With consideration of the species, location and farming systems it is possible to integrate energy crops into farms without significantly competing with existing agricultural crops and potential food production.

This report highlights some of the logistic and economic opportunities and issues in deploying woody species for bioenergy in agricultural areas of Australia through detailing the experience of the mallee industry over the last 20 years.

IEA Bioenergy

IEA Bioenergy Task 43
Report 2012:PR03

Promising resources and systems for producing bioenergy feedstocks

Developing Options for Integrated Food-Energy Systems – Volume 2

Supply chain logistics and economic considerations for short-rotation woody crops in southern Australia

Developing Options for Integrated Food-Energy Systems

Volume 2- Supply chain logistics and economic considerations for short-rotation woody crops in southern Australia

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KEY MESSAGES

It is possible to integrate energy crops into farms without significantly competing with agricultural crops and potential food production. But in water-limited environments this will require careful consideration of species, innovative planning and adaptive management.

From this paper the key messages are that to develop large-scale new bioenergy industry it is critical that supply chains are efficient and economically competitive.

Bioenergy must not only deliver lower carbon energy solutions but minimise the impact on natural resources and competition with food production.

Considered and flexible policy settings are required to address the social and environmental concerns whilst promoting economic opportunities for large-scale production. This will require further investment and long-term research and development programmes with clear goals.

In Australia bioenergy is still expensive compared to existing fossil fuel based energy. Coal is relatively cheap and dominates stationary energy production. However, bioenergy production systems can also address environmental issues that are currently dismissed as 'externalities'. If environmental benefits are to accrue, including the reduction of carbon emissions, then the farmers need to profit financially and the biomass needs to compete with current feedstocks such as coal. The policy framework in Australia is changing to incorporate 'externalities' such as carbon via an emissions trading scheme.

Energy crops must have an economic basis to allow for large-scale development with crops for multiple outputs such as energy production, environmental amelioration and potentially rural development. To be competitive however, the management of the integrated supply chain is fundamental.

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Cover Images: Top B.H. George & bottom R. Giles

EXECUTIVE SUMMARY

In this paper we discuss some supply chain issues confronting the efficient development of an Integrated Food-Energy System (IFES) based on incorporating short-rotation coppice woody crops with traditional farming systems in Australia. For example, some fundamental engineering issues, such as the development of a suitable harvester, need to be addressed.

The challenge remains to produce significant quantities of biomass to enable bioenergy industry development that is robust and competitive with the existing fossil fuel based generation of power whilst delivering optimal environmental outcomes. Future developments in Australia will focus on economically competitive production systems and it is likely that multiple products and streams of income will be required to give competitive returns along the value chain and enable incorporation of woody short-rotation crops (SRC) into existing farming systems. Recent research also indicates it is unlikely that biomass will be competitive as a feedstock for cofiring in electricity generation. Replacing fossil transport fuels is more likely.

For large-scale development to occur it is imperative that the required significant investment is based on a better understanding of the contributing risks. Specifically, the selection of species and growing; harvest and supply; markets and policy frameworks will all have impacts on the development of bioenergy options and contribute to uncertainty facing industry from the farmers to the processors. Whilst significant development and understanding of the products, species and economics has occurred in the last 20 years the uptake of bioenergy is still hampered by continued uncertainty of the changing policy settings in relation to energy transformation and climate change.

The woody crop IFES aims to develop into a large market-based industry through integrated plantings in traditional farming systems.

There remain important issues that need to be resolved including:

1. Species and site selection and planting designs that account for efficient production, reduction in competition when planted with other crops and other environmental considerations such as hydrology and salinity.

2. Development of economically robust supply chains that efficiently deliver biomass material for conversion into (potentially) multiple products including stationary and transport energy.

3. Development of stable policy with objectives including promotion of alternative energy systems that can compete with low-cost fossil fuels. This is required for large-scale industry investment and development.

Significant development is still required to allow for competitive supply of biomass to for example, electricity generators, at an economically competitive cost. If environmental benefits are to accrue, including salinity mitigation and the reduction of carbon emissions, then the farmers need to profit economically and the biomass needs to compete with current fossil fuels. The management of the integrated supply chain is fundamental to achieving economic competitiveness.

INTRODUCTION

We are approaching a critical point in the evolution of our energy systems as the access to 'cheap' energy declines and competition for food and water resources increases over the next 40 years. With this challenge an opportunity arises to investigate and exploit biomass systems that can be used as feedstocks for energy conversion and use, whilst minimising the impact of the production on other resources such as water. Ideally the bioenergy systems can minimise the impact on food production (Valentine *et al.*, 2012).

Demand for energy is increasing globally and within Australia (International Energy Agency, 2009). Domestically bioenergy supplies ≈5% of energy consumption within Australia (Australian Bureau of Agricultural and Resource Economics, 2010). And there is significant scope for bioenergy to replace fossil fuels for electricity generation and transport fuels. Short-rotation crops, including mallees and other woody species, could potentially replace as much as 9% of the current Australian electricity generation (≈ 20 TW h/yr) or 15% of national gasoline consumption (2.9 GL/yr) (Farine *et al.*, 2011).

There is significant scope to increase the use of bioenergy, however this is tempered by the need to develop clear policy goals and instruments that account for environmental externalities in an economic setting (Stern, 2007). The need to better understand and address the interrelationship between carbon, water and energy to promote integrated outcomes for the natural and built environments within Australia was identified by the Chief Scientist in the report "*Challenges at energy-water-carbon intersections*" (PMSEIC, 2010). Balancing competing demands and opportunities for food and energy through efficient and sustainable management of our natural resources is a major issue facing Australia. And these issues are regularly raised by industry, generally without conclusion (George and Sims, 2011; George, 2012).

Producers of bioenergy feedstocks need to consider their potential impact on food prices both directly through utilisation of feedstocks that could be used for human consumption and indirectly through increased competition for natural resources. Farmers face a dilemma in seeking new industries to address continued decline in their terms of trade (Bartle *et al.*, 2007) and the social implications of increased cost for food (Valentine *et al.*, 2012). Woody species will not compete directly with food production, especially when plantings are established in areas that are not suitable for cropping, or planned, managed and integrated into existing cropping lands with minimal competition for resources.

Volume 1 of this report (George and Nicholas, 2012), outlined the rationale for bioenergy from woody SRC and related industry development in Western Australia. And how, through the *Search* and *FloraSearch* projects in particular, species have been selected and field trials established to understand the silvicultural regimes required for successful establishment. Obviously increasing biomass productivity is critical to gain maximum returns. But larger volumes of biomass availability do not guarantee industry development. Without sound economic reasoning underpinned by robust markets and efficient supply chain logistics there is little scope for large-scale bioenergy systems in Australia.

Volume 2 of this report, by summarising related literature, aims to outline the significant challenges of the logistics in woody biomass production systems and some of the economic understanding of what limitations and opportunities exist in growing biomass in the low to medium rainfall areas of southern Australia.

UNDERSTANDING AND DEVELOPING AN EFFICIENT SUPPLY CHAIN

The supply chain and energy efficiency

Critical in the development of any large-scale industry is a comprehensive understanding of the components and processes that contribute to the supply chain ((George and Nicholas, 2012), Figure 6). An example of the operation and service supply flow chart is shown in Figure 1 highlighting the challenge of coordinating a potentially widespread supply of biomass to a centralized processing facility as is planned in the Integrated Wood Processing (IWP) model. A significant proportion of the financial cost is related to energy consumed during production, especially from harvest and haulage activities (see Figure 5 and later discussion). The importance of the supply chain costs on the economic competitiveness of bioenergy systems cannot be overstated. Wu *et al.* (2008), in proposed mallee systems, estimate fuel consumption at ≈60% of energy inputs with harvest and haulage contributing nearly 80% of inputs as shown in Table 1.

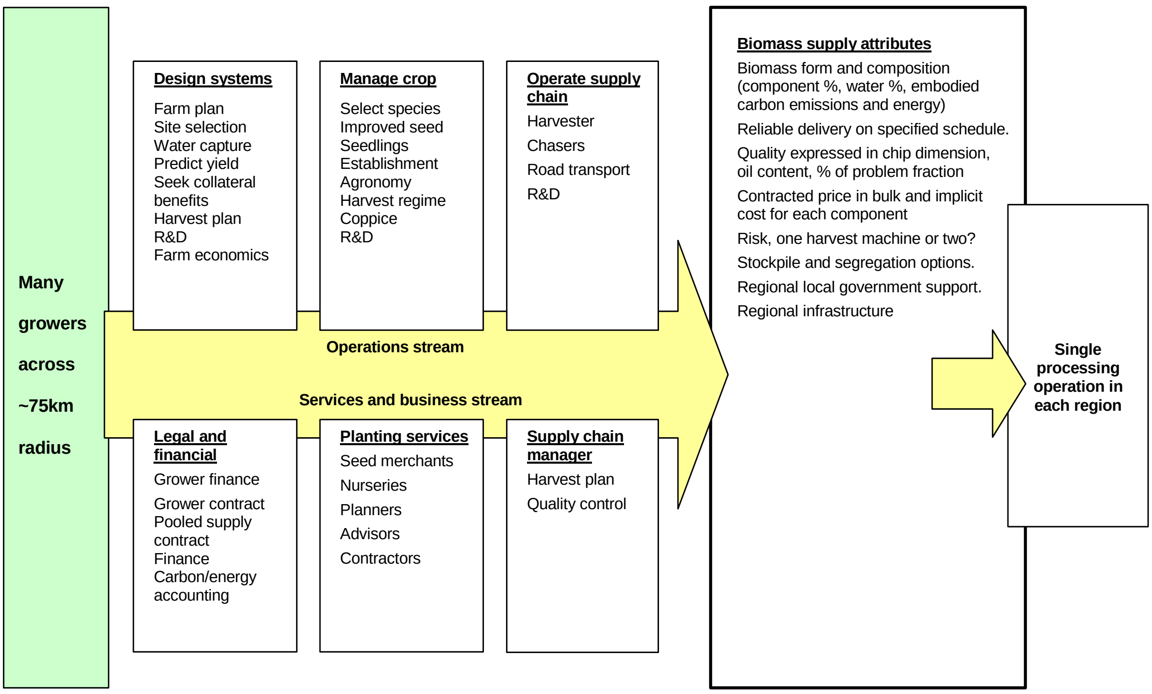


Figure 1. The biomass supply flow for a mallee system in Southern Australia. The integration of operations and services across a potentially geographically dispersed feedstock supply remains a challenge to production systems in lower rainfall (and productivity) areas (Hobbs, 2009).

As the value of carbon is incorporated into the business operating environment through legislation the ability to supply low-carbon energy options will be better recognized. In mallee Short-rotation Crops (SRC) Wu *et al.* (2008) calculated a significant energy return (R) of 41.7 (Table 1) indicating an efficient production system that also has the capability to significantly reduce the reliance on fossil fuels (and improved GHG balances). As energy prices increase, and assuming the modelled parameters remain static, the mallee energy systems will become more competitive with existing farming options (assuming a continued decrease in the terms of trade).

Modelling the supply chain options for mallee IFES

To improve planning and potential investment in nascent biomass production systems modelling is widely utilized to understand and test hypothetical logistics and supply chains. This is essential in the development and promotion of new industries and the successful integration of the woody crops for an IFES. Most of the models employed attempt to estimate the likely production and density of the biomass and then harvest, transport and processing costs in the supply of the biomass to potential processing facilities. Increasing the complexity of the models is that the biomass material may be utilised to generate various output (see Figure 6).

Table 1. The energy balance and breakdown of inputs of a modelled mallee system for the specific operations and categories of energy calculated by Wu *et al.*, (2008).

Energy input (operations)	**Total (MJ/ha for a production period)**	**Contribution (%)**
Seed	2 265	0.9
Seedling	4 827	2.0
Crop establishment	4 543	1.8
Sapling and coppice management	42 765	17.3
Biomass harvest	106 400	43.0
Biomass transport	86 630	35.0
total energy input	**247 429**	**100.0**
Energy input (categories)	**Total (MJ/ha for a production period)**	**Contribution (%)**
Seed	2 265	0.9
Seedlings	4 827	2.0
Machinery production, maintenance and disposal	15 112	6.1
Fuel and oil use	14 2716	57.7
Other operation costs	4 944	2.0
Labor	35 839	14.5
Agrochemicals	1 481	0.5
Fertilizers	40 245	16.3
Total energy input	**247 429**	**100.0**
Energy output	**Total (MJ/ha for a production period)**	**Contribution (%)**
Wood	3 971 463	38.5
Bark	26 814 99	26.0
Leaf	3 655 131	35.5
Total energy output	**10 308 093**	**100.0**
Energy ratio (R)		41.7
Energy productivity (GJ ha^{-1} yr^{-1})		206.3

Bartle *et al.,* (2007); Hobbs *et al.*,(2009) and Yu *et al.*, (2009) indicate the energetic and economic sensitivity of biomass energy systems to the:

1. Biomass harvest and collection costs;

2. Transport distance of the biomass (both on-farm and ex-farm gate to processor);

3. Impact of the competition with other crops;

4. Establishment of the bioenergy components in the IFES and management of the woody and existing crops.

If these components are not effectively designed and efficiently managed then biomass feedstock supply will not be competitive with existing fossil fuel source used in production. Competing coal supply systems, for example, are currently more efficient and relatively cheap compared to biomass supply systems.

Yu et al., (2009) conclude that potential strategies to reduce the delivered cost of biomass include:

1. locating the processing (plant) in more productive areas with higher planting density; and,

2. improving haulage efficiency (including the upgrading of on-farm roading and seasonal harvesting schedules to minimise climatic interruption.

Plant location is dependent on large-scale industry options whereas improving haulage efficiency is within the domain for the land manager.

We need to consider the biophysical competition between the mallee systems and other crops (Wildy *et al.*, 2000; Wildy *et al.*, 2004; Robinson *et al.*, 2006). More recent studies by Peck *et al.* (2012) indicate the potential for competition can be very significant and site specific management will be required to balance between resources used for the SRC and cereal/existing crops. This is discussed in more detail in Volume 1 (George and Nicholas, 2012).

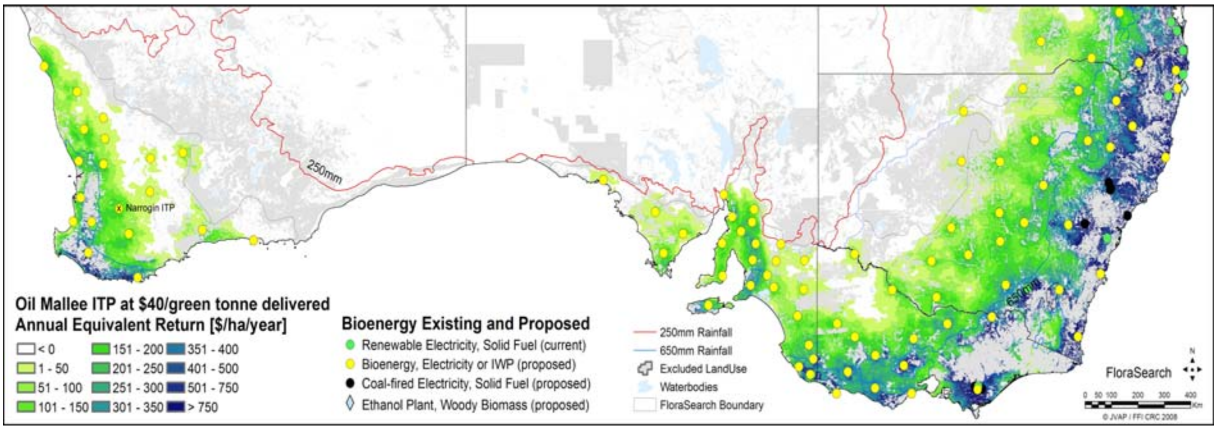


Figure 2. Modelled FloraSearch output showing the opportunity (Annual Equivalent Return) for biomass in Southern Australia. In this example existing and proposed IWP plants are located strategically to optimise biomass production and electricity generation into the existing grid whilst minimising distance for haulage to the plants. Note the Narrogin IWP is identified in Western Australia (image: T. Hobbs, updated from Hobbs *et al.* 2009).

During the *FloraSearch* programme Bennell *et al.* (2009) and Hobbs (2009) developed the Regional Industry Potential Analysis (RIPA) using the measured and predicted growth rates of woody species, including mallees, with a series of economic assumptions regarding harvesting, transporting and processing (Appendix 1). Potential outcomes for different bioenergy systems were modelled and an example shown in Figure 2. In this case the opportunity to grow and supply biomass material at $40/t green weight for conversion to electricity within the current grid network is shown[1]. The scale refers to Annual Equivalent Return (AER) calculated with the input parameters in Appendix 1 and an Internal Rate of Return (IRR) of 7%. Whilst indicating that bioenergy systems could be competitive two issues remain: (i) the sensitivity of the output information to potentially small changes in basic inputs, especially growth rates and harvest costs; and (ii) the market transparency, competition and risk for production systems.

One of the most significant and variable cost components for the land managers is the harvest and haulage of woody crops.

Harvest and haulage

The harvest and handling component of coppicing woody biomass systems has been clearly recognized as a critical issue for efficient production in any woody short-rotation crop system (Volk *et al.*, 2006). In SRC systems in Australia the ability to harvest large amount of biomass quickly is considered *the* most limiting factor in new biomass energy systems. Only recently has this issue been addressed through a collaborative project, coordinated through the Future Farm Industries Cooperative Research Centre (FFI CRC), to develop a harvester system specifically adapted to Australian species and conditions. There is little publicly available information regarding the operation of the harvesters or their efficiency. However, current industry feedback indicates that pre-commercial harvest machines will cut a single row at a time with at ≈3 km/hr achieving a throughput capacity exceeding 60 green tonnes/hour.

The supply chain costs are estimated to be ≈$20-$25/green tonne for harvest and on-farm haulage; ≈$10-$15/green tonne for road transport and ≈>$5/green tonne for administration costs. The Mallee belts do not require significant management input however an annual on-farm crop tending cost of ≈$5/ha for occasional miscellaneous jobs is included. Accounting for the loss in agricultural production due to the area under the mallees and competition zone will add ≈$10 - $25 /green tonne. Root pruning *may* prove useful in controlling root competition but current literature indicates limited success (Peck *et al.*, 2012). Economically, ripping to 0.6m costs ≈$15/km (≈$50/ha). The estimation of these costs will have significant influence over the information presented in Figure 4 and Figure 5.

FUTURE SCENARIOS FOR LARGE-SCALE IFES – OPPORTUNITIES FOR WOODY CROPS

Financial and economic considerations

The development of the woody energy crops in an IFES in Australia is predicated on long-term financial and economic viability[2]. Bartle and Abadi (2010) recently modelled the potential economic parameters associated with an IFES based on oil mallee energy plantings in Western Australia in the 450 – 500 mm per annum rainfall zones. Assuming a project lifespan of 50 years and an estimated cost of $800 per ha to establish two row belts of oil mallees (7 m across) with 72 m width in between for cropping (detailed in

[1] All dollar values are in Australian dollars ($AUD) unless otherwise indicated.

[2] We consider 'financial' to relate to the project or enterprise level monetary considerations and 'economic' to encompass off-farm and non-productivity related effects. See Thompson & George (2009) for more details.

Appendix 2) [3], they estimated that oil mallees could return more money to the land owner over time when compared to existing farming practices (Figure 4).

Figure 3. A pre-commercial mallee harvester during trials conducted in Southern Australia. Significant resources from industry and government are committed to the development of a harvester that is capable of efficiently harvesting native Australian species and chipping the biomass in-field (image: R. Giles).

Bartle and Abadi (2010) estimate that without accounting for a price on carbon, that is, no market value for CO_2-e, then over the 50 year period the Equivalent Annual Value (EAV)[4] for the oil mallee IFES is \$196/ha. This calculation assumed the farmer received a price of \$45/ green t delivered for the biomass. When a price starting at \$25/t CO_2-e is included the oil mallee IFES EAV increases to \$335/ha. However, we must consider that where the plantings are integrated with the agricultural production the area under oil mallee, in this example, represents 8% of the available land. This means there is little difference in the cash flow to the farmer on an annual basis. Importantly the addition of the drought tolerant oil mallee to the farming enterprise can mean that harvest can occur even in dry years thus improving cash flow at critical times. A sensitivity analysis varying key parameters of: harvest yield, harvest cost, biomass sale price and carbon by +/-10% was carried out indicating the mean \$335/ha EAV could vary from \$274/ha - \$395/ha. Until an accepted mechanism is put in place, that is legislation enacted, the value of carbon can only be approximated. Given the uncertainty of the prices and costs associated with the development of the oil mallee IFES caution regarding the expected economic outcomes is required. Significant variation can occur.

[3] All models are dependent on input data and establishment costs are still quite variable for many mallee based systems. Establishment costs between \$800 - \$1300 ha^{-1} is readily available in the literature and this will significantly impact on the output values.

[4] EAV and AER are the same calculation but different authors have individual preferences (e.g., AER is used in Figure 2 and EAV is preferred by Bartle and Abadi (2010)).

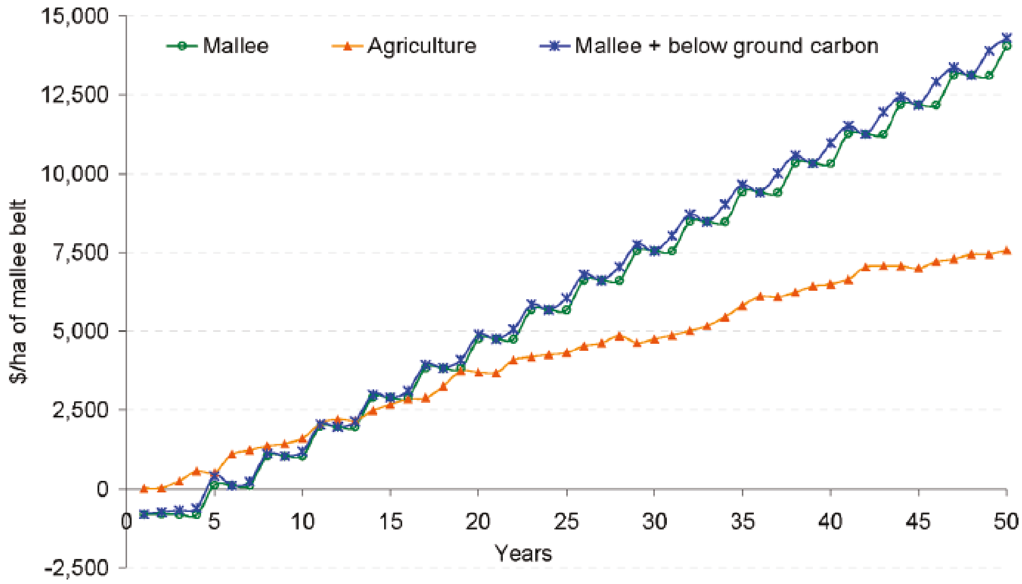
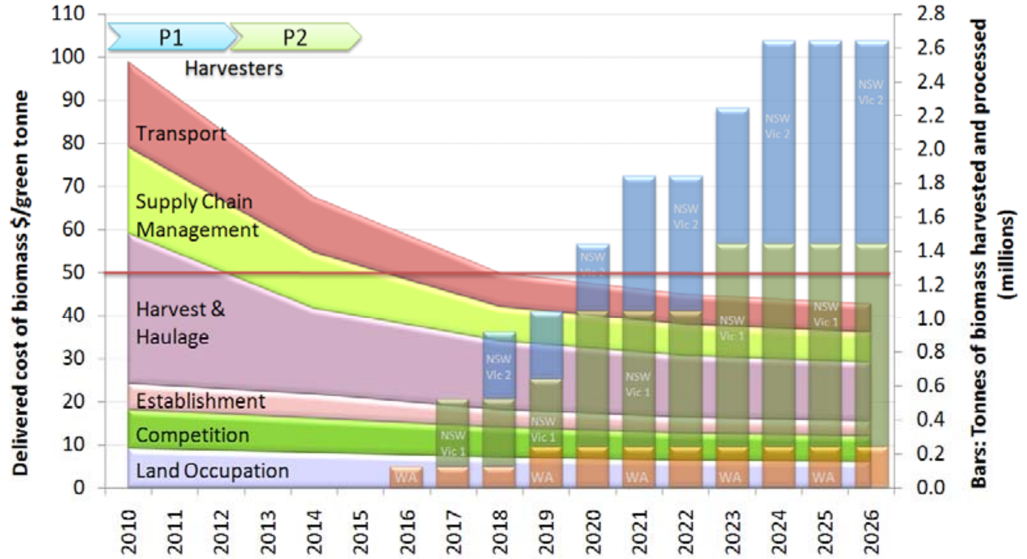


Figure 4. The cumulative undiscounted cash flow for conventional agriculture (grains), mallee and mallee including a value for soil carbon as estimated with the input parameters in Appendix 2 (Bartle and Abadi, 2010).



Tree Area (,000 ha):	2.4 13 31 50 68 86 105 123 139 155 163 163 163
Avoided emissions (Mt CO2-e)	0.1 0.3 0.8 1.3 2.1 3.0 4.0 5.1 6.4 7.8 9.1
Carbon sequestered (Mt CO2-e)	0.2 0.6 1.3 2.2 3.2 4.1 5.1 6.1 7.0 7.8 8.3 8.6

Figure 5. The breakdown of the delivered cost of biomass ($/green t) with expected effeciency gains with time. The right-hand side axis indicates potential biomass requirements (Mt) to meet electricity generation from two 8 MW plants in WA and co-firing coal fired stations in NSW and Victoria with 1.2 Mt biomass per annum. The orange bars represent potential biomass harvested and processed for two 8 MW plants in WA; the green bars – biomass required for cofiring one 80 MW plant in NSW; blue bars – biomass required for a second cofired 80 MW plant in NSW and Victoria (Future Farm Industries CRC, 2010).

The most sensitive parameter in terms of impact on the EAV is the price received for the delivered biomass for energy transformation. This price is a 'minimum' requirement for the biomass producer – the farmer. The cost of growing, harvesting and transporting the material for conversion is critical. This is the current focus of work coordinated through the FFI CRC (Future Farm Industries CRC, 2010). Their scenario modelling indicates that a delivery cost of $50/t biomass could be achieved by 2018 assuming significant improvements in transport, supply chain management and harvest and haulage costs and is shown in Figure 5. In this scenario 163 200 ha of oil mallee plantings producing 2.6 Mt of green biomass per year could generate 176 MW of electricity (by 2026).

Multiple product opportunities

The IWP process tested the development and efficiency of multiple product streams from the oil mallee biomass inputs. Initially focussing on three key outputs (*viz.*, electricity, activated carbon and eucalyptus oil) the IWP system highlighted the opportunity for mallee biomass to be converted into many products. The trial also highlighted the difficulty in developing a commercial operation that received multiple feedstock inputs producing multiple outputs. The selection of the end-product will have dramatic impacts on the economic viability. Recent research by Rodriguez *et al.* (2011b) indicates that biomass utilised for electricity generation is unlikely to be economically competitive unless a price for carbon exceeds $34/MWh and farmers receive at least $46/green t for the biomass potential for bioenergy is limited in important forest areas of Australia such as the Green Triangle. Further research by Rodriguez *et al.* (2011a) in the same geographical area suggests that use of biomass for transport fuels may become more economical to the biomass producers especially as fossil fuel process increase.

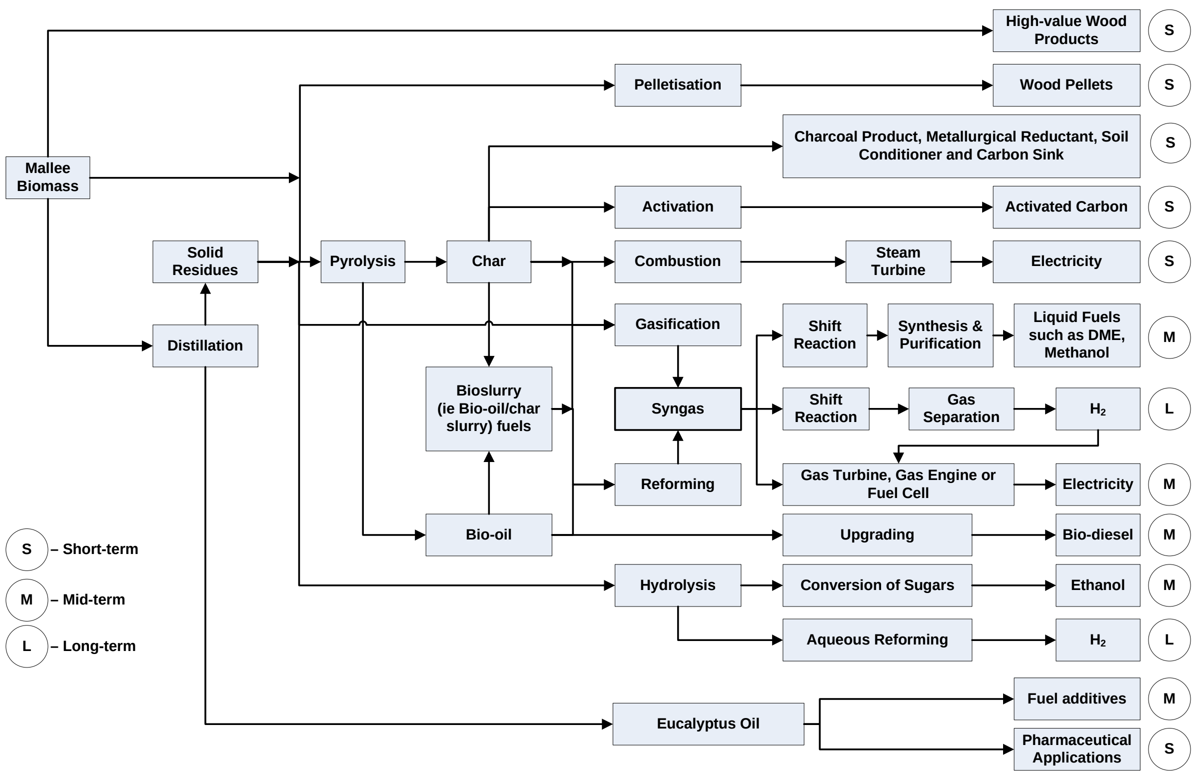


Figure 6. Potential products derived from mallee biomass feedstock via different processes. Products and the timeframe for developing competitive processing capability can be considered at different timescales (S - short term, M - medium term and L - long term). (Image produced and supplied by Prof. Hongwei Wu, Fuels and Energy Technology Institute, Curtin University, Australia).

The matching of the species traits with product opportunities underpins the development of low-rainfall IFES. Following the IWP process the opportunities for multiple products from mallee biomass are considered in more detail in Figure 6. Product classes or opportunities may be: existing, tangible and able to be sold into mature markets if competitive (e.g., high-value wood products); existing but a new application for mallee biomass (e.g., wood pellets); offer indirect benefits (e.g., biochar to improve soil health); or even contribute to developing and potentially non-tangible markets such as sequestration of CO_2 and avoidance of fossil fuel use. It is likely that developing the woody IFES based on mallee biomass will require a combination of market routes and products to become competitive and this contributes to the complexity in developing systems that can contend with existing industries, especially mature industries such as coal-fired power generation.

One of the product opportunities identified in Figure 6 is the pyrolysis of the biomass to bio-oil and subsequent upgrading. An Australian company, Renewable Oil Corporation (ROC), utilising fast-pyrolysis technology developed by Dynomotive in Canada, is planning the establishment of a demonstration plant in Western Australia during 2012[5]. The plant, with a planned capacity of 120 000 t green wood per annum, will utilise harvested oil mallee and plantation residues (Stucley, personal communication[6]). Through densification of the energy derived from woody biomass this project will allow for further supply chain development and the biomass utilised will develop opportunities for sale allowing for increased plantings.

Supply chain issues

Efficiency is critical in any large-scale supply chain. For electricity generation very large amounts of biomass could be consumed. But this means extensive networks and potentially complicated supply chains. Biomass yields less energy per tonne compared to coal and is more intensive in harvesting and haulage compared to mature coal mine and transport operations. For bioenergy densification options could become important (Fung *et al.*, 2002; Richard, 2010). As the opportunity for biomass products increases, for example international trade in pellets, then we expect market-based efficiencies to reduce costs through improved logistics and management. And as electricity prices increase in Australia (IPART, 2011) alternative sources of feedstock materials will potentially become cost-competitive with fossil fuels.

DEVELOPING INDUSTRY OPTIONS

Technology and policy will determine the opportunities for bioenergy over the next 10 years. In Australia there is significant discussion regarding the need to include a price for carbon. If this discussion leads to clear policy development then opportunities for biomass energy are likely to increase. Currently there are multiple policies in place such as the Renewable Energy Target but with questions regarding economic and environmental efficiency continually raised (IPART, 2009) it is unlikely that a clear policy direction will be established in the immediate future. However, it is clear that long-term policy will invigorate a market-based response (O'Brien, 2008). In Australia this is viewed as a preferred option. In jurisdictions such as the EU where clear GHG outcomes are sought (European Parliament, 2009), changes to implementation impact on the capacity of industry to attract significant funding to develop long-term responses. However sovereign risk remains a significant issue for industry impeding confidence and stifling investment (George, 2012).

[5] http://www.renoil.com.au/projects.html; accessed 15/6/11.
[6] Colin Stucley, Managing Director of Renewable Oil Corporation Pty Ltd; 15/6/11.

Technology developments will also lead to increased opportunities for processing and densification of energy from biomass, and hopefully at lower and more economically competitive costs (Sims *et al.*, 2008). But improved technology development and changing policy drivers will still not guarantee significant industry investment. For emerging technology the void between early high risk investors and required large-scale investment in maturing processes is not addressed and remains a critical issue in bioenergy systems (Ernst & Young, 2010).

However, strategies are being considered within the mallee industry to overcome three key impediments (URS Forestry, 2008):

1. There is still no clear technology/process that has market acceptance and scale for the utilization of mallee biomass that has a robust economic basis;

2. A 'chicken-and-egg' scenario exists where if a technology was available the scale of plantings is not significant enough to meet substantial demand;

3. Policy settings currently favour the planting, but not harvesting, of mallee species. This needs to be reconsidered or biomass will obviously not be available for processing.

Most of the research and trials reported here are focused on (1) and (2). By increasing knowledge and improving the capacity of farmers to respond we can plan to meet market opportunities as they arise. The policy aspects (3) remain open to debate. However, some fundamental aspects are changing such as including increasing energy prices (both stationary and transport[7]). As the understanding of the climate change issues, including potential ramifications, becomes clearer, we expect that policy will continue to develop. But a significant challenge that remains is how business investment responds to the uncertainties of developing bioenergy systems. Addressing this challenge could be achieved by, as stated in the 'Oil mallee industry development plan for Western Australia' (URS Forestry, 2008), "e*ncouraging flexible policy frameworks that allow the objectives of minimising greenhouse gas emissions to be achieved by harvesting trees for the production of bioenergy and wood products* ***and*** *by creating a carbon sink from the same crop, thereby enhancing the potential socio-economic value of carbon sinks*". These frameworks are yet to be formed and implemented in Australia.

CONCLUSIONS

The key messages we derive from the review of literature and assessment of current bioenergy SRC systems in Australia are that to develop a new, large-scale bioenergy industry, it is critical that supply chains are efficient. Costs of harvest and haulage greatly impact on economic viability. It is critical that bioenergy not only deliver lower carbon energy solutions but minimise the impact on natural resources and competition with food production. Further, considered and flexible policy settings are required to address the social and environmental concerns with the economic opportunities for large-scale production.

The woody crop IFES aims to develop into a large market-based industry through integrated plantings in farming systems.

Some Australian native species, including oil mallees, have been identified as providing biomass suitable for energy production. The species characteristics such as drought

[7] Stationary energy refers to electricity and/or heat production, transport is for fuels used in automobiles, airplanes and ocean transport.

tolerance, coppicing capacity and appropriate wood properties help with provision of biomass that is suited for multiple markets whilst improving options for farmers developing an IFES. These characteristics, such as the ability to coppice can assist with reducing the ongoing site disturbance whilst increasing the opportunity for production in water limiting environments.

There remain important issues that need to be resolved including:

1. Species and site selection and planting designs that account for efficient production, reduction in competition when planted with other crops and other environmental considerations such as hydrology and salinity.

    a. Integration of oil mallees into farming systems will require further understanding of species, environmental characteristics (e.g., capacity to intercept water) and impacts on other crops to complement and compete with existing agricultural crops.

2. Development of economically robust supply chains that efficiently deliver biomass material for conversion into (potentially) multiple products including stationary and transport energy.

    b. Development of harvesting technology, based on an improved understanding of their materials handling characteristics, is critical in delivery of low cost biomass.

3. Development of stable policy with objectives including promotion of alternative energy systems that can compete with low-cost fossil fuels. This is required for large-scale industry investment and development.

Significant development is still required to allow for competitive supply of biomass to for example, electricity generators, at an economically competitive cost. If environmental benefits are to accrue such as the reduction in carbon emissions and salinity mitigation then the farmers need to profit economically and the biomass needs to compete with existing fossil fuels. The management of the integrated supply chain is fundamental to achieving economic competitiveness.

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APPENDIX 1

The base case scenario assumptions used in the Regional Potential Industry Analysis (RIPA) by Hobbs (2009) are presented here. There are no insurance costs included and transport costs are variable depending on the distance from the production to processer. The trees are established at 1 000 stems per ha. The first harvest occurs at eight years of age (others have indicated the potential to harvest earlier (Wildy *et al.*, 2003; Huxtable *et al.*, 2009)). Subsequent (coppice) harvests are scheduled each five years.

Establishment Costs ($/ha)	Site planning, setup and land preparation	Seedlings, planting, fertiliser and watering	Weed/Pest management and control	Total Establishment costs ($/ha)
	425	800	75	1300
Production, Harvest and Investment Costs	Average Maintenance Costs ($/ha/year)	Harvest Costs ($/freshweight tonne of total biomass)	Freight costs - includes truck return trip ($/t/km)	Discount rate
	15	12	0.14	7%

APPENDIX 2

Parameters and estimated values and caveats regarding economic modelling for an IFES based on oil mallee plantings in belts on farms in southern Australia (from Bartle and Abadi (2010)).

Parameter	**Estimated value**
Project duration	50 years
Planting (belt) layout	Two row belts occupying 7m width with alley width of 72m to give a proportion of paddock area occupied of 8%
Establishment cost	$800/ha of belt area
Annual management cost	$5/ha/year
Harvest regime	Year 5, then 3 years later on a repeating cycle (i.e., coppice cycle every 3 years)
Yield above ground	50 (green) t/ha of belt area every harvest
Yield below ground	Below ground biomass grows at 50% of above ground biomass to first harvest. There is a 30% loss of root biomass on harvest, followed by a net 7.5% gain by the following harvest.
Competition loss factor[8]	0.8 (i.e., crop immediately adjacent to belt area decreases yield to 80% of average crop yield)
Harvest and delivery	$26/(green) t consisting of harvest, on-farm haulage and delivery to processing point 50 km away
Delivered biomass price	$45/(green) t (includes all production and supply chain costs)
Price for carbon sequestered in root biomass	Projected to rise from $25/t CO_2-e in year one to $115/t at year 50[9]
Equivalent Annual Value (EAV) from agriculture[10]	$164/ha/year
Overall management of mallee crop and supply chain	Estimated at 20% of the delivered biomass price (above)
Emissions limits on agriculture	No emissions limits are currently applied to agricultural practice in Australia

[8] The loss of productivity in the paddock immediately adjacent to the mallee belt as a proportion of the belt area due to competition for resources – predominantly water. Recent research indicates that the competition could be significantly larger. For example see Peck, A.; Sudmeyer, R.; Huxtable, D.; Bartle, J. R.; Mendham, D. S. 2012: Productivity of mallee agroforestry systems under various harvest and competition management regimes. Pp. 247. Canberra, Australia..

[9] As of 2012 there is no formal mechanism to price biomass carbon and so this is an assumed amount.

[10] The annualized Net Present Value (NPV) from agriculture, derived from a cash flow configured to reflect seasonal variability.

ACKNOWLEDGEMENTS

We acknowledge our respective employers in allowing us to dedicate time to this report. Helpful comments to an earlier manuscript were provided by Peter Hall (NZ), Tat Smith (Canada) & Paul Wells (Australia). Prof. Hongwei Wu (Fuels and Energy Technology Institute, Curtin University, Australia) supplied Figure 6.

This report is part of a series 'Promising resources and systems for producing bioenergy feedstocks' prepared by IEA Bioenergy Task 43.

IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

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This publication was produced by Task 43 within the Implementing Agreement on Bioenergy, which forms part of a programme on international energy technology collaboration undertaken under the auspices of the International Energy Agency.