grower enterprise that includes much use of electricity or heating energy for a packhouse or greenhouse. It would usually involve direct combustion of the crop or waste, but might also include gasification to a fuel such as ‘producer’ gas. On-site use to run engines or generators is also a good option for use of BG.

4 Literature search findings

4.1 Biodiesel feedstock crops

Since BD fuel is now in use in several parts of the world, the starting point has been to report on those crops already being used. These are rapeseed oil in the EU and soybean oil in the USA, plus some tropical oils. The tropical oils being imported into the EU (mainly from oil palm) are not only poorly suited to our climate, but most of the crops are also perennial. So research findings on these have been excluded from this report.

4.1.1 Rapeseed oil

Information on BD from rapeseed oil is abundant for production in the EU from commercial sources and from the following reports on specific aspects such as rapeseed breeding and BD quality (Vicente 2006; Stibbe 2006; Wiegland 2005; Friedt 1998). The best formulation of BD from most oil and fat types is the methyl ester (Lang 2001). There is also a text on the use of Brassica oils (Kimber & McGregor,1995) and one specifically on oilseed rape (Scarisbrick & Daniels 1986). Other reports include particular issues of rapeseed crop production, such as pre-harvest seeding into grain (Wagner 2000) and the effect of reducing inputs on yield (Bona 1999). Environmental studies of this crop are covered in Section 5.2.

Information on production of rapeseed oil in New Zealand is largely from research reports in the early 1980s, after the oil price shocks (Harris et al. 1979; NZ Energy Research & Development Committee 1980; Liquid Fuels Trust Board 1990). Research included crop trials at several locations around New Zealand, with good field data and economic analyses. However, a new industry in rapeseed oil production would want to consider using the new purpose-bred cultivars from the UK and EU (Stibbe 2006; Kimber & McGregor 1995) and also have a new economic analysis done for today's conditions.

4.1.2 Soybean oil

As with rapeseed, there is a large amount of technical information from commercial sources and research reports, but for this crop it is nearly all from the USA where there was a crop surplus and its production is subsidised. Most BD research there is on soybean oil (Tapasvi 2005; Kim 2005). Regular reports occur in special BD issues of the Journal of the American Oil Chemists Society.

4.1.3 Sunflower oil

Brazil has a long record of researching sunflower oil, including its use for BD (Paes 2005). Other reports are from Europe (Vicente 2006; Bona 1999) while in the USA the large sunflower oil crop is not getting as much attention for BD, perhaps due to it not being in surplus like soybeans.

4.1.4 Other oil crops

Camelina sativa *oil*

An Irish study tested BD from this oilseed crop, which has lower production costs than rapeseed (Frohlich 2005). It found that the quality of BD was similar to rapeseed in most respects.

***Brassica carinata* oil**

This is an alternative to rapeseed oil from a related crop (Vicente 2006).

Linseed oil

This oil is produced for industrial uses and has been made into BD in some cases (Lang 2001).

4.2 Bioethanol feedstock crops

4.2.1 Crops with stored sugar or starch

Maize grain

This source of BE is being used on a very large scale in the USA and there is already ample information on its production and use. This was the topic of a talk by overseas speaker Paul Higgins at the Foundation for Arable Research's 2006 Maize Conference. An objective reading of current research findings and analysis leads to a clear conclusion that it is not a good choice as a BE feedstock. This is true in terms of either profit (when unsubsidised) or for its contribution to reduced greenhouse gas emission targets when substituted for petrol. There is room for improvement via breeding work (Stibbe 2006), but even then the best gains are likely to be in terms of using the non-grain parts of the maize plant (see Section 4.2.2).

Cereal grains

There are a number of reports on crop research into BE from small grains crops. Winter wheat and triticale were the preferred crops in some cases (Rosenberger 2005). The work on these crops plus rye also calculated the cost of BE production and response to agronomic practices (Rosenberger 2003). Earlier German work also looked at N fertiliser effects on BE production from the same three crops (Aufhammer 1996). Greater adaptability is attributed to rye than wheat (Bushuk 2001). Some favour plantings with mixed wheat cultivars (Swanston 2005), or even mixed grain species. This has been done to some extent for end purposes other than grain or starch yield. Advances in fermentation techniques of rye and triticale have improved the economy of these feedstocks (Wang 1998). In New Zealand trials with triticale, yields have reached 15-20 T/ha dry matter, not dissimilar to maize (K Sinclair, pers. comm.).

Other grains

Sorghum: Sweet sorghum has been studied as a fuel alcohol feedstock for years, starting in Italy before World War II (Henk 1994). Its dry weight is 40% sugar, and Henk tested silage processing as a beneficial pre-treatment (an approach of interest with other forage crops as well). Sweet sorghum requires warm growing conditions and has been investigated for use in the

Pacific (Nguyen 1984). New hybrids are probably better suited to New Zealand growing conditions (M Lieffering, pers. comm.).

Millet: Pearl millet is well adapted to dry conditions, so is a potential BE feedstock in such areas (Wu 2006). This could prove useful in future decades in East Coast areas if the predicted drier climate materialises.

Root crops

Sugarbeet: This crop has been used as a source of BE feedstock in several areas, including current production in France (Jaggard 2005) and Italy (Mantovani 2006). Other higher yielding beetroot cultivars were compared to sugarbeet, but the best sugarbeet cultivars always produced equal or greater sugar despite lower root yields (cited by Mantovani 2006). This crop is the principal source of refined sugar in cooler climates, but is well below sugarcane in productivity. Brazil is the world leader in BE production because of its very large sugarcane production capability.

Turnips: Both silage and bulb cultivars can give high DM production (K Sinclair, pers. comm.), so these should also be candidates for BE production.

Potatoes

This is a crop with very high dry matter yield, but usually considered more valuable for uses other than for fermentation. However, BE could prove a good use of reject crops, such as those that have sweetened (Egg 1982). The high water content of potatoes poses some fermentation difficulties. Another option could be anaerobic digestion to BG (see Section 4.3).

Jerusalem artichoke

A consultant report on BFs (Judd 2003) to the Energy Efficiency and Conservation Authority (EECA) and the city of Christchurch listed Jerusalem artichoke as yielding 2–5 times the BE of any other crop, but the reference was not in a science journal and a footnote suggested the value was misinformation. However, there is a science report from Europe (Caserta 1995) on the crop that I have requested. Even if it does prove a good source of BE, it cannot be recommended for use in crop rotation due to its well known property of becoming a difficult weed due to tuber pieces inevitably left in the ground at harvest.

4.2.2 Cellulosic ethanol

What are being referred to as second generation BFs are mostly petrol substitutes like BE and similar products, the difference being that they will be produced from sugars released from cellulose by new biotechnologies, usually involving enzymes (Dien 2006; Vogel 2001). There are also new options for BD, which interestingly will be sourced from cellulosic feedstocks rather than oils. Gasification of wood or crop residues produces gases that can be converted to Fischer-Tropsch Liquids (FTLs) that can power compression engines (Demirbas 2006).

While the most-discussed future sources for this cellulose are tree crops, some herbaceous crops are also considered to have good potential, along with crop residues.

Maize

The main issue with a solar efficient C4 crop like maize or sweetcorn is how much of the stover is surplus to the needs of soil husbandry (Kadam 2003). New Zealand has the advantage of higher than average soil organic matter, so the optimal balance between soil carbon and income from selling residues needs to be researched here in New Zealand.

Other C4 grasses

Switchgrass: The grass that has attracted the most research attention for use as BF is switchgrass or *Panicum virgatum*. This is a very large perennial bunch grass that prefers hot humid summer climates. Most research, including on environmental impacts and breeding programmes to enhance the potential of switchgrass for BE, is being done in the USA (Schmer 2006; Nakatawa 2006; Florine 2006; Roth 2005). In terms of New Zealand use, it does not seem well adapted to most vegetable-growing districts, but may be worth testing for adaptability to the warmest areas.

The greater issue is whether switchgrass can be established quickly enough to produce a high DM yield in 1 or 2 years, and then be removed efficiently enough for the paddock to be ready for the following vegetable crop. The answer may have been determined by now, but direct inquiries to research programmes would need to be made.

Miscanthus: This cane type C4 grass *Miscanthus* x *giganteus* (or elephant grass) is a huge triploid form among several *Miscanthus* species that are of interest as BE feedstocks. It is being researched in many temperate climates from the UK to Turkey (Rich 2001; Hansen 2004; Lewandoski 2006; Acaroglu 2005) and in the USA (Heaton 2004). These species appear more promising for adaptation to New Zealand conditions than switchgrass. In the UK over 2000 ha are already grown for fuel, even before the new technologies for cellulosic sugar extraction are available.

The main issues to sort out are, as with switchgrass, the costs of establishing a perennial crop and then removing it again after only one or two years. *Miscanthus* x *giganteus* is sterile, so needs to be established from corms. Most species are rhizomatous, which would seem to be a red flag in terms of use in vegetable rotation ground. However, the research organisation ADAS has the UK National Miscanthus Germplasm Collection, so there may be prospects for more suitable annual or biennial types to be identified (DEFRA Science and Research 2007). Some other *Miscanthus* species are already present in New Zealand as weeds (M Lieffering pers. comm.).

Mixed prairie systems

Recent research indicates that the plant system with the greatest ability to fix atmospheric carbon into dry matter is not a forest but a mixed prairie with several grass and herb species, as existed in some areas before conversion to farming monocultures. It was noted for wheat in Section 4.2.1 that mixed-variety plantings are an advantage for BE yield. Other research is in progress in North America.

Legumes

Several crops were mentioned as having good capability for high dry matter by K Sinclair (pers. comm.).

Tickbeans: These can grow 2 m tall and produce considerable dry matter in cool conditions.

Fava beans: This crop is very adapted to cool weather and also can yield quite high dry matter. There is a good body of Australian literature on fava bean cultivation.

Lupins: These require warmer conditions to mature, but are very high dry matter yielders when matured.

Field peas: While not yielding as much dry matter as many crops, the starch in peas has been proposed as a BE feedstock after separation of the protein components for other uses before fermentation (Nichols 2005).

It may be possible within a vegetable rotation to grow a legume or grass crop during the winter plus spring or fall (depending on other rotation crops). A decision to use a winter crop for fuel should be based in part on how its value for that use compares to its value for grazing.

4.3 *Biogas feedstock crops*

A literature search on BG and digestion yielded about 1800 references, the list of which can be made available and accessed with Endnote software. Most of them had to do with municipal waste treatment. The bibliography in this report reduced that list to the 76 references that also focused on use of a crop or weed species.

While versions of BG technology have been around for a long time, there have been significant advances. This research area is receiving renewed interest as petroleum-based fuels are no longer as cheap nor abundant. Currently, the most energy efficient way to produce energy from biomass is by anaerobic digestion with capture of methane (see Section 5.2.3). There has also been integration with fuel cells to produce hydrogen (Weiland 2003).

This technology could be of interest to vegetable growers because the scale of the required technology can be smaller than that used for BD or BE production, making it possible for use on-farm. An EU model for the 'energy self-sufficient farm' has been developed using silaging and digestion (Karpenstein-Machan 2001).

Research into improved methane yield or quality has been encouraging in a number of crops, including sorghum (Lehtomaki 2006; Jewell 1993), grass (Lehtomaki 2006; Jewell 1993), silage from corn, alfalfa and grass/clover (Nordberg 2007; Jarvis 1997), sugarbeet tops (Bohn 2007; Svensson 2005; Parawira 2004) and several weed species (Subramanian 1999; Gunaseelan 1998; Chanakya 1997; Abbasi 1994).

Another use of digesters is to offer an environmental service by processing stillage waste from large-scale ethanol plants, especially those using cellulosic feedstocks (Wilkie 2000).

4.4 Fuel crops for heating/cogeneration

The use of fuel crops for heating/cogeneration is an area that is currently being explored within the domain of New Zealand covered crops. It could also have relevance for diversified field vegetable growing where the operation has greenhouses to heat or packing shed equipment that has a high energy demand. In this case, buildings would be supplied with energy from outdoor crops. It would usually involve direct combustion of the crop or waste, but might also include anaerobic digestion to BG or gasification to a fuel such as 'producer' gas to run engines or generators. Research reviews have indicated the benefits of this at the whole economy scale (Karpenstein-Machan 2001), but different engineering literature would need to be explored to find detailed farm-scale analysis of these technologies.

5 External criteria to meet

In addition to a grower basing the choice of rotation energy crop on business considerations some higher level criteria may need to be considered.

5.1 Environmental impact of cropping

Since one of the key drivers for the switch to BE is concern over the contribution of fossil fuels to greenhouse gas emissions, there has been much attention paid by government and researchers to the energy balance between the energy a crop provides to the user and that required to produce it.

The procedure to calculate this is called an LCA, life cycle assessment (or life cycle accounting). The full life cycle includes all the energy costs of making fertilisers and pesticides as well as shipping the fuel to end-users. There is already a substantial literature on this, including for BD crops (Horne 2003; Kim 2005; Hill 2006). Some examples of the LCAs for BE crops are for maize (Lal 2006; Johnson 2006), cereals (Lal 2006; Lewandowski 2006), and grasses (Spatari 2005, Lewandowski 2006).

The other environmental aspect is the sustainability of the cropping system from the standpoint of soil health, water quality, etc. One change since technical literature was published in New Zealand on BE crops in the early 1980s is that future research will need to measure and report on these aspects. One EU study included a model of soil management (cultivation) in relation to CO_2 released. It found that the balance depends on amounts of crop residues returned to the soil (Bona 2003). Another looked at the use efficiency of nitrogen, energy and land use for rye and miscanthus (Lewandoski 2006).

5.2 Economic analyses

5.2.1 Biodiesel

These studies examine the oil value in relation to production costs and are often integrated with life cycle assessments (Dorado 2006; Kim 2005; Wechel 2002). One study in Lithuania calculated that a 2 t/ha yield of rapeseed was required to produce a profitable amount of fuel (Janulis 2001). A USA study looked at the economics of grower ownership of processing plants (Kenkel 2006).

A key aspect of profitability is often the value of the BF processing by-products. For BD these are generated at two stages. When oil is extracted from oil seeds there is often a seed meal with good protein content for use as animal feed (McAllister 1999). Access to such a feed market could be an issue in New Zealand. At the next step, oil processing into BD, the main by-product is glycerol (glycerine). Sale of glycerol at a good price is often necessary for profitable BD production. The quality of glycerol may vary with oil type (Thompson 2006).

5.2.2 Bioethanol

Many studies have focused on the economics of BE fuel production, most of them concluding that for energy to be produced at a profit the competing price of cheap fossil fuels must increase. The analysis for maize has been presented in New Zealand at FAR’s 2006 Maize Conference in Hamilton. The main exception has been sugarcane BE in Brazil, although cane production with low fertiliser inputs may not be sustainable. More inputs would reduce the favourable ratio of energy in to energy out. A good overview of the range of economic and social issues of BF cropping has been made in Brazil (Lucon 2006).

5.2.3 Biogas

One measure of the economic viability of this technology is the large number of BG plants being built in the EU and Russia (Biogas Nord engineer, pers. comm. while visiting New Zealand). The economic attractiveness follows in part from the positive energy conversion assessment. The most favourable bioenergy LCAs ever reported show that the most energy efficient way to generate energy from biomass is by anaerobic digestion with capture of methane. It has been calculated in the EU that a large investment in BG plants could theoretically enable the EU by 2020 to replace half of their current natural gas use, equal to total imports from Russia (M Lieffering, pers. comm., based on Karpenstein-Machan 2001; Weiland 2003).

5.2.4 Fuel crops for heating/cogeneration

Research reviews have indicated the benefits of this at the whole economy scale (Karpenstein-Machan 2001), but different engineering literature would need to be explored to find detailed farm-scale analysis of these technologies. There should be overlap with the information used by the covered crops sector.

5.3 Fuel quality

Bioethanol quality would not usually be an issue for the grower, since the processing to extract sugars and ferment them would likely be done by an energy company. There are relevant criteria, however, such as having a consistent crop moisture content, that may need to be met. The market risks for BE are that it is harder to keep free of water than petrol, so quality control issues for the energy company could affect the grower.

With BD, quality is a greater issue. The government will be regulating processor quality closely for use as transport fuel. For the grower, the additional issue is that different oils process into BD fuels with different inherent quality. Oil from rapeseed can currently be made into BD with the highest quality. Alternative oil crops need to be processed into BD of similar quality, which requires a more flexible processing plant.

There are also potential market advantages for producing BD from crops. For instance, tallow BD has the poorest performance in cold weather. An early producer of crop oil may be able to share the benefit of the processor selling BD at a premium, perhaps for blending with tallow BD.

There is a very large body of science and engineering literature on processing vegetable oil into BD. Models have been developed to assess and compare oil quality from different feedstock crops, with most testing done on soybean (Tapasvi 2005), rapeseed (Lang 2001; Wiegland 2005) and sunflower (Bona 1999; Vicente 2006).

5.3.1 Grower-owned fuel processing

If New Zealand growers are considering co-operative ownership of fuel processing facilities, as practised by maize growers in the USA, then there is a larger body of research on fuel quality that should be considered. This has been collected as part of the literature review, so could be accessed. New Zealand government regulatory documents would also be very relevant.

6 Key findings

6.1 Biodiesel

- The initial commercial production of BD in New Zealand will be from tallow feedstock, and even tallow is the major cost component for BD processors.
- Oil seed crops will not easily compete with the tallow price to processors.
- The tallow supply will be fully utilised by 2012, opening the BD market to crop oils.
- Oil crops for BD will usually need to be a dedicated full year crop in a rotation and the number of annual/biennial crops to choose from will probably be quite limited in the foreseeable future.

- The EU dominant feedstock, rapeseed oil, is likely to be the most acceptable crop oil to grow and market in the early years, although sunflower oil should not be ruled out.
- The economics of New Zealand rapeseed production (last calculated in 1984) have not been determined using the newer cultivars nor has allowance been made for any possible constraints due to environmental impacts.

6.2 Bioethanol

- For BE to be produced at a profit from grains the competing price of cheap fossil fuels must increase; maize also fails to much reduce the carbon dioxide output when substituted for petrol.
- Other promising feedstocks with storage sugars are sugarbeet and sorghum hybrids; these may benefit from pre-treatments such as ensiling before fermentation.
- The next generation technology with cellulosic ethanol will lower the feedstock cost, which is the main cost component with maize and other grains.
- Triticale and some legumes have high dry matter but lower inputs than maize, for use as direct energy or cellulosic feedstocks.
- The highest BE production per ha has been from perennial C4 grasses like switchgrass and miscanthus (elephant grass), but using an energy-inefficient processing technology. These crops could also be difficult to use in vegetable rotations.

6.3 Biogas

- Anaerobic digesters for BG are very promising and an efficient means to create bioenergy.
- Digesters are feasible at the farm scale, but perhaps better at a regional scale; transport costs are not prohibitive for producing digester feedstocks for a BG plant a modest distance away.

6.4 Fuel for heating/cogeneration

- While detailed engineering data was not included in this study, this seems a promising aspect of using energy crops and residues from a smart cropping rotation.
- Cogeneration of electricity is valuable in locations that are off-grid or poorly supplied.
- Use of energy crops for direct combustion is used in the UK and the scale may suit farm energy needs.
- Anaerobic digesters for BG can be scaled for on-farm heating or cogeneration.

6.5 Recommendations

6.5.1 Biodiesel

- The first action on BD crops is to support efforts by arable crop growers to import seed of new rape cultivars so that variety trials can be run; the importation will be slowed by the fact that it is the same species as canola oil, and regulated because seed could be mixed with genetically modified seed.
- The follow-up trials with the best cultivars need to have life cycle assessments (LCA) done to establish the level of environmental benefit from displacing diesel with rapeseed BD.

6.5.2 Bioethanol

- The options for BE crops are more numerous than for BD and may include winter crops; in some cases these could also be crop residues from food/feed crops; choose the best using environmental and economic LCA analyses.
- I cannot recommend maize as a long-term BE feedstock, but it would be the quickest to get up and running; the arable industry should work with potential investors in BE processing plants to map out a contingency plan for a rapid deployment if the New Zealand petrol supply was suddenly reduced.
- Sorghum hybrids should be investigated for warm area production and sugarbeet for cooler areas, for the same reason just given for maize.

6.5.3 Biogas

- Since anaerobic digesters for BG are very promising and efficient means to create bioenergy, efforts to develop smart cropping rotations should investigate silage-making and digester options.
- This is worth investigating at the farm scale, but it could also be viable to produce digester feedstocks for a regional BG plant.

6.5.4 Fuel for heating/cogeneration

- I recommend that this means of using energy crops and residues on-farm be given full consideration; this would apply particularly to farms not well positioned on the electricity grid, where deregulated power prices after 2014 could greatly increase.
- In the short term, use of energy crops for direct combustion may have a place in meeting farm energy needs, prior to new cellulosic ethanol technology.
- Given the promise of anaerobic digesters for BG to create on-farm energy, the first BG recommendation above applies here as well.

7 Literature citations

7.1 Notes

1. Adobe .pdf files of full papers of several citations can be emailed to the client organisation on request.
2. Most citations are in English language journals, but a few other papers from the EU and Brazil were considered important to include.

Biodiesel citations

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