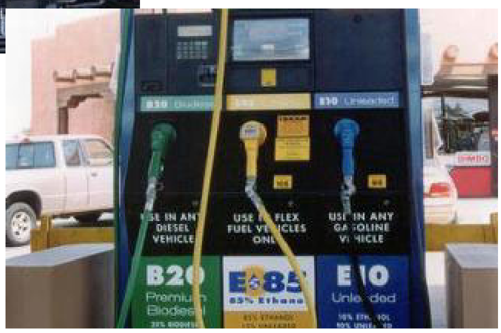
BIOMASS TECHNOLOGY REVIEW: PROCESSING FOR ENERGY AND MATERIALS



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BIOMASS TECHNOLOGY REVIEW: PROCESSING FOR ENERGY AND MATERIALS

PREPARED BY
CRUCIBLE CARBON
FOR
SUSTAINABILITY VICTORIA
APRIL 2008

Disclaimer

Front cover photos (top to bottom):

Photo 1 – multispecies native assemblage forestry as a biomass resource for lingo-cellulosic materials.[1]

Photo 2 – biomass thermal processing to useful products such as solid, liquid and gaseous fuels.[2]

Photo 3 – sale of liquid biofuels.[3]

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[1] *Photograph sourced from http://www.outdoorssa.com.au/images/The_Murray/Mallee.jpg*
[2] *Fast pyrolysis unit - photograph sourced from http://www.dynamotive.com/assets/photos/guelph/en/index.html*
[3] *Photograph sourced from http://www.federalsustainability.org/initiatives/biodiesel/biodieseltrg.htm*

EXECUTIVE SUMMARY

This report is designed for those who want to better understand biomass processing options as a business opportunity for production of bioenergy and material products.

A future carbon neutral society will still require carbon based products and services, such as high energy density fuels, organic materials, chemicals and reductants, which are now primarily sourced from fossilised coal, oil and gas.

Biomass is the originator of fossil carbon sources and can therefore produce similar energy and material products with the distinction that the carbon in biomass is recently sourced from the atmosphere and therefore is part of an intrinsically balanced carbon cycle.

The report is focussed on primary technology options for biomass with guidelines for addressing critical issues and identifying major strategic opportunities.

Biomass Processing

Biomass processing technologies capture value from biomass in different ways because biomass resources have varying ratios of distinctly different molecular structures (essentially water soluble carbohydrates, water insoluble carbohydrates and hydrocarbons). Value adding technology must be tailored to the biomass type to achieve optimum outcomes.

Lignocellulosic material (woody biomass) is overwhelmingly the most common form of biomass in agricultural, industrial, municipal, forest and natural environments. Tree based lignocellulosic biomass can be essentially harvested on demand therefore offers the most stable and scalable primary resource for biomass technologies. The abundance of lignocellulosic biomasses provides strategic advantages to the thermal technologies and to emerging cellulosic fermentation.

There are six generic technologies for energy conversion based on: direct combustion for power; anaerobic digestion for methane rich gas; fermentation of sugars for alcohols; oil exaction for biodiesel; pyrolysis for biochar, gas and oils; and gasification for syngas. These can then be followed by an array of secondary processing options depending on specific final products.

Anaerobic digestion, fermentation and oil extraction are suited to specific biomasses that have easily extractable oils and sugars or high water contents. Such biomass resources are mainly associated with the food chain and are strategically constrained (limited availability and/or competition for land). Digestion, oil extraction and fermentation of sugars are all well established commercially.

Thermal technologies such as direct combustion, pyrolysis and gasification, can effectively process all forms of biomass, including complete utilisation of lignocellulosic materials. Combustion and gasification of biomass for heat and power is commercially proven. Of the thermal processing options, pyrolysis provides the most flexible product platform, being able to generate solid, liquid and gas outputs roughly analogous to their coal, oil and gas fossilised counterparts. However, there are still relatively few commercial pyrolysis operations using biomass feedstocks.

Pyrolysis outputs are mainly used in basic heat and power applications, with developments underway to produce higher quality transport fuels through the further refining of biocrude. Pyrolysis char (biochar) can be used for energy, metallurgical reduction, activated carbon, or for carbon sequestration in soils.

Evaluating Opportunities

The success of bioenergy projects depends fundamentally on sustainable biomass supply, techno-economically viable processing and a societal licence to operate

Given the pressures of climate change along with rising oil and gas prices, major investments in bioenergy technologies can be expected in the coming decade. This will especially occur in high potential emerging technologies (lignocellulose to liquids) with accelerating improvements in technical performance, capital intensity, energy efficiency and product development.

Bioenergy has already advanced to the point that there are a wide range of opportunities for viable business development based on proven technologies (especially combustion, digestion, fermentation and oil extraction). The opportunities will greatly expand as pyrolysis and cellulose fermentation of lignocellulosic biomass become more established in the coming years.

The report presents an evaluation tool for bioenergy projects to assist help address the critical issues encountered when developing a project around specific biomass resources, selecting process technology for targeted markets and obtaining support from stakeholders.

Sustainable biomass supply is critically dependent on land, water and biodiversity management. This includes minimising the use of prime agricultural land, maximising soil fertility and carbon sinks, ensuring balanced nutrient cycles and water budgets while promoting regenerative practices with respect to native habitats and ecosystems in impacted regions. There are strategic sustainability advantages of biomass sourced from multispecies native assemblages.

A viable processing business is critically dependent on security and availability of feedstock supply, selecting technologies that are capital effective and demonstrated for the feedstock and product applications as well as clear market insight and strategies. Critical to business success is the ability to balance risk and innovation in what is certain to be a dynamic environment with respect to emerging technologies, emission standards, feedstock competition, carbon trading and oil prices.

Securing a societal licence to operate involves alignment with government policy, proactive engagement with local communities and regional development, and participation in the wider public debates on energy futures and the environment.

An evaluation tool is of course no substitute for detailed analysis of the financials and all other aspects of the business case. Weaknesses identified by the evaluation tool do not necessarily mean a project should be abandoned, but rather that the issues should prompt fresh thinking, innovation and better risk management responses.

Bioenergy is strategically attractive because it has the potential to be carbon neutral, or even better (carbon negative) when combined with sequestration. However, robust carbon and sustainability accounting on a complete life cycle basis is needed to defend the environmental credentials and greenhouse benefits of bioenergy projects.

GLOSSARY

GJ	Giga-Joule – unit of energy corresponding to 10^9 Joules
PJ	Peta-Joule – unit of energy corresponding to 10^{15} Joules
kW_e	Kilo-Watt electrical – unit of electrical power equivalent to 10^3 Watts
kW_{th}	Kilo-Watt thermal – unit of thermal power equivalent to 10^3 Watts
CO_2	Carbon dioxide gas
CO_2e	Carbon dioxide greenhouse gas equivalent
N_2O	Nitrous Oxide – a potent greenhouse gas released by the bacterial breakdown of soil nitrogen and combustion
Alcohol	Alcohols are hydrocarbons with an –OH group attached somewhere to the carbon chain. Hydrogen bonding means that alcohols form liquids at much shorter chain lengths than hydrocarbons, and are more water soluble with a lower energy density than hydrocarbons
Anaerobic Digestion	Biological degradation via microorganisms of carbonaceous material in the absence of oxygen to methane (CH_4) and hydrogen (H_2)
Biochar	Black carbonaceous solid resulting from the pyrolysis of biomass
Bioenergy	Technically any thermal or electrical energy sourced from the oxidation of biofuels, sometimes limited to specifically referring to electricity generated from biofuels
Biofuel	Technically any biologically derived solid, liquid or gaseous fuel for use in combustion applications, but sometimes limited to referring specifically to transport fuels
Biomass	Any living or recently living material – typically composed of insoluble carbohydtrates (lignocellulose). Other important components of biomass are soluble sugars/starch, proteins and lipids
Calorific Value	Calorific value refers to the amount of energy released during the combustion of a fuel.
Carbohydrates	Molecules usually of biological origin consisting of carbon, hydrogen and oxygen. Often containing sugars such as glucose arranged as either soluble polymers (starch or glycogen) or insoluble polymers (cellulose). Partial oxygenation means that the energy density of carbohydrates is approximately half that of hydrocarbons. Soluble sugars are the main feedstock for alcohol production via fermentation
Carbon Sequestration	The capture and medium-to-long term storage of atmospheric carbon (primarily carbon dioxide) into carbon 'sinks' such as forests, soil, oceans and geological formations.
Cellulose	An insoluble crystalline polymer of glucose and largest bulk molecular component of plants. See Lignocellulose and Carbohydrates
Climate Change	Variation in mean global temperature as a result of anthropogenic activities. Changes include ice cover, ocean currents, rainfall, weather patterns and temperature distributions. (Also referred to as global warming)
Cogeneration	A generating facility that produces electricity and another form of useful thermal energy (such as heat or steam) used for industrial, commercial, heating, or cooling purposes.
Combustion	Complete oxidation of carbonaceous material to produce heat

Coppice	Trees or shrubs that are cut for re-growth at regular intervals to provide a sustainable source of wood.
Dryland Salinity	Dryland salinity refers to the degradation of land due to increasing concentrations of salt in soils and watercourses primarily attributed to rising water tables bringing dissolved salts to the surface
Fermentation	Biological degradation of soluble sugars to ethanol or butanol via microorganisms in the absence of oxygen
Gasification	Heating and partial oxidation of carbonaceous material to produce 'syngas'
Greenhouse Gases	Air emissions that contribute to global warming. They include carbon dioxide (CO_2), methane (CH_4=25 CO_2e), nitrous oxide (N_2O=296 CO_2e) and other gases generated during industrial processes
Hydrocarbons	Molecules consisting of carbon and hydrogen arranged in a chain, branching or ring structure; the basis of liquid transport fuels
Joule	Standard measure of energy equivalent to the energy required to increase the temperature of 1 gram of distilled water at standard temperature and pressure by 1 degree Kelvin
Life Cycle Analysis	(LCA) A robust accounting of material and energy flows within well documented system boundaries (refer to ISO1440 series standards). LCA's may be used to compare systems (processes and products) on common a functionality basis
Lignin	An amorphous matrix molecule in plants containing linked aromatic rings. See Lignocellulose
Lignocellulose	An insoluble carbohydrate found in plant cell walls and therefore making up the majority of plant derived biomass. Comprises cellulose fibres within a lignin matrix with some hemicellulose to aid in bonding
Protein	A soluble carbohydrate with high nitrogen and sulphur content carbohydrate like polymers. Nitrogen and sulphur are often limiting nutrients to growth, so proteins are well suited as an animal feed but not to many bioenegy uses
Pyrolysis	Heating carbonaceous material in the absence of oxygen to produce char, oil and gas outputs
Pyrolysis Oil	Complex mixture of highly oxygenated hydrocarbons resulting from the thermal depolymerisation of biomass in the absence of oxygen
Sustainability	The ability to create value in society without systemic social or ecological degradation; meeting the needs of today without jeopardising the needs of future generations
Syngas	A mixture of Hydrogen (H_2) and Carbon Monoxide (CO) produced by gasification that can be combusted or used as chemical feedstock for synthesis reactions
Watt (W)	Unit of power equivalent to 1 Joule of energy use per second

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1 BACKGROUND AND INTRODUCTION

This report is designed for those who want to better understand biomass technology options as a business opportunity for production of bioenergy and material products.

The report was commissioned by Sustainability Victoria, a state government organisation with a focus on the development of policy and practical initiatives designed to reduce everyday environmental impacts and to use resources more efficiently.

The report has been written by Crucible Carbon Pty Ltd, a research and consulting organisation that links sustainability, business strategy, innovation, engineering and science. The report is focussed on technology options for biomass with guidelines for addressing critical issues and identifying major strategic opportunities.

In a carbon constrained future, society will still require carbon based products and services, such as high energy density fuels, organic materials, chemicals and reductants, which are now primarily sourced from fossilised coal, oil and gas.

Biomass is the originator of fossil carbon sources and can therefore produce similar energy and material products, with the distinction that the carbon in biomass is recently sourced from the atmosphere and therefore is part of an intrinsically balanced carbon cycle. Bioenergy is strategically attractive because it has the potential to be carbon neutral, or even better (carbon negative) if combined with sequestration.

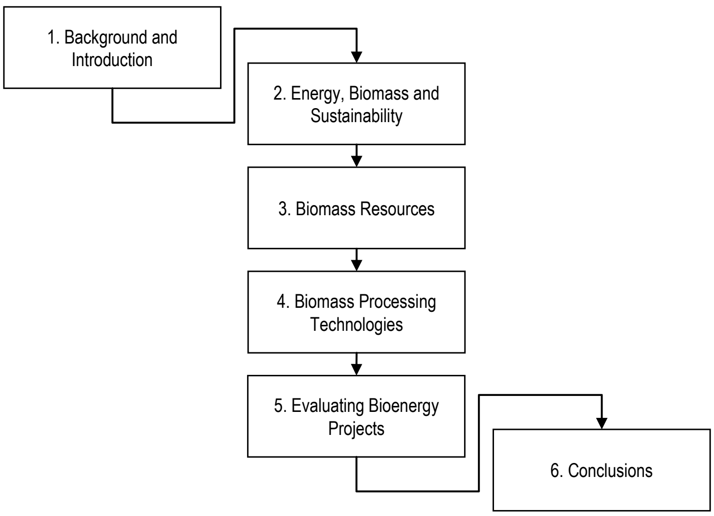

Figure 1 – Overview of the report structure

The structure of this report is presented in Figure 1 above. Following this introductory section the report consists of sections designed to place the details of biomass resources and processing technologies within a systems perspective of scale and sustainability considerations. Key information for understanding the details of specific technologies is provided in sections 2-4 inclusive. Section 5 integrates the findings into a Sustainability Analysis Tool designed to assist those developing specific projects. This tool provides an easy to use analysis framework that guides proponents through the insights of the report and helps to make determination of issues as they apply to their unique case. The final section summarises the major strategic relationships and opportunities identified by the review with regards to the development of sustainable bioenergy opportunities.

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2 ENERGY BIOMASS AND SUSTAINABILITY

This section describes the use of biomass as an energy resource and its relevance to the pattern of Victorian energy usage. Biomass as an energy resource is fundamentally different from carbon free renewable energy technologies, creating distinct energy and materials products that overlap with existing fossil fuel uses. Biomass also has significant current use as food, materials and habitat which must be sensibly and sensitively integrated with energy use if bioenergy systems are to be developed sustainably.

2.1 An Overview of Energy in Victoria

Victorian society is currently underpinned by the large scale, systematic consumption of fossil based energy. This energy is integral to the abundant supply of food and the production of goods and services that constitute an enviable standard of living. Although recognising these large societal benefits, we now accept that reliance on fossil fuel resources is unsustainable in regard to long term supply, damage to the global carbon balance and degradation of natural systems. Net Victorian Greenhouse gas emissions, which relate to the use of fossil fuels and land practices, were 121.9 Million tonnes carbon dioxide equivalent ($MtCO_2e$[4]). There is a clear and pressing need to establish sustainable energy technologies and production systems to stabilise and reduce atmospheric carbon concentrations and to rebuild landscape habitats to provide resilience to environmental change.

The current energy backbone of Victoria involves mining fossil fuels from concentrated reserves as either gases (natural gas), liquids (crude oil) or solids (brown coal) and distributing the energy to the community via electrical, gas, liquid or solid fuel distribution networks. As of 2007 Victoria had substantial reserves of coal (99 per cent remaining), declining reserves of natural gas (43 per cent remaining) and depleted reserves of oil (14per cent remaining).[5] Electricity production from brown coal is currently the most carbon dioxide (CO_2) intensive method of electrical energy production (1.158-1.58 kilogram carbon dioxide equivalent per kilowatt hour ($kgCO_2e/kWh$))[6] and places Victoria in the unenviable position of being the clear Australian leader in electricity related emissions.

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[4] *Department of Climate Change, 2007, 'State and Territory Greenhouse Gas Inventories 2005', Australian Government Department of Climate Change, accessed at http://www.climatechange.gov.au/inventory/stateinv/index.html, February, 2008; CO_2e represents CO_2equivalent and is a common measure of relative greenhouse impact. Other gasses such as CH_4 and N_2O are also greenhouse gasses and represent a different CO_2e depending on their potency.*

[5] *Data accessed from Chemlink, http://www.chemlink.com.au/vicchem.htm, February, 2008; State Government Victoria Department of Primary Industries, accessed at http://www.pesa.com.au/vic_supp/vicsupp_5.htm February, 2008; This means Victoria is currently self sufficient in relation to electricity (via brown coal combustion), but must increasingly import its liquid fuel requirements and will need to import gas within the coming decades.*

[6] *Actual emissions depend on particular power station and variation in load use. Typically older infrastructure such as Hazelwood has higher intensity than newer infrastructure such as Yoy Lang A. Berger, C and Phelan, T, 2005, 'Greenhouse Pollution Intensity in the Victorian Brown Coa lPower Industry', Australian Conservation Foundation and Environment Victoria, accessed at http://www.envict.org.au/file/Greenhouse_Brown_Coal_05.pdf February, 2008.*

2.2 Biomass Attributes

Each year in Victoria approximately 2,200 Peta -joules (PJ) of solar energy is captured by the leaves of plants and converted into biomass through photosynthesis.[7] This is only 1.6 times the energy consumption of the state[8], which means that biomass as a significant scale energy resource is certainly not limitless, and must complement biomass use for food, material products (wood, paper etc.), habitat conservation and ecosystem services.

Biomass is the progenitor of fossil fuels in that natural gas, oil and coal are biomass that has been converted into concentrated energy forms by geological processes akin to pyrolysis (heating in the absence of oxygen) under pressure. This means that with appropriate industrial processing, newly harvested biomass can be converted into homologs of current gas, liquid and solid fossil fuel resources. All other renewable or low carbon energy technologies (eg. solar, wind, nuclear) can only produce heat and power; whereas biomass is able to supply a range of carbon based products with material qualities, such as liquid fuels, metallurgical reductants, lubricants and a wide range of petrochemical substitutes. This could contribute to a relatively seamless progression to a low emission future with respect to existing downstream technologies and infrastructure assets, and in general it will wise be concentrate the use of biomass to applications where material qualities can be brought to bear. The comparative features and outputs from biomass processing technologies is summarised in the table below.

Table 1 – Biomass processing technologies in comparison with other low carbon energy technologies

Low Carbon Energy Technologies	Features and Outputs							
	Renewable	On demand energy	Heat	Electricity	Gas[9]	Liquid	Solid	Chemicals
Reference: Fossil Fuels with Sequestration		✓	✓	✓				✓
Hydro	✓	✓		✓				
Wind	✓			✓				
Solar thermal	✓		✓	✓				
Solar photovoltaic	✓			✓				
Geothermal[10]	✓	✓	✓	✓				
Wave/Tidal	✓			✓				
Nuclear		✓	✓	✓				
Biomass	✓	✓	✓	✓	✓	✓	✓	✓

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[7] Modeling based on data from 'Australian Natural Resource Atlas', Australian Government, accessed at http://www.anra.gov.au/topics/land/carbon/vic/ February, 2008. Technique used average primary productivity data to determine annual 'bone dry tonne equivalen' biomass production for the state and then multiplied this by the bone dry calorific value of biomass (assumed to be 20GJ/t). This number varies annually depending on climate and agricultural practices.

[8] Based on a primary energy consumption of 1394.7PJ in 2004-2005 'Energy Generation in Victoria', Sustainability Victoria, accessed at http://www.sustainability.vic.gov.au/www/html/1817-energy-generation.asp, February, 2008.

[9] Note that while the production of Hydrogen (H_2) from water using electrolysis means that an energy rich gas can be produced from any source of renewable electricity, the thermal efficiency of this process is limited to <60 per cent which makes it a relatively unattractive technology 'High-Temperature Electrolysis for Hydrogen Production From Nuclear Energy', Idaho National Laboratory, accessed at http://www.inl.gov/scienceandtechnology/factsheets/d/hightemperatureelectrolysis.pdf, February, 2008.

[10] Geothermal energy is not strictly renewable, but is abundant enough to be often classed as such in many jurisdictions.

Only biomass processing can potentially match the full range of fossil fuel attributes. Low carbon fossil fuel use depends on geosequestration which, even when proved, will be limited to stationary heat and power applications and chemicals.

2.3 Sustainability Considerations

Biomass resources are highly distributed in comparison to fossil fuel resources with the 2,200 PJ of biomass growth each year in Victoria almost uniformly distributed over the entire state land mass. The use of bioenergy therefore has a very great capacity to impact on land use and demands that the sustainability case be thought through extremely rigorously. 'Renewable', 'Low greenhouse gas emission' and 'Sustainable' are not synonymous terms and none can be guaranteed with biomass projects.

Biomass is a renewable resource (See Figure 2) as long as the average rate of harvest is less than or equal to the average rate of regrowth.[11] Biomass production systems are nutrient dependent, hence non-renewable if they systematically degrade the material value of finite nutrient resources.[12]

Biomass processing has low net greenhouse gas emissions despite CO_2 emissions during combustion, because the carbon in the biomass was sourced from the atmosphere as CO_2 during plant growth, as shown in the schematic below. This is particularly attractive as it allows for continued use of high energy density carbon based fuels in dispersed applications, such as transport, where carbon capture and storage is not practically possible.

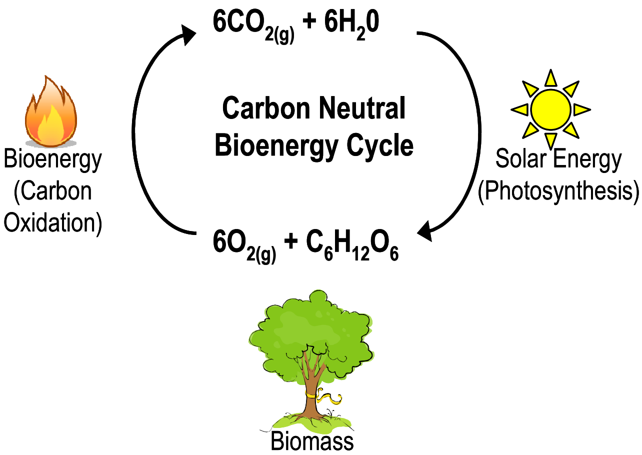

Figure 2 – Schematic of balanced carbon cycle[13]

In reality, bioenergy projects will exist on a scale from carbon negative (net removal of CO_2e from the atmosphere) to carbon emitting (net addition of CO_2e) depending on the growth practices, transport, and processing technologies.[14] The ability to be carbon negative is distinct from other renewable technologies,

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[11] In cases where the regrowth of biomass is hindered by a land use change (such as the transition of forest to grazing, cropping, urban or mining land) the biomass harvested may be used for bioenergy, but is finite in volume and cannot be considered 'renewable' (the successful rehabilitation of mining land would make originally cleared biomass renewable).

[12] An example of this is biogas production from the anaerobic digestion of sewage where the resultant nutrient rich biosolids are degraded by deliberate dispersal into the ocean instead of being recycled to productive lands.

[13] Photosynthesis uses solar energy to make biomass (mainly cellulosic sugars) from carbon dioxide and water. The energy in biomass can be harvested and used via oxidation, re-releasing the carbon dioxide and water.

[14] A carbon negative balance is achieved if the standing stock of biomass increases or carbon is removed from the carbon cycle via inactive soil carbon, pyrolysis char or carbon capture and storage.

which can only achieve carbon neutrality at best.[15] Bioenergy projects can be net greenhouse gas emitting, if there are significant additional emissions over the life cycle, such as nitrous oxide (N_2O) and methane (CH_4).[16]

Sustainability is a more fundamental term to describe projects than 'renewable' or 'low emissions'. Sustainability implies value being created in society without systemic degradation of ecological and social systems, that is meeting the needs of today without jeopardising the needs of future generations. Moreover, there has been a historical degradation of resources by agricultural and industrial activities, so that in many cases it is possible, or indeed necessary to be 'better than sustainable' by reversing past problems and thereby being environmentally or socially 'regenerative'.

Bioenergy projects inevitably have impacts across a wide range of environmental, economic and social domains that all must be considered to determine their sustainability status. Projects will not be fundamentally successful unless they can demonstrate sustainable biomass supply, viable business conditions and societal support, as summarised below.

Table 2 – Hierarchy of sustainability considerations for biomass processing projects

Project Level	Sustainability Building Blocks	Specific Issues
Sustainable Bioenergy and Materials Production	Ecologically Sustainable and Viable Biomass Supply	– land – water – biodiversity
	Commercially and Technologically Viable Processing Business	– feedstock supply – technology – products and markets
	Licence to Operate	– government – community – public

2.4 Biomass and Food Production Competition

In Victoria the production of grains, meat and dairy products exceed state requirements and are exported to other states and countries.[17] Fertile agricultural land is a globally limited resource and agricultural products are globally traded commodities. The diversion of land use[18] or crop outputs from food production in Victoria therefore assists in reducing the global food supply and places upward pressure on

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[15] In reality 'renewable' energy technologies often have residual emission footprints through embodied energy and fossil fuel related operating and maintenance emissions.

[16] N_2O has a greenhouse gas intensity 310 times that of CO_2. N_2O emissions can be a by-product of Nitrogen fertilise s addition and anaerobic soils. CH_4 has a greenhouse gas intensity 21 times that of CO_2 and is associated with anaerobic decomposition of biomass. Ssubstantial amounts of methane are also produced by ruminants (cattle and sheep) during foregut digestion hence adding to net greenhouse gas emissions of biofuel derived from animal sources. '2008 National Greenhouse Accounts (NGA) Factors', Australian Government Department of Climate Change, accessed at http://www.climatechange.gov.au/workbook/pubs/workbook-feb2008.pdf, February, 2008.

[17] 'Australian Commodity Statistics 2007', Australian Bureau of Agricultural and Resource Economics, accessed at http://www.abareconomics.com/publications_html/acs/acs_07/acs_07.pdf, February, 2008.

[18] In this context claims that non-food biofuel crops such as Jatropha do not compete with food production may be misleading.

food prices.[19] Rising food prices disproportionally affect the world's poor for whom the cost of food is a larger proportion of income. For these people the consumption of meat is already financially prohibitive, hence it is socially responsible to focus dedicated bioenergy activities towards grazing lands (as opposed to crop lands) unless management models can be found that produce biomass for bioenergy while protecting food crop output. The range of biomass resources is discussed in further detail in Section 3.

2.5 Overview of Near Future Carbon Pricing

In a carbon constrained world businesses will have to measure their carbon flows as accurately as cash flows in order to determine their carbon impact. The Greenhouse Gas (GHG) Protocol is commonly used as the standard for reporting and accounting of greenhouse gas emissions based on relevance, completeness, consistency, transparency and accuracy.[20] The GHG Protocol also provides guidance on the operational boundaries for reporting as three levels of 'scope', with businesses who claim to be reporting in accordance with the Protocol required to report on Scope 1 and 2 emissions as a minimum.[21]

In Australia greenhouse emissions reporting will become mandatory for approximately 700 medium to large companies under the National Greenhouse and Energy Reporting Act, set to come into effect on 1 July 2008. Reporting thresholds start at 125,000 tonnes of CO_2e, but will decrease down to 50,000 tonnes of CO_2e by 2010-11, meaning that even more companies will be required to report.[22] The Act also establishes a Greenhouse and Energy Data Officer, and it is likely that reporting on Scope 1 and 2 emissions will be mandatory, with non-compliance becoming a civil offence for chief executive officers.[23]

The main intent of mandatory reporting is to support emissions trading in Australia. While the final shape of a national emissions trading scheme is yet to be decided, emissions trading is likely to commence in 2010-11. The clear signal of demand under this mandatory scheme will be given by the mid-term target at 2020. A modest target, for example, a return to 108 per cent of 1990 emission levels, will result in a low carbon price. A more robust target, for example, a 20 per cent reduction (1990 levels) in emissions by 2020 will result in a higher price.

Previous modelling for an electricity sector emissions trading scheme in Australia estimated that trading would start between $6 and $12 per tonne of CO_2e, and steadily increase to between $17 and $31 per tonne of CO_2e at 2020.[24]

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[19] *Prior to the advent of biofuels agriculture has experienced a gradual decrease in terms of trade due to increases in food production outstripping population growth, Mullen, J, 2007, 'The Importance of Productivity Growth in Australian Agriculture', Connections, accessed at http://www.agrifood.info/connections/2007/Mullen(1).pdf, February, 2008.*

[20] *WRI and WBCSD, 2004, 'The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition)', World Resources Institute and World Business Council for Sustainable Development, Geneva, accessed at http://www.ghgprotocol.org/DocRoot/7e9ttsv1gVKekh7BFhgo/ghg-protocol-revised.pdf, April 2008.*

[21] *Scope 1: Direct Greenhouse Gas Emissions – reporting on emissions of the six Kyoto gases arising from direct combustion of fossil fuels (including car fleets), chemical production and other industrial process emissions. Scope 2: Electricity Indirect Emissions – emissions that are created from electricity generation according to the amount of electricity usage by the company. Scope 3: Other Indirect Emissions – an optional reporting category for all other indirect greenhouse emissions that occur as a consequence of company activities; including extraction and production of purchased materials, emissions from product use, outsourced activities, contractor vehicles, employee travel and waste disposal.*

[22] *AGO, 2007, 'National Greenhouse and Energy Reporting Act 2007 - Fact Sheet', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/reporting/publications/pubs/nger-fs.pdf, April 2008.*

[23] *AGO, 2007, 'National Greenhouse and Energy Reporting System Regulations Discussion Paper', Australian Greenhouse Office, Canberra, accessed at http://www.greenhouse.gov.au/reporting/publications/pubs/ngerregs-discussion.pdf, April 2008.*

[24] *1McLennan Magasanik Associates Pty Ltd, 2006, 'Impacts of a National Emissions Trading Scheme on Australia's Electricity Markets', National Emissions Trading Taskforce, Sydney, accessed at http://www.emissionstrading.net.au/__data/assets/pdf_file/0009/2016/060811_Final_MMA_Report.pdf, April 2008.*

This compares to trades in NGACs (NSW Greenhouse Gas Abatement Certificate) which traded between \$12 and \$14 per tonne of CO_2e prior to the scheme collapse (caused in some part by uncertainty regarding integration of NGACs with a national scheme.[25]

Other comparisons include current trades of VERs through the Australian Climate Exchange which sells Greenhouse Friendly™ VERs at A\$8.75 each.[26] International trades in carbon are much higher. For example the Chicago Climate Futures Exchange which trades in Certified Emission Reductions (CERs) under the CDM mechanism of the Kyoto Protocol report a December 08 futures price for of US\$25.30 per tonne,[27] and December 08 prices on the European Carbon Exchange were €22.60 per tonne.[28]

It is highlighted that the interim '2020' emission reduction targets will be the first solid indication of the likely price for greenhouse gas abatement in Australia. This information should be available towards the end of 2008. Until that time, a range of \$20 to \$30 per tonne of CO_2e seems appropriate.

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[25] *Smith, R, 2007, '160 Million Light Years', Greenhouse 2007 Proceedings, accessed at http://www.greenhouse2007.com/downloads/papers/071005_Smith.pdf, April 2008.*
[26] *Australian Climate Exchange, undated, 'Home Page' accessed at http://www.climateexchange.com.au, December 2007.*
[27] *Chicago Climate Futures Exchange, undated, 'Home Page', accessed at http://www.ccfe.com/, December 2007*
[28] *European Climate Exchange, undated, 'Home Page' accessed at http://www.europeanclimateexchange.com, December 2007.*

3 BIOMASS RESOURCES

Biomass resources have varying ratios of distinct molecular structures which interact with processing technologies in different ways. Biomass technology must be tailored to the biomass type to achieve optimum outcomes. This section shows the alignment between biomass structures and processing conditions and also highlights some of the features of biomass resources that have an impact on the appropriateness and sustainability of their use for bioenergy applications.[29]

3.1 Biomolecular Constituents

All organisms are technically included under the title of biomass. The overwhelming majority of biomass available for bioenergy is general plant material rather than specific grains or animal products, the term 'biomass' is therefore often synonymous with 'whole plant biomass', while specific grains or animal products are usually referred to directly.

At a fundamental level, biomass is composed mainly of water insoluble carbohydrates (lignocellulose) with the remainder as water soluble carbohydrates (sugars, starch and proteins)[30] and hydrocarbons (lipids - fats and oils).

Hydrocarbons contain mainly carbon and hydrogen, have a high energy density[31] and are used for energy storage by biological organisms where weight and volume are critical. Carbohydrates also contain carbon and hydrogen, but have approximately one atom of oxygen for each atom of carbon in the structure. Oxygen reduces the energy density of carbohydrates compared to hydrocarbons, but has other valuable biological outcomes such as making the molecule water soluble (proteins, sugars and starch) so that it can be easily transported within the organism, or aiding in the formation of polymers for structural roles (lignocellulose).

Humans are only able to successfully digest soluble carbohydrates and lipids hence lignocellulose is not a direct human food. Animals are able to maintain the structural integrity of amino acids during digestion and hence use food protein for their own growth and development. This means that if protein can be separated from other biomass components it can often have more value as an animal (including human) feed where the nitrogen and sulphur are an asset rather than a pollutant.

The energy density and physical properties of the biomass are critical factors for bioenergy feedstock considerations and need to be understood in order to match a feedstock and processing technology. Section 4 of this report identifies six generic biomass processing technologies for the development of bioenergy and material products. The capacity of these generic biomass processing technologies to process the different fundamental biomolecular types is shown below in Table 3.

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[29] The shear scale of biomass supply required to make a major difference to societal greenhouse gas emissions means that failure to address the issues of potential competition with food production, as well as potential impacts on soils, water quality and biodiversity, may lead to dysfunctional outcomes.

[30] Proteins are only carbohydrates from a broad perspective, they contain Nitrogen and Sulfur in addition to Carbon, Hydrogen and Oxygen which is a problem for combustion applications where these become pollutants. Proteins are more complex chemically than the repeating sugar monomers of the other carbohydrates. Proteins are essential for the growth of biological organisms and therefore usually have more value as a feed than as bioenergy.

[31] The long carbon chains in fat and oils are similar in structure to the hydrocarbons in diesel fuel and can be easily converted to biodiesel via transesterification.

Table 3 – Primary processing technologies and the ability to process different biomolecules

Processing Technology	Hydrocarbon Fats, Oils	Soluble Carbohydrate: Protein	Soluble Carbohydrate: Sugars, Starch	Insoluble Carbohydrate: Lignocellulose
Direct Combustion	✓			✓
Anaerobic Digestion	✓	✓	✓	Cellulose only
Fermentation		✓	✓	Cellulose only
Oil Extraction	✓			
Pyrolysis	✓	✓	✓	✓
Gasification	✓	✓	✓	✓

Some of the important features of different biomass resources are presented on the following pages. Broad distinction is drawn between crops which contain extractable non-lignocellulosic value, bulk lignocellulosic crops and biomass wastes and residues.

3.2 Crops Containing Extractable Non-lignocellulosic Values

Crops that contain extractable non-lignocellulosic value include annual grassy crops, annual oilseed crops and oil tree crops.[32]

3.2.1 Annual Grassy Crops

Annual grassy crops include cereal grains, sugar cane and other grasses. Grassy (monocotyledon) plants form the bulk of modern broad scale agriculture. Selective breeding has been used to alter the seed/plant biomass ratio in many species which has led to large increases in seed yield. Increases in total plant biomass have also occurred over time as a result of improved management of soil nutrients (often through synthetic fertiliser addition), crop pest management and improved development/matching of varieties to local conditions. Seeds from these crops tend to be a good source of starch (with some additional protein) and are usually the key revenue generating portions of the crop. The rest of the plant body (often the bulk of the biomass) is composed of lignocellulose and additionally sugars in some species. Some grasses such as maize and sugar cane are known as C4 plants (in contrast to common plants which are C3 plants) which have increased water use efficiency and hence yield in hot conditions.

Agricultural processing normally consists of selectively removing the grain or stem sugars for food and using the remaining lignocellulosic residues as animal fodder or mulch. Residues can be directly combusted for bioenergy (heat and power). The starch and sugars can be used as a bioethanol feedstock when economically viable, but can also be used for butanol, methane and hydrogen production through biological processing options. If the price of oil is high, energy use can affect the availability of grains and sugar and raise the price of food.

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[32] *Annual crops generally survive for a single growing season and must be replanted, perennials live for many seasons and may undergo multiple harvests. Perennials generally have deeper and more established roots and so are better able to access soil moisture and protect against dry land salinity. Perennials also tend to have a larger above and below ground standing biomass stock and therefore store more carbon in the landscape.*

3.2.2 Annual Oilseed Crops

The seeds of most plants contain oil, and in some cases the value and quantity is sufficient to cover the costs of oil extraction (usually through maceration, mechanical pressing and solvent extraction). Plant oils have existing uses in food, food preparation, soaps and cosmetics. Oil in these crops usually compliments other seed constituents (protein or starch) as part of the crop revenue stream. Oil seed crops have a different evolutionary history to cereal crops and therefore can have an additional benefit as a break crop in reducing plant soil pathogens, and those that are legume crops can increase soil nitrogen via fixation of atmospheric Nitrogen.

The plant body (lignocelluloses), traditionally used as mulch or fodder,[33] can also be combusted for heat and power. The plant oils can be used for higher value bioenergy applications, especially as a diesel replacement. Australian experience has shown that competition for feedstock is an extremely important factor in the economics of biodiesel production; in recent times this has had a serious negative impact on the viability of biodiesel manufacture.

3.2.3 Oil Tree Crops

A number of tree crops produce oils either in harvestable seeds or in the leaves. Seeds often have high food value. Many oilseed trees are tropical or subtropical, such as palm, coconut, and macadamia. Palm oil in particular has developed a poor environmental reputation, mainly due to clearing of rainforests to create palm plantations.

Oil tree crops with lower inherent food values can be a resource for bioenergy, and as perennials provide additional soil, water and carbon sink benefits. Non-food crops will also not display spikes in value associated with food supply and demand issues. Poisonous oil producing species such as Jatropha can be useful for bioenergy and are often promoted as not competing with food crops.[34] There are concerns however that such species can display many properties associated with weeds and potentially subject to bans.

3.3 Bulk Lignocellulosic Crops

Bulk lignocellulosic crops include perennial grassy crops, lignocellulosic tree crops and multispecies native assemblages.

3.3.1 Perennial Grassy Crops

Grasses have adapted to avoid being killed by fires or heavy grazing by protecting their growing point (shoot apex) close to the ground, exposing only the sacrificial leaves. Perennial pastures can be productive sources of lignocellulosic biomass, which is cut as fodder or fed directly to grazing animals. Note that fodder production and direct grazing are the most common land use activities on Victorian farms.

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[33] *These often have a high nitrogen content which requires stock management.*
[34] *Claims such as these should be taken with caution, these crops still require land and if that land is cropping land then indirect competition still exists.*

Biomass of this type can be used as bioenergy feedstock when the economics are viable. Fast growing reeds and canes (such as *Arundo donax,* elephant grasses) are examples of grassy crops that can make good use of high water and nutrient availability for increased biomass productivity.[35]

3.3.2 Lignocellulosic Tree Crops

The life cycle of many tree species focuses first on a substantial growth phase, only later partitioning energy into reproduction. Such trees display a strong increase in lignocellulosic biomass over years to decades. Whilst they may be initially intensive to establish, they have low inputs as a proportion of total biomass harvested. Trees may be harvested once, or many times (coppiced) depending on the species and impact on productivity. Lignocellulosic tree crops stabilise soils and improve the quality (while reducing the volume) of water runoff. As a tree grows, biomass is laid down mostly as lignocellulosic vascular material in the roots, trunk and branches. Lower limbs are often stripped of nutrient and discarded, the nutrient being redistributed to the growing regions of the plant. This means that tree crops are able to establish a large amount of biomass on minimal nutrient resources. Many Australian natives form symbiotic relationships with fungi and bacteria that help them to access phosphate and build nitrogen resources which are important in depleted soils.

Australian eucalypt species are a diverse group containing some of the fastest growing hardwoods that are well suited for use as materials (for example timber products, pulp and paper) or bioenergy. These species are suited to growing in multispecies assemblages or monocultures.[36] Eucalypts have evolved to survive in almost all of Australian environments. Acacia species are also well represented in Australia.[37] Acacia species are not often used for materials, however many of them have high protein edible leaves that make them candidates for a combined fuel and fodder crop. Softwoods may also be grown as lignocellulosic tree crops for materials and bioenergy; these are not usually based on indigenous species in southern Australia. Softwoods tend to grow in monocultures and often competitively exclude other species in the vicinity.

The productivity of tree crops may be low until a closed canopy is formed, which can be brought forward with high planting density and one or more thinning harvests to enhance later stage growth.[38] In regions of low rainfall it is unlikely that timber or woody plants would reach milling standard. In this case the whole plant biomass may be used for bioenergy and therefore present opportunities for streamlined harvesting techniques that may significantly reduce costs.

3.3.3 Multispecies Native Assemblages

Multispecies Native Assemblages are purpose grown biomass plantations designed to mimic natural biological communities in order to provide additional biodiversity and sustainability value while growing. Habitat types are a general outcome of the available species pool functioning within the local disturbance regime. As harvesting alters the ‘naturalness’ of this disturbance regime multispecies native assemblages cannot be considered true ‘native environments’ but nonetheless are able to maintain and interconnect biodiverse regions of indigenous flora and fauna. Being predominantly deep rooted perennials they

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[35] Hence they are often considered potential weeds of inland waterways. These materials may be harvested and regrown from rhizomes (special underground roots), with the harvested biomass sometimes having value as structural materials in addition to their value as lignocellulosic bioenergy feedstocks.
[36] In reality monocultures are often multispecies with an herbaceous understorey.
[37] Acacias do not have the high oil content of eucalypt species; they are able to form symbiotic relationships with nodulating root bacteria that fix nitrogen and hence allow them to perform well in nitrogen depleted soils.
[38] Thinnings are suitable for bioenergy or pulpwood.

stabilise soils, build soil carbon, reduce eutrophication and soil emissions, while protecting against dry land salinity. These properties help to build resilience to climate change via transport corridors for native species. As bioenergy processing technologies such as pyrolysis and gasification are relatively insensitive to the material and bio-toxin qualities of lignocellulosic woody biomass sources it is possible for the system to remain robust in terms of energy production despite large changes in species composition as a result of climate based habitat migration.

While biomass from existing native forest is excluded by legislation from dedicated bioenergy use in many states, the development of 'restoration plantations' on private lands are allowable and strategically attractive propositions if economic.

A key feature for bioenergy use of lignocellulosic tree based biomass is that the biomass is accumulated over several years and is then available to harvest independently of growing seasons with minimal impact on system productivity.[39] This effectively shields the bioenergy feedstock supply from annual and seasonal variation, allowing well planned and integrated bioenergy processing facilities that maximise plant capacity and capital investment.

3.4 Residues and Wastes

Potential biomass based residues and wastes include plant and animal residues. Note that residues and wastes are inherently constrained in scale by the scale of the parent activities. It is important to recognize that wastes often contain both energy and nutrient components. A basic rule for ecological sustainability is that energy may be extracted from production/consumption systems but nutrient must be recycled.[40] It is not advisable to base a bioenergy project on waste streams that should be minimised or converted to higher value outcomes.

3.4.1 Plant Residues

Plant residues come in a number of forms and from a number of industries. Green waste is predominantly lignicellulosic plant material from municipal sources and includes tree prunings and grass clippings.[41] Municipal putrescibles such as food scraps contain lignocellulosic material but have a higher moisture, soluble sugar and protein content than green waste. Cropping residues are derived from the lignocellulosic parts of plants after the valuable food components have been removed and include plant stubble[42] and bagasse. Food industries typically produce additional residues during value adding processing which include seed husk/pods, grape marc and inedible seeds as well as nutrient or sugar rich waste water. Forestry activities produce thinnings and prunings during growth as well as tops, leaves, stumpage and sawdust during harvesting. Processing of timber at sawmills produces slabs, sawdust, shavings, wings and offcuts. Construction and demolition activities produces sawdust, offcuts and timber waste.

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[39] *This is in relation to seasonal or annual crops which typically lose value if not harvested within a window of weeks.*
[40] *The non-recycling of nutrients within our current food production/consumption systems is a massive scale failure of systems design and places reliance on increasingly depleted phosphate reserves for continued food production.*
[41] *Current best practice for municipal green waste is composting to avoid the methane emissions and other environmental impacts associated with landfilling.*
[42] *This is often the bulk of the plant biomass.*

Some degree of sorting and pre-processing may be required depending on the waste stream at a particular site. Care must be taken to consider the impact of contaminants (chemically treated timbers, metal fixtures, plastics, and batteries), their behaviour during processing and whether they finally report to emission and residue streams or to products.

Thermal processing can in principal deal with all forms of green and organic waste. Other technologies, such as cellulosic fermentation for alcohols, may be suitable for clean cropping residues such as wheat stubble or sugarcane bagasse while anaerobic digestion is well suited to wastes with high moisture, soluble sugar and protein contents such as putrescible and sewage wastes and may benefit from blended streams of these wastes in terms of both performance and reliability of feedstock supply.

3.4.2 Animal Residues

The processing of animals for meat produces a number of secondary product or waste streams. High nutrient wastes such as blood, bones and intestinal residues are low in energy and high in water and therefore have higher value as fertilisers. On the other hand, rendered fat (tallow) can be the source of high energy hydrocarbons for diesel production.[43]

Animal manures (including human) and bedding may also be used as a bioenergy feedstock. The high water and protein content of some wastes (dairy and piggery) makes them ideal candidates for anaerobic digestion, while some of the drier wastes with a higher lignocellulosic content (for example chicken litter containing sawdust or wood shavings) may be more suited to pyrolysis. In these cases, the biosolids and char respectively should be recycled back to agricultural lands for conservation of nutrients.

3.5 Productivity

A highly productive and scaleable bioenergy industry will have to make full use of biomass resources and constituents to recover maximum value. This overview highlights that lignocellulose is the most common and highest volume constituent of biomass, as shown in Table 4 below. Therefore thermal processing, and cellulose fermentation once proven, will underpin the bioenergy world of the future, with specific processes (digestion, oil extraction and fermentation) being used as a primary processing treatment for biomass sources with significant extractable non-lignocellulosic values.

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[43] *The tallow is dewatered for biodiesel production. It has long chain saturated fatty acids; to meet fuel standards it must be either blended or cracked.*

Table 4 – Biomolecular composition of different biomass resources.					
Biomass Source		Hydrocarbon (Fats, Oils)	Carbohydrate (Protein)	Carbohydrate (Sugars/Starch)	Carbohydrate (Lignocellulose)
Annual Crops	Grassy Crops			✓	✓
	Oilseed Crops	✓	✓		✓
Perennial Crops	Grassy Crops				✓
	Oil Tree Crops[44]	✓	*sp. dpndt*	*sp. dpndt*	✓
	Lignocellulosic Tree Crops	✓			✓
	Multispecies Native Assemblages				✓
Residues and Wastes	Green Waste				✓
	Animal Waste	✓	✓		✓

The key business challenge for potential bioenergy projects is demonstrating the profitability of bioenergy production when compared to other land uses within a complete life cycle analysis. This means lowering the costs of production and transport. An important factor here is biomass productivity, that is the tonnes of biomass grown per hectare per year and the energy/cost inputs to sustain it.

Species selection is an important factor in productivity, however it is important to remember that plants are governed by natural laws. There is no magical plant (Genetically Modified Organisms (GMO) included) that has high productivity without the basic inputs of nutrient, water and sunshine. These physicochemical inputs govern much of productivity, while species selection plays a role in disease and insect resistance, the ability to develop symbiotic relationships with soil microbes, and the partitioning of biomass among the roots, stems, leaves and reproductive organs. Some mechanisms for increasing productivity, such as using mined phosphate resources, may be unsustainable in the longer term. High growth strategies may be unsustainable in terms of soil degradation, excessive water draw, and eutrification from high fertiliser usages.

As a general guide, abundant woody biomass production systems yield around 5-15 dry tonnes per hectare per annum, when averaged over growing and harvesting cycles. Many higher productivity systems have been demonstrated, such as rapid growing grasses, with annual yields as high as 50 dry tonnes per hectare. However these systems require appropriate land and climate resources to support high growth rates.

Productivity defines the land footprint supporting a bioenergy project. For instance, a facility processing 500,000 green tonnes of biomass each year would require some 25,000 hectares of land to produce the biomass, assuming an average annual productivity of 10 dry tonnes per hectare and an average biomass moisture content of 50 per cent. That is an area of approximately 256 square kilometres.

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[44] *'sp. dpndt' denotes species dependent opportunities.*

Biomass productivity also affects the costs of harvesting, transport and other logistics. The great advantage of biomass (ubiquitousness) is also one of its key disadvantages, in that is costly to aggregate in central processing facilities. Another perspective on this is that the level of productivity in the above example could generate as much as 15 million green tonnes annually within a transport distance of 50 kilometres from a processing hub. Concentrated biomass production assists in achieving economies of scale at processing plants.[45]

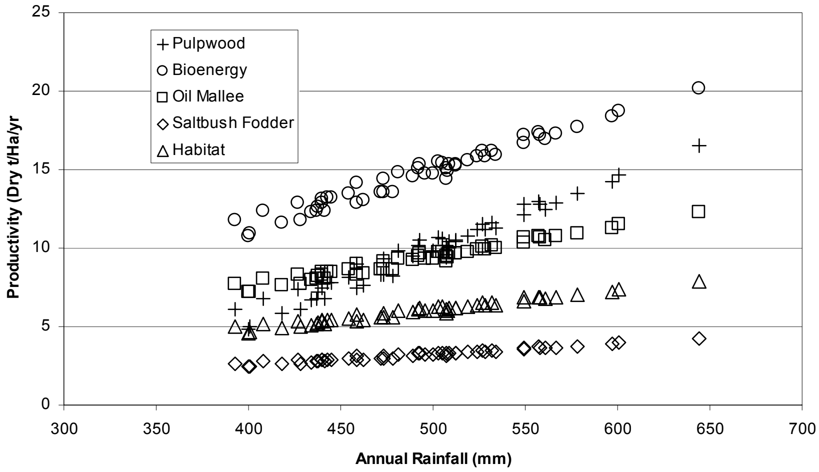

Figure 3 – Rainfall as a fundamental driver of productivity

Rainfall is a fundamental driver of productivity, as shown in a South Australian study (see Figure 3 above),[46] where productivities on a dry weight basis ranged from 5 to 20 tonnes per hectare depending on biomass groupings and rainfall.

3.6 Integration

Each biomass resource needs to be examined on its merits for specific value creating opportunities and specific risks and challenges. Notwithstanding this, from the general perspective of sustainable biomass supply for bioenergy, the underlying strategic direction would be to:

- maximise carbon storage, above and below ground, within the biomass and the soil
- favour perennial rather than seasonal crops
- avoid using prime agricultural land
- promote biomass species and eco-systems that draw the least on constrained nutrient and water resources and protect or restore biodiversity
- minimise the energy inputs (fertiliser, machinery etc) to biomass production.

The table below presents a summary of biomass supply from this context. Green denotes the most favourable outcomes and red the least favourable outcomes, with yellow in between.

[45] *This strategy underpins much of existing softwood and pulpwood plantations of Victoria and other states.*

[46] *Crucible Carbon modelling based on the data in T.Hobbs et al "Woody Biomass Productivity and Potential Biomass Industries in the Upper south East", 2006, FloraSearch, SA Department of Water, Land.and Biodiversity Conservation, CRC Plant-based Management of Dryland Salinity. This data has good applicability to western Victoria.*

Table 5 – Sustainability considerations of biomass sources

Biomass Resource	Carbon Store[47]	Availability – Land Base[48]	Nutrient Requirements[49]	Watershed Impact[50]	Biodiversity	Energy Inputs[51]
Annual Grassy Crops	Biological – low Soil - low	Seasonal - Cropping	Medium	High	Low	High
Annual Oilseed Crops	Biological – low Soil - low	Seasonal - Cropping	Medium – high	High	Low	High
Oil Tree Crops	Biological – med Soil - med	Seasonal – Prime Ag.	Medium	Low	Low	Medium
Perennial Grassy Crops	Biological – low Soil - high	Seasonal – Prime Ag.	Low - medium	Medium	Low - medium	Medium – high
Lignocellusoic Tree Crops	Biological – high Soil - high	On demand – all lands	Low - medium	Medium – high	Low - medium	Low
Multi Species Native Assemblages	Biological – high Soil - high	On demand – all lands	Low	Low	High	Low
Green Waste	n/a	n/a	n/a	n/a	n/a	Medium – high
Animal Residues/Waste	n/a	n/a	n/a	n/a	n/a	Low

From this first cut analysis, lingo-cellulosic biomass produced in multi-species native assemblages has the greatest strategic attraction for feedstocks to the bioenergy industry of the future, assuming ecological sustainability shapes society's responses to climate change.

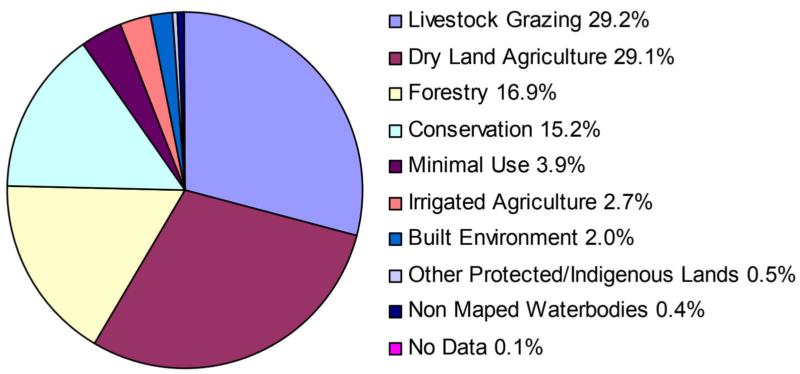

Figure 4 – Land use in Victoria[52]

[47] *Carbon Store is the ability for the particular biomass source to store carbon in the landscape. This is divided into above ground (plant material) and below ground (roots and soil carbon).*
[48] *Availability is when the biomass may be harvested from the landscape; Land Base is the recognized current land use that would be used for production.*
[49] *Nutrient requirement is the likely nutrient required (Nitrogen, Phosphorus and Potassium) for economic growth.*
[50] *Watershed Impact examines the likely deviation from pre-European above and below ground hydrology as a result of developing the biomass source.*
[51] *Energy Inputs are those required for preparation, planting, maintenance and harvesting of the biomass sources as well as collection and transport to the biomass processing site. High input crops have additional energy burdens due to fertilizer and herbicide/pesticide use.*
[52] *Data from 'Land Use – Land Use in Victoria', Australian Government Australian Natural Resource Atlas, accessed at http://www.anra.gov.au/topics/land/landuse/vic/index.html, February, 2008.*

Biomass is not a limitless opportunity. Victorian landscapes are highly utilised, with the main uses being, in similar proportions, livestock grazing, dry land agriculture, forestry and conservation.[53] As carbon trading is introduced and the carbon price increases to reflect public commitment to effective abatement measures, we may see significant shifts in land practices.

A shift over time to bioenergy from lignocellulosics will inevitably lead to innovation in farming methods for maximum overall value capture from land assets and a change in the comparative economics of existing farming methods. Bioenergy from lignocellulosics is seen as an opportunity to profitably underpin the regeneration of biodiversity and ecosystem function in significant tracts of cleared and degraded lands.

Forestry, especially multispecies native assemblages, is an ideal platform for low input, stable, bulk production of biomass and is likely to expand as the potential of thermal processing and fermentation of lignocellulosics is realised.[54]

Dry land agriculture and the common wheat/sheep rotations may change to wheat/biomass rotations with a mixture of alley farming and residue recovery. Livestock grazing may diversify into lignocellulose biomass, as production becomes a more competitive use of marginal lands. Meat and sheep production in areas of low pasture quality may shift to open forestry and native animal farming.[55]

Given the limits on Victorian land, the emergence of large scale biomass production for bioenergy will need to be implemented in ways that complement other forms of land use.

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[53] This is a different profile to other mainland states, where livestock grazing is typically the predominant land use. Society has already made the choice to set aside conservation areas, thus not available.

[54] As shown in Section 4, thermal processing of lignocellulosic biomass is already commercially available, but improvements in pyrolysis performance (capital intensity and energy efficiency) as the most flexible platform will probably be needed to facilitate significant breakthroughs. Fermentation of cellulose is at the pilot demonstration stage and may become commercialised in the reasonably short term.

[55] There no methane emissions from kangaroos!

4 BIOMASS TECHNOLOGIES FOR ENERGY AND MATERIALS

The majority of biomass that is in principle available for bioenergy projects exists as solid unprocessed plant material with a moisture content typically around 50 per cent. In addition there is a diverse range of available biomass resources associated with human activity, particularly residues and wastes from agricultural, industrial, municipal, forest and other economic activities.

There are six generic biomass processing technologies based on direct combustion (for power), anaerobic digestion (for methane rich gas), fermentation (of sugars for alcohols), oil exaction (for biodiesel), pyrolysis (for biochar, gas and oils) and gasification (for carbon monoxide (CO) and hydrogen (H_2) rich syngas); which can then be followed by an array of secondary treatments (stabilisation, dewatering, upgrading, refining) depending on specific final products.

The versatility of biomass processing technologies to produce energy and materials in heat, gas, liquids and solid forms is highlighted in Table 6 below. Each technology is discussed further in this Section with additional background information in the footnotes provided.

Table 6 – Overview of biomass technologies

Generic Technologies	Energy and material building blocks			
	Heat	Gas[56]	Liquid[57]	Solid
Direct Combustion	✓			
Anaerobic Digestion		✓		
Fermentation			✓	
Oil Extraction			✓	
Pyrolysis	✓	✓	✓	✓
Gasification	✓	✓	✓	

The selection of processing technologies needs to be aligned to the nature and structure of the biomass feedstocks and the desired project outputs. From the above table, it can be seen that direct combustion or gasification of biomass are appropriate when heat and power are required. Anaerobic digestion, fermentation and oil extraction are suitable when specific biomasses are available that have easily extractable oils and sugars or high water contents. Only the thermal processing of biomass by pyrolysis can provide the platform for all of the above forms of product.

Many thermal technologies require the water content of biomass to be low (<15per cent) for proper operation. For these technologies the energy cost of drying can represent a significant reduction in process efficiency.

[56] Gasses from different processes are not directly comparable – Anaerobic digestion produces mainly methane (CH_4) and some Hydrogen (H_2) roughly equivalent to Natural Gas (~50GJ/t); Pyrolysis gas is weak by comparison and a mixture (in descending concentration) of CO_2, CO, CH_4, C_2H_6, C_3H_8 (~6GJ/t); Gasifier gas is a mixture (in descending concentration) of CO_2, CO, H_2, CH_4 (~16-18GJ/t). The energy content of Pyrolysis and Gasifier gas assumes that the processes are oxygen rather than air fed.

[57] Fermentation usually yields Ethanol (C_2H_5OH – 31.1GJ/t) or Butanol (C_4H_7OH – 43GJ/t); Oil extraction produces hydrocarbon methyl esters $C_{15\text{-}18}H_{31\text{-}33}CO_2CH_3$ (35-43GJ/t); Pyrolysis oil is a complex mixture of aromatic and oxygenated hydrocarbons (17-20GJ/t); Gasification does not produce liquids directly, but Fischer-Tropsch liquids may be synthesized from syngas and are ideal for liquid transport fuel applications (40-45GJ/t).

4.1 Direct Combustion

Biomass combustion can produce heat or steam.[58] Dry woody biomass has an energy content of approximately 20 Giga Joules per tonne (GJ/t), slightly higher for softwoods due to higher lignin content. This is comparable to lower ranked coals, making biomass suitable for electricity generation. Lower grade waste heat from biomass combustion can also be used in combined heat and power applications.

The direct combustion of woody biomass for power production is currently the highest volume bioenergy market. Biomass may be the sole fuel for heat and power generation or may be blended with coal in a process known as co-firing.[59] The residues from biomass combustion are essentially ash, which can be process wastes or better utilised as soil conditioners to close nutrient cycles. The key features of biomass combustion are summarised in the table below.

Table 7 – Direct combustion technology

Technology Attributes	Description
Process	Direct combustion of biomass or co-firing with coal[60]
Products	Heat and power; domestic heating, industrial process heat, boiler heating for electricity generation
Feedstock	At least partially dried biomass, including wood chips and timber wastes, purpose grown crops and residues such as sugar cane bagasse. High possibility of large scale sustainable feedstock supply
Status	Commercially proven and established large scale technology; larger operating plants are 500 Mega Watts thermal (MW_{th}) or more
Capital Intensity	$75-100 per annual green (as received) tonne feed
Carbon Balance	All carbon sequestered in the biomass is released back into the atmosphere. Carbon balance is dependent on changes in biomass standing stock and additional transport emissions. Typically 25per cent of calorific content of input biomass can be converted into electricity and >50 per cent of calorific value can be accessed in heating applications

Combustion is designed to capture the calorific value of biomass only. As biomass resources become more constrained, with increasing demand for renewable energy, they can be expected to be directed more to applications that capture additional value from their inherent material qualities.

Combustion of biomass for process heat or electricity production may also be conducted indirectly via the combustion of pre-processed biomass products such as compressed or torrefied wood pellets, pyrolysis oil and pyrolysis char.

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[58] Unprocessed, newly harvested and partially dried biomass is suitable for direct combustion applications; as with fossil fuels, only refined bioenergy fuels (liquids or gas) are suitable for internal combustion engines.
[59] Co-firing can be an attractive option as it makes use of existing infrastructure and helps to improve the efficiency of energy conversion through better combustion and larger production units. The opportunities for co-firing are limited (generally less than 5per cent of total fuel) without resorting to less efficient moving grate based systems or some degree of biomass pre-processing to biogas, oil or char.
[60] Co-firing with coal allows for greater efficiency of combustion due to larger scale infrastructure but there is usually a maximum limit of 5per cent biomass in the fuel blend.

The principle advantage of the indirect combustion route is the transportability of the intermediate products which have a lower bulk density than green biomass, allowing a greater area for biomass sourcing.

Figure 5 – One of the largest heat and power plants is the Alholmens Kraft facility in Finland, which generates 560 Mega Watts thermal (MW_{th}) and 240 Mega Watts electrical (MW_e)[61] from woody biomass[62]

4.2 Anaerobic Digestion

Anaerobic digestion is conducted by prokaryotic microbes (Eubacteria and Archaea) that evolved their metabolic pathways prior to the development of an oxygen rich atmosphere. Prokaryotes have the necessary enzymes to catalyse a range of organic polymer decomposition reactions at benign temperatures and pressures. These reactions include the generation of Hydrogen and Methane from biomass.

Anaerobic digestion for methane production is mainly used as a waste processing technique for biomass with high nitrogen and low lignin content[63]. If untreated, the biological breakdown of this waste will produce CO_2 and CH_4. Deliberate anaerobic digestion is a way of ensuring that CH_4 emissions are controlled and captured while recovering energy from the biomass. This can reduce greenhouse gas emissions from water treatment plants and landfill. Anaerobic digestion residues can be returned to the landscape to help close nutrient cycles and be a net benefit where land is used for food production.

Digesters are typically run at 35 degrees Celsius to 60 degrees Celsius with higher temperatures giving a faster reaction rate but with increased heating costs. They may be operated under continuous, plug or batch conditions with higher production coming from continuous or plug flow.

Digesters may often accept waste from a number of sources and this variety of inputs may aid in digester function through better nutrition of the microbes. Rapid and large scale changes in the composition of the feed may reduce digester performance. There are a number of highly automated commercial designs available.

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61 MW_{th} is thermal heating power generated while MW_e is electrical power generated.
62 Picture sourced from http://www.tekes.fi/opet/pdf/Alholma_2002.pdf.
63 Anaerobic digestion is not well suited to woody biomass.

Table 8 – Anaerobic Digestion technology summary	
Technology Attributes	Description
Process	Biomass feed is placed in a sealed digesting tank where bacteria break it down releasing biogas
Products	Methane rich biogas, plus biosolids, which can be recycled to productive land to close nutrient cycles
Feedstock	Generally human and animal wastes; high nutrient and water content biomass with low lignin content. Limited but sustainable feedstock supply
Status	Established proven commercial technology; one of the largest anaerobic digestion facility has eight 3.7 Ml digesters treating the manure of 10,000 cows, producing methane (1.8TJ/d[64])
Capital Intensity	$200-300 per dry annual tonne feed[65]
Carbon Balance	All carbon sequestered in the biomass is released back into the atmosphere. Deliberate anaerobic digestion of wastes may avoid fugitive emissions of environmental waste degradation. Efficiency of conversion of volatile carbon into methane is approximately 70 per cent, with non-volatile carbon typically decaying to CO_2 in the biosolid residue. Ammonia and N_2O emissions from decaying biosolids can be significant depending on feedstock

An example of commercial anaerobic digestion at the Carrum sewage treatment plant of Melbourne Water is shown in Figure 3 below. This facility generates 3.4 Mega Watts (MW) of electricity[66] and the digesters are partly underground to improve thermal regulation.

Figure 6 – Anaerobic digestion at the Carrum sewage treatment plant of Melbourne Water[67]

4.3 Fermentation

Biomass fermentation of glucose or fructose sugar rich feedstocks produces ethanol. This is the most commercially established of the liquid biofuel technologies. Ethanol is usually blended with standard petrol or diesel. Blending requires anhydrous ethanol in order to mix effectively with hydrocarbons without water

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[64] *'Microgy Case Study: Huckabay Ridge', Environmental Power, accessed at http://www.environmentalpower.com/companies/microgy/cs-huckabay.php4, February, 2008.*
[65] *Actual feed water content is highly variable from 80 to 99 per cent so data is presented as dry tonnes.*
[66] *'The Green Light', The Source, 2002, accessed at http://library.melbournewater.com.au/content/publications/the_source/the_source_issue_21.pdf, February, 2008.*
[67] *Picture sourced from http://www.melbournewater.com.au/content/publications/fact_sheets/sewerage/eastern_treatment_plant.asp.*

deposits. Dehydration of ethanol and growing high productivity crops can be very energy intensive processes, which significantly reduce the net energy returns for bio-ethanol[68], although the recent development of molecular sieves has improved the situation.

Technologies are under active development for conversion of cellulosic materials[69] to sugars so that they can be used as a feedstock source. This process will be far less feedstock constrained because of the abundance of lingocellulosic biomass. The production of Butanol rather than Ethanol via fermentation is also under development.

There is considerable public debate about the use of first generation biofuels such as bioethanol and calls have been made for a moratorium on expansion of production capacity. Debate has focussed on the diversion of staple food crops to biofuel use in the first world and the corresponding increase in food prices for the worlds poor[70]. Exaggerated Greenhouse reduction claims (since energy intensity is high)[71] have also been a point of debate and improvements over the use of fossil based fuels for some cases may be negligible. The high profile US corn based bio-ethanol industry is driven more by energy security than climate change. Brazil is a global leader in bioethanol use based on sugar cane feed.

Table 9 – Fermentation technology summary

Technology Attributes	Description
Process	Yeast or bacteria use sugars for metabolic energy during their growth, producing alcohols in the process
Products	Mainly ethanol, but significant potential for butanol, acetone,[72] isopropanol and hydrogen; distillers grain is the standard by-product
Feedstock	Sugars or starch rich biomass can be used directly. Low probability of large scale sustainable feedstock supply for direct sugar/starch feed, high possibility of sustainable feedstock supply from next generation cellulosic sources
Status	Ethanol from sugar/starch biomass is now established commercial technology; larger production facilities are around 500 Mega litres (Ml) per year and more; Australia's largest facility at Nowra is 100 Ml per year Fermentation of cellulose is at pilot demonstration stage
Capital Intensity	$300-400 per annual tonne grain feed
Carbon Balance	Carbon balance of ethanol production is contentious with debate around the inclusion or exclusion of burdens from co-products such as distillers grains. Significant emissions via land clearing, machinery and fertiliser use are generated during the growth of feedstock, purification of ethanol to anhydrous state is energy intensive and distillers grains used as a livestock feed supplement incurs a burden from livestock emissions

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[68] Energy returns for sugar cane are reasonable and much higher than for corn, which can often generate no more energy than used in its production.
[69] Sugars can also be derived from the depolymerisation of cellulose using enzymatic, thermal or acid hydrolysis allowing use of wood and agricultural residues.
[70] 'UN adviser calls for halt on biofuels investment' ABC News, accessed at http://www.abc.net.au/news/stories/2008/05/03/2234549.htm, May, 2008
[71] Greenhouse gas reduction claims are complicated by agricultural soil emissions during growth and the use of co-products such as distillers grains as animal feeds. Searchinger, T.D., 2008, 'Response to New Fuels Alliance and DOE Analysts Criticisms of Science Studies of Greenhouse Gasses and Biofuels', Environmental and Energy Study Institute, accessed at http://www.eesi.org/programs/agriculture/tsearchinger_iluc_response_022908.pdf, February, 2008.
[72] Acetone-butanol from sugar/starch biomass was an established commercial technology before being replaced by petrochemicals. Butanol has benefits over ethanol as a fuel – higher energy content, not water soluble, blends with standard petrol at any concentration for use in petrol engines.

Figure 7 – The world's largest fuel ethanol plant, Jilin, China, processes close to 2 M tonnes of corn per year to produce some 2.3 Ml per day ethanol[73]

4.4 Oil Extraction

Animal and plant oils are especially suited as a liquid fuel feedstock as unlike carbohydrates they are largely deoxygenated and similar in structure to the long chain hydrocarbons of Diesel and Jet fuel. Chemical conversion to fuel substitutes is therefore relatively simple with high energy and process efficiency once oils are separated from the bulk biomass.

Oil can be extracted directly from biomass by mechanical separation or solvent extraction. Mechanical separation can extract up to 90 per cent of available oils (typically 70-80 per cent). This is the preferred technology for the extraction of high value food oils[74] and for processing high oil content feedstocks.

Solvent extraction is mainly used with lower oil yielding biomasses or following mechanical separation. The oil is recovered by evaporating the solvent, which is then recondensed and reused. Solvent losses are usually small[75] and form a negligible cost when compared to the cost of the biomass feedstock.

Vegetable oils and animal fats are also available in concentrated form as recycled cooking oils and tallow. While plant oils can directly be used in diesel engines, there are storage and temperature related viscosity issues. Transesterification[76] or hydrogenation, the process of converting oils to biodiesel, alters the viscosity so that transport fuel standards can be met. The physical and chemical properties of the resultant biodiesel is dependent on both the qualities of the oil feedstock and the processing technology.

[73] *Picture sourced from http://www.worldbiofuelssymposium.com/WBS05/WBS-Jilin-Plant-Tour-Information.pdf.*
[74] *FAO Agricultural Services Bulletins, 2002, 'Traditional Techniques and Innovations in Small-Scale Palm Oil Processing', FAO, accessed at http://www.fao.org/DOCREP/005/Y4355E/y4355e05.htm, February, 2008.*
[75] *N-hexane is a fossil resource and has occupational health and safety concerns such as health and fire/explosion risk, and contributes to environmental pollution such as photochemical smog; 'Substance Fact Sheet n-Hexane', Australian Government Department of Environment, Water, Heritage and the Arts, accessed at http://www.npi.gov.au/database/substance-info/profiles/47.html, February, 2008.*
[76] *Transesterification typically react the triglyceride (oil) with methanol to separate the fatty acid chains from the glycerol backbone. Either an alkali base or supercritical fluid is used to ensure that the oil and methanol contact properly for the process.*

Table 10 – Oil Extraction summary	
Technology Attributes	Description
Process	Oils or fats within biomass are removed mechanically or with solvents; transesterification produces biodiesel
Products	Biodiesel; glycerol as a by-product
Feedstock	Oil rich plants (especially seed crops), waste cooking oil, fats/ tallow. Limited but sustainable feedstock supply from wastes; low probability of large scale sustainable feedstock supply from oil seed crops
Status	Established commercial technology; larger facilities operate up to 500 Ml per year and more. The costs of oil extraction from high oil (30-50 per cent) feed stocks are around 8-18 cents per litre of oil produced
Capital Intensity	$50-100 per annual tonne oilseed processed
Carbon Balance	Oil extraction and conversion to biodiesel is energy efficient as the product is easy to phase separate from water. Emissions are generated during feedstock growth via land clearing, machinery and fertiliser use

The biodiesel industry in Australia is severely feedstock constrained, with the drought, food and export competition greatly increasing costs of feed over recent years. Many facilities are operating well below capacity and several have recently had to close. Australian biodiesel production is dominated by tallow and waste oil processing; capacity is around 525 Ml per year (total annual Australian use is 14 Giga litres (Gl) fossil diesel per year), although much of this has been mothballed due to uneconomic feedstock prices.

Figure 8 –Natural Fuels Biodiesel plant in Darwin[77]

4.5 Pyrolysis

Pyrolysis is thermal decomposition of organic material with no or limited oxygen. It can be applied in principal to any forms of biomass. The main products of pyrolysis are gas, oil/tar liquids and char,[78] with flexibility to vary the amounts oil, gas and char. Slow pyrolysis increases char yields and fast (or 'flash') pyrolysis increases the liquid fraction.

[77] *Picture sourced from http://www.naturalfuel.com/index.php?option=com_content&task=blogcategory&id=12&Itemid=17.*

[78] *The pyrolysis gas includes CO_2, CO, H_2, CH_4, C_2H_2, C_2H_4, C_2H_6 etc, liquids include tars, high molecular weight hydrocarbons and water) and char. Lower processing temperatures and longer solids residence times favour the production of char (slow pyrolysis). Moderate temperatures and short vapour residence times promote the formation of oils and tars (fast or flash pyrolysis). High temperatures and longer vapour residence times increase the conversion to gas.*

The energy contents of pyrolysis gas, oil and char are about 6, 18 and 36 GJ/tonne respectively. Pyrolysis oil has about half the energy content of crude oil. There are well established commercial char making facilities focused on high value metallurgical applications, using high quality biomass inputs, such as eucalyptus chips, with capacities around 35,000 tonnes of char per annum. This high cost regime is not generally scalable to the emerging bioenergy industry.

The pyrolysis of biomass for bioenergy is a relatively undeveloped technology although the pyrolysis of coal is well established for the production of town gas. Existing commercial slow pyrolysis units for biomass are based on kiln type technologies and produce only gas and char outputs. Fast pyrolysis technologies take a number of different approaches such as fluidised beds, ablation and mixing with heat distribution sources such as sand, but all require a small input particle size of less than 2mm and quench the oil and char outputs together which causes difficulties with particulates in the oil. Hot filtration is being investigated in an effort to reduce this as an issue.

Pyrolysis technologies using a wider range of lower cost biomass feeds, including woody crops and wastes and residues, are under active development with several operating commercially. Reducing the capital intensity and improving the energy efficiency of pyrolysis is important in spreading the technology.

Table 11 – Pyrolysis technology summary

Technology Attributes	Description
Process	Biomass is heated in the absence of oxygen and depolymerises to oil, gas and char in varying proportions depending on heating rates and residence times
Products	Relatively weak gas, complex pyrolytic oils ('bio-crude oil') and char ; Pyrolysis oils and char can be used directly for stationary power applications but do not currently meet commercial fuel standards; secondary upgrading and refining for higher quality applications will progress rapidly; Char has energy content, but also markets will emerge for char as a soil conditioner (see following page)
Feedstock	Any reasonably dry biomass. Some examples of this technology class require small particle size. High possibility of large scale sustainable feedstock supply
Status	Several commercial pyrolysis plants, processing up to 66,000 tonnes per annum biomass
Capital Intensity	$50-150 per annual green (as received) tonne feed (a range of emerging process designs)
Carbon Balance	Carbon balance depends on what is done with the products of pyrolysis. If all products used for energy then balance is similar to that of direct combustion. If biochar is sequestered in soils rather than combusted then the technology may be carbon negative

The largest flash pyrolysis plant (Dynamotive, West Lorne, Canada – see Figure 9 below) processes 200 tonnes per day (t/day) wood waste in a bubbling fluid bed to generate primarily fuel oil, while the largest commercial slow pyrolysis plant (MTK, Japan) processes 100 t/day woodchips in a rotary kiln. Although oil is an intrinsic product of pyrolysis (approximately one third of output), current commercial operations remove the 'oil' fraction in a gaseous phase.

Figure 9 – Dynamotive flash pyrolysis plant in West Lorne Canada[79]

4.5.1 A Note on Pyrolysis Char

Pyrolysis is the only biomass processing option that produces char. Biochar formation, which is optimised by slow pyrolysis conditions, represents one of the very few value adding opportunities for removal of CO_2 from the atmosphere. 'Agrichar' is very stable in soils and therefore has the potential to be a major carbon sink[80]. Char rich soils, such as the Amazonian 'terra preta' have retained their carbon for thousands of years. A 'carbon pump' in the reverse direction to Greenhouse gas emissions is therefore created by the sequence: photosynthesis - biomass - pyrolysis – soil char.

The high surface area of chars contributes to their beneficial effects on soil quality by providing a substrate for microbial growth, improving soil structure, reducing soil tensile strength and enhancing water and nutrient retention. Terra preta soils are highly productive and require less water and fertiliser.[81]

Figure 10 – Soil regeneration through 'terra preta'[82]

Biochar is a strategic opportunity in a carbon constrained world where significant soil degradation has occurred through clearances and intensive agricultural practices, which themselves have contributed to greenhouse emissions and climate change. In pyrolysis, the nutrients in biomass report to the char, so that 'agrichar' provides a pathway for nutrient recycling back into soils.

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[79] *Picture sourced from http://www.dynamotive.com/en/technology/westlorne.html.*
[80] *Soil carbon sequestration is not yet recognised in the Kyoto protocols, but there are increasing arguments in favour of recognising agrichar in soils as a sink.*
[81] *NSW DPI is conducting research demonstrates the benefits of soil char in Australian conditions.*
[82] *Picture adapted from http://www.geo.uni-bayreuth.de/bodenkunde/terra_preta/*

Given the sustainability advantages of char in soils there is little doubt that there will be increasing activities in this area[83]. These benefits will act as an additional driver for higher volume and/or low capital cost pyrolysis technologies.

Biochar is not yet a developed market and in the shorter term the selling price of pyrolysis char may be underpinned by its energy value.

4.6 Gasification

Gasification is a process in which oxygen-deficient thermal decomposition of organic matter (coal, oil or biomass) produces non-condensable fuel or synthesis gases. Gasification combines pyrolysis with partial combustion to provide heat for the endothermic decomposition reactions[84]. Unless the gas is combusted directly for power, it is cooled, filtered and scrubbed to remove condensables and carry-over particles. The syn-gas produced can be used in a variety of energy conversion devices (internal combustion engines, gas turbines, fuel cells etc.) or converted to high value fuels and chemicals.[85]

Biomass gasifiers based on packed/moving bed configurations are limited to small scale operations, typically less than 1 $MW_{e.}$ Fluidised bed gasifiers offer much higher throughput capacity and have demonstrated commercial viability on a range of biomass sources. The largest biomass gasifier is 70 MW_{th} fed by around 200,000 tonnes per annum of forestry products.

Table 12 – Gasification technology summary

Technology Attributes	Description
Process	Finely ground biomass undergoes controlled partial combustion which heats it sufficiently for complete thermal depolymerisation to CO, H_2 and CH_4. The gas can be combusted directly or converted to syngas (CO, H_2) for high temperature synthesis reactions
Products	Electricity, heat; potential for conversion to syngas, hydrogen, ammonia, synthetic fuels/petrochemical precursors; ash can be returned to productive lands to close nutrient cycles
Feedstock	Any reasonably dry biomass that can be ground to a small size; Gasification of pyrolysis products often allows for greater feed flexibility and thermal efficiency than direct biomass gasification. High possibility of large scale sustainable feedstock supply
Status	The production of electricity and heat via gasification of biomass is proven commercial technology
Capital Intensity	$200 per green (as received) annual tonne
Carbon Balance	If all products are combusted then carbon balance is similar to that of direct combustion. Syngas may be converted to synthetic fuels with a process efficiency of approximately 50 per cent, or slightly more if waste heat is used for combined power generation

[83] As highlighted by the recent 'International Agrichar Initiative Conference', Terrigal, NSW, April 2007; accessed at www.iaiconference.org, February, 2008.
[84] A well-designed gasifier will decompose high-molecular-weight organic compounds into low-molecular-weight, non-condensable compounds (tar cracking). Charred organic matter participates in a series of endothermic reactions at temperatures above 800°C producing gaseous fuel constituents, i.e. CO, H_2, and CH_4.
[85] These products include Hydrogen, Fischer-Tropsch Liquids and Ammonia.

Figure 11 – Battelle gasifer in Vermont, USA[86]

The Battelle gasifer in Vermont, USA, as shown in Figure 8 above, processes 320 tonnes of woodchip per day and generates $40MW_{th}$. One the world's largest gasifiers, the Kymijärvi Power Plant at Lahti, Finland,[87] generates 70 MW_{th}. The biomass used contains 20 to 60 per cent water and includes bark, wood chips, sawdust, wood waste, household and industrial waste, including old tyres and railway sleepers.

4.7 Integration

A synthesis of the key factors for biomass processing technologies is presented in the table below. Thermal technologies are the least sensitive to the qualities of the feedstock and are able to effectively process lignocellulosic materials. These technologies are inherently the most scalable and do not require purpose grown biomass.

Established technologies other than Direct Combustion are significantly limited in scale through dependence on specific and limited feedstocks. Technologies that provide high volume and value opportunities are currently the most immature and are the most likely candidates for future innovation. The analysis highlights the strategic attractiveness of thermal processing to solid, liquid and gas energy products, while recognising that immediate term projects are likely to be limited in scale.

Table 13 – Sustainability Considerations of Biomass Processing Technologies

Biomass Processing Technology	Possible Scale[88]	Feedstock Flexibility	Conversion Efficiency[89]	Output Flexibility	Market Value of Product	Development Status
Direct Combustion	Large	High	Low	Low	Low	Established
Anaerobic Digestion	Small	Low	Medium	Low	Medium	Established
Fermentation	Medium[90]	Low[91]	Medium	Low	High	Established
Oil Extraction	Small	Low	High	Low	High	Established
Pyrolysis	Large	High	Medium	High	Medium	Early Commercial
Gasification	Large	Medium	Medium	Medium[92]	Medium	Early Commercial

[86] *Picture sourced from http://www.climatetechnology.gov/library/2005/tech-options/tor2005-236.pdf.*
[87] *'Kymijärvi Biomass CFB Gasifier, Finland', Power Technology, accessed at http://www.power-technology.com/projects/kymijarvi/, February, 2008.*
[88] *Scale is of possible industry is dependant on the scale of the available biomass resource. Those technologies able to use lignocellulosic biomass are at an advantage.*
[89] *Energy efficiency is a measure of the amount of energy in the feedstock is retained in the products.*
[90] *De-polymerisation of cellulose to sugars will allow access to a larger biomass pool, however, this technology is not commercially established.*
[91] *This may be higher if technologies that generate sugar feedstocks from cellulose become mature.*
[92] *The direct products of gasification are low, but this is the basis to a vast array of fuel and chemical products via synthesis reactions.*

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5 EVALUATING BIOENERGY PROJECTS

The success of bioenergy projects depends on (a) ecologically sustainable and viable biomass supply, (b) the establishment of a commercially and technically viable processing business and (c) having a societal licence to operate (see Tables 14 - 16). We have developed an evaluation tool (sustainability scorecard) to help address these critical success factors and the main issues that impact on the outcomes.

5.1 Sustainability Scorecard

The tool is based on a 5 point grading scale for each of the above areas, with further breakdown to the next level of detail.

Table 14 – Ecologically sustainable biomass supply	
5	Maximum value capture from resources, with regenerative impacts on land, water and biodiversity
4	Sustainable production; no systemic degradation of ecosystems
3	Project based on adoption of best practices; minimum environmental harm
2	General industry standards applied to biomass growth and supply
1	Standards driven by compliance with legislation only

Table 15 – A commercially and technologically viable processing business	
5	Very attractive proposition, creating a platform for business growth and proliferation
4	An attractive business opportunity with respect to its inputs, technology, cost structure and markets
3	The project is basically viable, without significant subsidies and with manageable risks
2	Unresolved significant risks around technology, feedstock supply and prices, products
1	Unviable project in terms of capital intensity, unproven technology, commercial risks

Table 16 – The licence to operate	
5	Government, community and public stakeholders have become advocates of the project
4	Positive support for the project from stakeholders
3	Acceptance of the project
2	Significant discontent with the project
1	Open hostility

Each of these factors is further broken down to critical sub-themes. Sustainable biomass supply is influenced by land, water and biodiversity. Business viability is influenced by capital intensity, development status of the technology, feedstock flexibility of the technology, feedstock flexibility, feedstock security, product flexibility and markets for the products. The licence to operate has government, community and general public dimensions. Definitions and grading scale descriptors are provided in Table 17 following.

Table 17 – Grading Scale Descriptors for Bioenergy Project Sustainability Considerations

	Grading Scale 1=Worst to 5=Best				
Consideration	1	2	3	4	5
Ecologically Sustainable Biomass Supply					
Land	Compliance with land use change statutes	Industry standard carbon and soil management	Best practice carbon and soil management	Limited carbon sink, sustainable soil fertility and nutrient dynamics	Sustained carbon sink, increased soil fertility and microbial activity, sustainable nutrient dynamics
Water	Compliance with water use statutes and markets	Industry standard water budget	Best practice water use budget	Sustainable water use budget (no significant change in soil, runoff or aquifer)	Restorative water budget (returns soil, runoff and aquifer to historical levels)
Biodiversity	Complies with endangered species/habitats, introduced species and routine agricultural practice legislation	Industry standard agricultural species management	Best practice grazing, cropping and silviculture species management for biodiversity	Multispecies native assemblage with active exclusion of introduced species	Continuous multispecies native assemblage under historical disturbance regime linking existing native habitats with active exclusion of introduced species
Commercially and Technically Viable Business					
Capital Intensity	High Capital Requirements, greater than $150 per annual green (as received) tonne processed	Capital Requirements, $100 - $150 per annual green (as received) tonne processed	Medium Capital Requirements, $75 - $100 per annual green (as received) tonne processed	Capital Requirements, $50 - $75 per annual green (as received) tonne processed	Low Capital Requirements, less than $50 per annual green (as received) tonne processed
Development Status	Technological/commercial risk and small scale opportunity R&D to proof of concept	Technological/commercial risk and large scale opportunity Pilot	Commercially proven small scale opportunity Demonstration (at least 1 commercially operating plant)	Early Commercialisation (limited numbers of commercial operations)	Commercially proven (at scale, types of feed and products of your project)
Feedstock Flexibility	Dependent on single species with limited climatic distribution	Many species but constrained soluble sugar or oil fraction	Broad species/residues but only utilise cellulose fraction	Lignocellulosic biomass but difficulties with non-lignocellulosic impurities and energetically sensitive to moisture content	Lignocellulosic biomass as well as high impurity and moisture content (green) biomass

Table 17 (contd…) - Grading Scale Descriptors for Bioenergy Project Sustainability Considerations

	Grading Scale 1=Worst to 5=Best				
Consideration	1	2	3	4	5
Feedstock Security	Uneconomic unsecured feedstock supply (too expensive or too far away)	Limited scale unsecured feedstock supply	Scalable cost competitive unsecured feedstock supply or limited scale secured feedstock supply	Long term secured cost competitive feedstock supply	Low production cost feedstock supply is consistent and exceeds bulk energy market allowing growth while containing price
Product Flexibility	One type of product only	Two types of product output according to process	Two types of product output and ability to optimise for most viable solution	Multiple products according to process (limited variation of output quantity)	Multiple products with ability to optimise for most viable solution
Markets	Dependence on limited scale high value markets or no developed market	Some dependence on limited scale high value markets or limited market development	Limited products into established large scale markets	Multiple products to high volume markets	Multiple products suitable for high volume markets able to attract a sustainability premium with additional ability to supply small volume high value markets
Licence to Operate					
Government	Project not supported by government policy	Government indifference to project	In line with stated government policy	Specific government support and in line with government policy	Project informs and leads government policy
Community	Development application passed	Reactive community engagement	Best practice community engagement	Local employment and community amenity concerns addressed	Project improves community employment, education and amenity
Public	Conforms to mandatory reporting requirements	Industry standard public engagement and transparency	Best practice public engagement and transparency	Strong public support and recognised sustainability attributes	Comprehensive public support, proactive engagement with concerned citizen groups for independent validation, leads public education and discussion, supported marketing premium

5.2 Illustrating the Score Card

For illustrative purposes, consider a hypothetical project with a planned pyrolysis plant processing feedstock from a combination of sources: forest/timber residues and agricultural crop wastes and woody crops. The primary market focus is fuel oil. This project would have the following attributes:

- changed land practices have positive impacts on above and below ground carbon stocks
- ground water management improvements from alley farming of woody crops
- no significant alterations to biodiversity
- capital intensity of the technology is high
- limited commercialisation of the technology, but feed successfully tested in an existing operation
- the process is able to accept all planned inputs but has lower efficiency for high moisture feed
- the company has secured long term supply arrangements with the main biomass producers
- the process produces secondary energy and materials products
- markets for pyrolysis oil based fuels may be large but are undeveloped
- strong state government support for renewable energy and regional development
- the community generally welcomes the business and employment opportunities
- the public debate is influenced by opposition to use of forest residues.

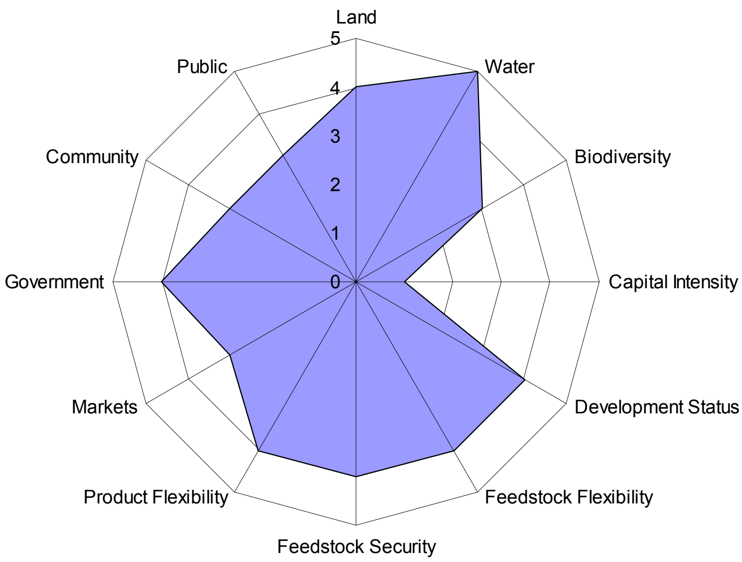

Figure 12 – Schematic representation of evaluation of a pyrolysis based bioenergy project

The evaluation presented here is provided as a trigger to help highlight project weaknesses and opportunities. It is not intended as decision making tool, rather a way to prompt consideration of critical issues. If a project has a poor score it does not follow that the project should not be done. Identification of risks and opportunities using the tool will help with project planning and the project should only not proceed if innovative pathways cannot be developed to overcome issues.

For the illustrative case above, the project would be strengthened by both working to reduce the capital intensity of the technology or establishing a partnership with an oil company willing and capable of developing the market for bio-fuels so the return on the high capital investment is secured and maximised.

5.3 Integration

There is a logical alignment between biomass resources and their constituents, the selection of processing technology and the downstream product application, as shown in the figure below. The objective in specific projects is to maximise the value of the system as a whole.

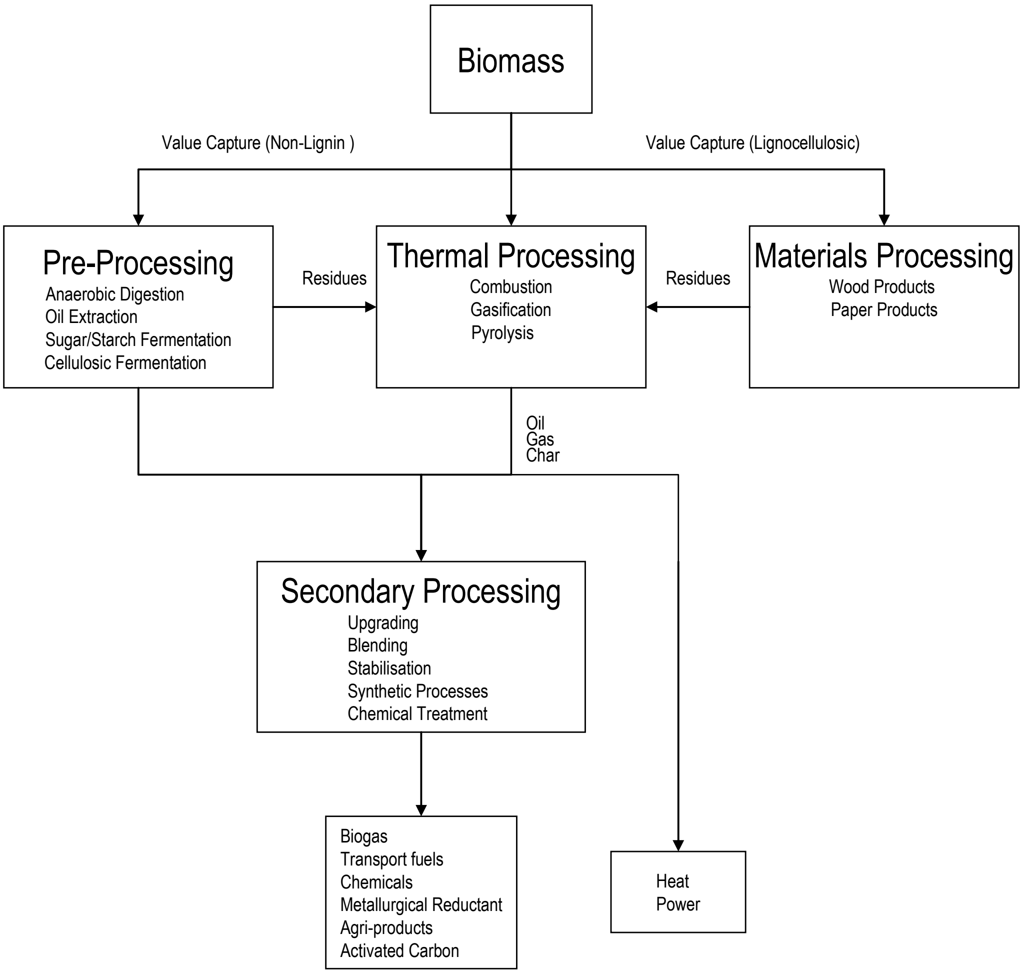

Figure 13 – Strategic platform for maximum value capture from bioenergy resources

An evaluation tool is of course no substitute for detailed analysis of the financials and all other aspects of the business case. Weaknesses identified by the evaluation tool do not necessarily mean a project should be abandoned, but rather that the issues should prompt fresh thinking, innovation and better risk management responses.

Equally robust carbon accounting on a complete life cycle basis is needed to defend the environmental credentials and greenhouse benefits of bioenergy projects.

6 CONCLUSIONS

The analysis conducted in this review highlights that the availability and sustainability of feedstock is a critical consideration in the strategic development of bioenergy projects and is intimately linked with the selection of biomass technologies for energy and materials.

Lignocellulosic biomass resources are by far the most significant in scale and are best placed to work synergistically rather than competitively with existing biomass use such as food, materials, ecological services and natural habitat. The use of longer rotation Multispecies Native Assemblages of woody biomass grown on previously cleared grazing land represents the most significant opportunity for the development of new large scale biomass resources that support biodiversity, environmental carbon stores and ecosystem services with minimal impact on food resources.

The review has clarified that each processing technology class is suited to a specific range of constituent biomass biochemistries. Thermal processing options are the most flexible of all the technology classes and the best able to make complete use of strategic scale lignocellulosic biomass resources.

Processing technologies that produce multiple energy and material products with large scale markets are most likely to meet societal needs and provide sustainable business opportunities. A carbon neutral future will still require significant carbon based resources such as liquid transport fuels, metallurgical reductants and organic chemicals so thermal processing technologies that address these multiple outputs are preferred.

The Pyrolysis technology platform is able to produce solid, liquid and gaseous fuel and material outputs from lignocellulosic biomass and is therefore likely to be a core technology in a future carbon balanced society. Pyrolysis derived Biochar can act as a value adding carbon sequestration pathway providing the opportunity for carbon negative bioenergy options.

A sustainable business case requires that maximum value is captured from the biomass resource. Those biomass co-products that make use of the inherent material qualities of the resource typically capture more of the value. Preprocessing for the extraction of wood, oils, protein and soluble sugars is therefore encouraged if in economic proportions in the feedstock and should be seen as supporting the economic case for bioenergy production as long as markets are of appropriate scale.

The development of specific bioenergy projects fundamentally requires securing a societal licence to operate, incorporating environmental, technological, financial and social concerns. To aid in this end this review presents a sustainability evaluation tool to assist in reviewing areas of concern. Once factors outlined in the tool have been adequately addressed proposed projects would be expected to be scrutinised by case specific technoeconomic modelling as a precursor to a prefeasibility study, Life Cycle Assessment and a full feasibility assessment. Successful completion of each of these stages is important to control development risk and maintain societal and investor confidence in bioenergy opportunities.