Promising resources and systems for producing bioenergy feedstocks

Developing Options for Integrated Food-Energy Systems – Volume 1

Rationale for industry development, species criteria and selection of woody species in agricultural production areas for bioenergy in Australia

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 draws on the experience of the mallee industry development in Australia over the last 20 years to highlight progress and some of the current challenges for large-scale industry development. Species suitability and supply chain management is critical in establishing a vibrant industry.

IEA Bioenergy

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Developing Options for Integrated Food-Energy Systems

Volume 1- Rationale for industry development, species criteria and selection

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KEY MESSAGES

There are multiple drivers for the production of biomass outside provision of feedstock for alternative energy systems including: addressing environmental concerns (e.g., climate change via mitigation, salinity); social aspects (e.g., opportunities for regional development); and economic (e.g., enterprise options to address continued declining terms of trade for primary producers).

The development of a robust bioenergy industry in Australia has taken some years and much planning. But, the industry is still in early stage development without a significant and vibrant nation-wide market for biomass feedstocks. Several small markets exist that are developing in different locations (e.g., Western Australia and mallee feedstocks) with domestic and international opportunities. This situation is, however, changing.

More understanding of the opportunities and limitations of the current and proposed systems is required to ensure development that is not only large in scale but also recognizes limitations and enhances development that will be economically and environmentally sustained.

Successful utilization of woody biomass for energy requires consideration of the species, location and farming systems. And it is possible to integrate energy crops into farms whilst minimizing competition with agricultural crops and potential food production. To do so successfully however, requires a good understanding of the respective species physiology (e.g., water use) and adaptive management to balance production and competition. Understanding and predicting the impacts of competition effects is critical in integrating bioenergy production systems with food, feed and fibre production.

Alternative crops must have an economic basis to allow for large-scale development especially where multiple outputs such as energy production, amelioration of environmental concerns and rural development are the stated objectives. Thus the species selected and the supply chains developed must be appropriate and efficient.

In the production of the biomass, recent findings indicate large intra and inter site and species variation in biomass yields depending on the climate, nutrient availability, species suitability and management. Predicting biomass yields will be difficult.

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Cover Picture: A mallee planting in Western Australia with sheep grazing in the background.

EXECUTIVE SUMMARY

> *A safe integration of food and energy production may be one of the best ways to improve national food and energy security and simultaneously reduce poverty in a climate smart way* (FAO, 2011).

The Food and Agriculture Organization (FAO) of the United Nations - Natural Resources and Environment group recently reported on the concept of *Integrated Food-Energy Systems* (IFES) and the role of energy and food production, especially in developing countries. The concept of integrating energy crops with existing production systems is not new.

This *IEA Bioenergy Task 43 Promising Resources* report, consisting of two volumes, outlines an approach undertaken in Australia to integrate energy systems in this case, biomass production from short-rotation woody plantings, within existing farming regimes. These systems, predominantly based on eucalypt species native to Australia, have been investigated and promoted as having commercial and environmental outcomes. The eucalypt mallee IFES in Australia are targeted in the lower rainfall areas (300 – 700 mm/yr) in southern Australia that is generally known as the 'sheep-wheat' belt.

Though Australian farmers are fortunate, in that they do not have to face the level of poverty experienced in many other parts of the developing countries, the declining terms of trade over the last 40 years have reduced the profitability of many farms. Farmers have adapted by increasing the scale of their operations and/or intensifying the production systems with increased innovation required to remain profitable. At the same time, a better understanding of the limitations to existing farming systems, and attempts to address problems such as salinity have increased the need for alternative approaches to sustain production.

Climate change will require further consideration of species (i.e., adaptation) and changes to current agronomic practices to reduce impacts as well as offer opportunities to develop systems that can mitigate Climate change effects through sequestration of carbon (or CO_2-equivalents, i.e., CO_2-e) and displacement of fossil fuels.

In Volume 1, we predominantly focus on mallee species (*Eucalyptus* spp.) due to their capacity to produce biomass in lower rainfall areas with characteristics suitable for utilisation as a feedstock in multiple product strands including bioenergy. Biophysical issues remain including understanding: the physiology of different species; establishment and growth; optimal harvesting regimes (timing and costs); the impact on and competition for site resources, especially water and nutrients.

In Volume 2 (*Supply chain logistics and economic considerations for short-rotation woody crops in southern Australia*), we outline some supply chain issues such as the development of a suitable harvester and highlight some of the recent economic modelling and potential industry development opportunities. The challenge remains to produce significant quantities of biomass to enable the development of a competitive and robust industry 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 enable incorporation into existing farming systems.

The focus of the report relates to the production of biomass for energy. But the opportunity for multiple product outputs from many biomass systems (i.e., the options from biorefineries) is recognised and that selected output products will be largely determined by the economic opportunities. This could mean that energy 'products' are but part of a suite of options.

INTRODUCTION

Energy use is increasing globally and within Australia. From 2000 – 2007 the rate of growth world-wide increased by 2.63% per annum (International Energy Agency, 2009). Australia exceeded this growth with energy production increasing at an average rate of 3.5% a year from 1997-98 to 2007-08 (Australian Bureau of Agricultural and Resource Economics, 2010). Domestically bioenergy supplies ≈5% of energy consumption within Australia (Australian Bureau of Agricultural and Resource Economics, 2010).

Use of biomass material ranges from low technology systems such as open fires for domestic heating to adaptation of existing large-scale infrastructure such as co-fired power plants (e.g., Berndes *et al.*, (2010b)) and dedicated heat and power generation (e.g., Bernotat and Sandberg (2004)). There is significant scope to increase the use of bioenergy but limitations remain on a policy and commercial basis. 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). Integration of food, energy and resources is a major issue facing Australia.

Though debate continues in respect to quantification of anthropogenic contribution to climate change (Solomon *et al.*, 2007), there are significant environmental issues regarding the supply and consumption of energy (International Energy Agency, 2010). Sustainability questions in relation to soil, water and atmospheric limitations are also being considered and addressed for bioenergy production (Pimentel *et al.*, 2009; Tilman *et al.*, 2009; Berndes *et al.*, 2010a; Blanco-Canqui, 2010). In Australia it has been recognised that short-rotation woody crops have considerable potential to contribute to large-scale sustainable production of biomass for energy production (Bartle *et al.*, 2007). And these production systems can contribute to the mitigation of carbon through sequestration and the displacement of fossil fuels (Cowie *et al.*, 2006).

Discussion regarding the potential and actual role of carbon mitigation through increased use of biomass is ongoing and beyond the scope of this paper. For details concerning some of the positive mitigation potential of bioenergy see, for example, Schlamadinger & Marland (1996) and Berndes *et al.* (2003). There are some concerns regarding the potential impact of increased biomass production and the carbon balance (Melillo *et al.*, 2009; Bird *et al.*, 2010; Zanchi *et al.*, 2010). The issues related to potential *indirect* impacts have also been investigated by Berndes *et al.* (2011), Dale *et al.* (2010) and Plevin *et al.* (2010). More recently there has been significant conern regarding the competition between crops grown for energy and food. This is particularly so where food-based crops such as wheat are converted to ethanol and effectively 'removed' from the human food supply chain (Dale *et al.*, 2010; Solomon, 2010; Valentine *et al.*, 2012).

Policy and market mechanisms concerning competition for food, carbon emissions and climate change are dynamic and subject to significant debate. The response to climate especially is still country-specific with some, for example New Zealand, implementing a market-based Emissions Trading Scheme (ETS) and others relying more on defined policy driven outcomes. An example of this is the European Directive 2009/30/EC that requires greenhouse gas (GHG) reduction targets to be met in production of biofuels. The policy settings and requirements will significantly impact economic viability of existing and developing industry including mallee IFES (highlighted in Volume 2, (George and Nicholas, 2012)). Whilst important, the form and function of the proposed policy and ETS approaches are not discussed in detail in this paper.

Salinity is a significant problem across the world and especially in Australia (Rengasamy, 2006; Sudmeyer and Goodreid, 2007). In Western Australia salinity was identified as a threat to agriculture particularly in the south east and significant investment made during the late 1990s –

2000s to minimise salinity threats. Recently much of the investment and its value has been questioned due to mixed priorities (Pannell and Roberts, 2010). Developing sustainable land use options is challenging and developing those that can generate positive returns to the farmer more so (Thompson and George, 2009). Woody vegetation, and in particular mallees including *Eucalyptus polybractea*, *E. loxophleba* and *E. horistes*, can deliver benefits in mitigating salinity whilst offering alternative income streams.

A farming system that is economically sound and capable of ameliorating environmental issues underpins the philosophy of developing mallees[1] as the basis of biomass production for energy in low rainfall areas across southern Australia.

This report aims to summarise some of the initial logic and thinking and then key actions that have occurred in the development of the industry to date.

Figure 1. A four-row mallee belt planted into an annual cropping farming system in Western Australia. Note the rows in the background highlighting the integration into the farm landscape (image: J.R. Bartle).

In Volume 2 of this report (George and Nicholas, 2012), we outline the significant components and issues in developing a large-scale biomass industry based on production of woody material that is integrated into farming systems across southern Australia.

DEVELOPING A RESPONSE TO ECONOMIC AND ENVIRONMENTAL PROBLEMS

Economic considerations

An underlying principle assumed is that maintained or increased financial return allows for increased capacity to address environmental limitations and threats. This potentially leads to conflict where the financial and economic returns to the farmers and community respectively, through an increased price for a product, are considered ‘good’ and ‘bad’. For example, the improved ‘terms-of-trade’ for the farmers may lead to increased prices in staple foods in poorer countries. This leads to conflict and concern, especially when feedstocks are removed from the food supply chain for use in energy products (Pimentel *et al.*, 2009; Baffes and Haniotis, 2010; Solomon, 2010; Valentine *et al.*, 2012). Woody SRC systems aim to at least part-evade this dilemma through production of non-food feedstocks and ideally through complementing existing cropping systems. Managing the impact of biophysical and economic competition is however challenging.

The development of the mallee industry in Western Australia aimed to establish an industry that could address social, economic and ecological challenges. In many rural areas farming has become less profitable due to the long-term reduction in the ‘terms of trade’ (Productivity

[1] Mallees are used in this paper to encapsulate short-rotation/cycle woody species suitable for growing in mid to lower rainfall regions across Australia.

Commission, 2005). This in turn led to increased farm size and mechanization with a subsequent reduction in local population and services. With limited government support for agricultural production, especially compared to the US and the EU (Bartle and Abadi, 2010), any change to farming systems needs to be economically based in order to achieve large-scale implementation.

In Western Australia significant industry development promoting the planting and use of mallee species has contributed to the necessary learning, adaption and opportunities expressed by the "The Integrated Wood Processing (IWP) system". Much of the potential is yet to be realized but the primary view of a market-based solution remains.

Complicating the supply chain for biomass is the opportunity for multiple outputs.

Environmental drivers

Salinity

Salinity has been identified as a large and increasing threat to biodiversity and productivity (Bell *et al.*, 2001; Rengasamy, 2006). This problem is not only confined to Western Australia but much of Australia due to the salt embedded in the landscape and the changes to hydrology (Prime Minister's Science Engineering and Innovation Council, 1999).

Dryland salinity (Figure 2) has been identified as a major problem in the Australian 'wheat-belt' areas. The National Land and Water Resources Audit (2001) estimated that more than 5.6 million ha are currently affected and that the area at risk will increase to 17 million ha by 2050. Due to its geomorphology and climate, Western Australia is likely to be affected more severely than other Australian states.

Figure 2. An example of significant salinity impacts due to changes in local hydrology in Western Australia. The local salinity in the foreground is likely to have resulted from clearing and land use change in the background where little perennial vegetation now exists. Salt is moved by water through the soil profile and concentrates lower in the landscape (image: B.H. George).

Increased salinity in groundwater is associated with changes in the hydrological balance that are caused by the clearing of native vegetation to establish pastures and crops. Under native and deep-rooted vegetation areas, most of the available water is utilised in the active root zone and there is little leaching. The soil therefore contains a high concentration of mineral salts (mainly sodium chloride) to which native species are well- adapted. Because annual crop and pasture plants use less water than the previous native species and ecosystems, mobilisation of salts will occur increasing their concentration in groundwater. These salts are then transported into lower landscape positions. This can have the following consequences:

- Reduction of productivity on previously fertile lower slopes;
- Reduction of biodiversity;
- Increased salinity of stream and river water;
- Increased surface run-off and soil erosion due to reduction of the vegetation canopy;
- Changes (increases) in the height and frequency of peak flood events;
- Water damage to roads and infrastructure, including buildings in towns.

Although the basic hydrological principles are well understood, there is a need for better management of soil water movement at the farm production level (Barrett-Lennard, 2002; Herron *et al.*, 2003; Vertessy *et al.*, 2003). Changes in cropping practice leading to increased or decreased water movement on a small scale (e.g., in a single paddock) can have consequences that only become evident years, decades or even centuries later; often at a considerable distance of kilometres or even hundreds of kilometres from the area of land use change.

In Western Australia the movement of sub-surface water in most catchments is considered at a 'local scale' because the catchments are relatively small in size and show a rapid response to changes in hydrological conditions. For instance, replacement of native vegetation with annual crops has been found to cause salinity problems within a decade or two (Salama *et al.*, 1999). In eastern Australia catchments are larger, that is they are not only local but also 'intermediate' or 'regional' scale, and salinity changes may not become evident for many decades. The location and form of cropping practice is more variable and the hydrological implications are more complex. However, there is clear evidence that plantings of deep-rooted woody perennials can reduce sub-surface water flow and recharge aquifers through increased water use and 'mining' of available soil water (Crosbie *et al.*, 2007; Sudmeyer and Goodreid, 2007).

Though hydrological impacts can be significant at local and larger scale catchments (Herron *et al.*, 2003; Vertessy *et al.*, 2003), recent studies in Western Australia indicate that a large proportion of catchments would need to be planted to mallees to significantly reduce salinity. Bennett *et al.* (2011) found at sites located in 450 mm rainfall zones that "*a belt canopy area of 3–10 per cent of the landscape accounted for up to a 30 per cent net decrease in recharge to groundwater systems*". However, this had "*no discernable effect on catchment-scale groundwater levels*". They concluded that two-row mallee systems would have a strong competitive effect with crops whilst not significantly ameliorating secondary salinity.

Climate change – adaption and mitigation

More recently the value of increased mallee plantings, integrated with existing farming systems, has been considered in the context of Climate change. Mallee species are hardy and can withstand drought conditions enhancing their potential role in adapting to Climate change (Hobbs *et al.*, 2009a). The production of woody biomass material and conversion to energy and co-products offers the opportunity to mitigate Climate change through increasing sequestration, especially compared to cleared agricultural land, and displacement of fossil fuels (e.g., oil and coal). To evaluate the mitigation potential of mallees and their systems Life Cycle Assessment (LCA) work is underway with initial results indicating significant displacement of carbon from energy systems utilizing mallee as the feedstock source (Yu *et al.*, 2008). Wu *et al.* (2008) estimated that mallee crops could yield ≈ 200 GJ ha^{-1} yr^{-1} with an energy ratio of ≈ 42 (i.e., the ratio of total energy outputs divided by the total non-renewable energy inputs). This compared favourably with rapeseed systems having an estimated energy ratio of < 7. The energy and greenhouse gas (GHG) balances will obviously be determined by the input and growth rates of the biomass and the supply chains and conversion to energy. These issues are not discussed in detail in this report. However, the capacity to store carbon below ground is important for production and potentially in carbon trading schemes (discussed in Volume 2).

POTENTIAL OPPORTUNITIES FOR WOODY ENERGY CROPS

The potential for strategically integrated energy tree crops include benefits such as:

1. Production of feedstocks for low carbon emission bioenergy systems;
2. Provision of local base-load electricity generation across the grid, reducing transmission losses;
3. Diversification of farm incomes and regional economies by complementing rather than displacing existing food-based agricultural industries; and
4. Provision of salinity mitigation and biodiversity benefits (Future Farm Industries CRC, 2010).

Refining the respective opportunities and demonstrating the capacity and capability of bioenergy systems in meeting these objectives has, and will, need further significant planning, investment and persistence. The industry development has taken some 20+ years and has been based on multiple initiatives including the pioneering work of the IWP facility at Narrogin in Western Australia.

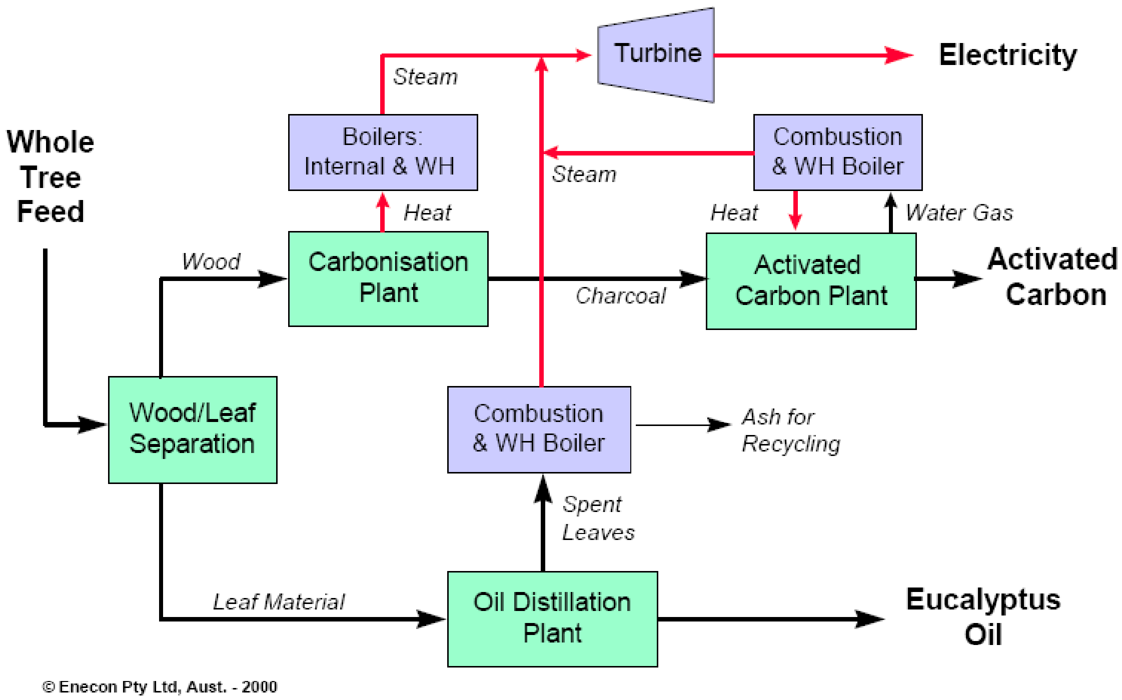

Figure 3. A schematic diagram of the IWP concept for the plant/biorefinery built at Narrogin in Western Australia illustrating the pathway for biomass utilisation into multiple products (indicated on the right hand side). Image taken from a RIRDC report prepared by Enecon (2001).

The Integrated Wood Processing (IWP) system in Western Australia

To optimise production from woody biomass an IWP facility was developed in Western Australia during the early 2000s. Funded by government[2] and industry the IWP facility (a '*biorefinery*')

[2] Total project funding is estimated at approximately $20M AUD as reported to the Western Australian Parliament (http://www.parliament.wa.gov.au/Hansard%5Chansard.nsf/0/dec9bcfe0c117c15c825757b00275be0/$FILE/C37%20S1%2020060413%20p1692c-1693a.pdf; accessed 04/04/2011)

aimed to demonstrate the capacity to take biomass feedstock from mallees and create multiple products including electricity, activated carbon and eucalyptus oil (Figure 3).

The pilot plant (Figure 4), built at Narrogin located approximately 200 km SE of Perth, was run to test the concept and engineering of a multi-product plant as well as the capacity to handle biomass feedstock – chipped mallees. The process aimed to utilise the above ground component of the mallee and separation of the leaves and wood.

Figure 4. The IWP at Narrogin (Western Australia). Designed and run as a pilot plant to test the integrated output capacity from mallee feedstock (note the mallee woodchip piles in the foreground), the plant operated for several years proving the concept (image: J.R. Bartle).

Test runs conducted post 2005 indicated it was technically feasible to yield multiple products. A Front-End Engineering Design (FEED) conducted by Verve Energy, further demonstrated potential. However, there have been no further investments to move to a commercial scale production (at mid 2012). If a 1 MW power plant was established then approximately 20 000 t per annum of mallee biomass would be required as input feedstock. In turn this feedstock would be sourced from approximately two million mallee trees harvested on a 3 – 5 year cycle. The process and likely output for a 1 MW plant is shown schematically in Figure 5. The optimum plant size depends on factors such as: geographical location; plant efficiency; network supply and capacity; and, available supply of biomass.

IDENTIFYING THE BIOMASS RESOURCE AND DEVELOPING EFFICIENT SUPPLY CHAIN SYSTEMS

The IWP concept highlighted the critical need for robust and cost-efficient supply chain logistics. The need to consider and develop efficient systems for establishing, growing, processing and transforming biomass is well known (Wu *et al.*, 2008; Bauen *et al.*, 2010; Junginger *et al.*, 2010) and shown in Figure 6. The FFI CRC, with government partners and industry, has invested heavily in developing efficient harvesting technology. This work is critical for large-scale development of woody energy crops and continues[3].

[3] http://www.futurefarmonline.com.au/research/new-woody-crops/mallee-harvester.htm; accessed 01/5/2011.

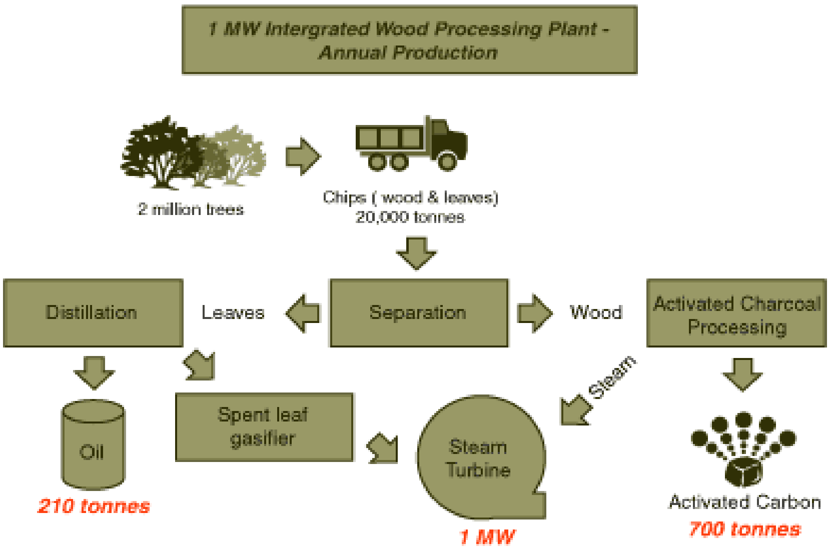

Figure 5. Schematic representation of the mallee biomass input and processing for multiple products. This process would require at least 20 000 t per annum of biomass for operation[4].

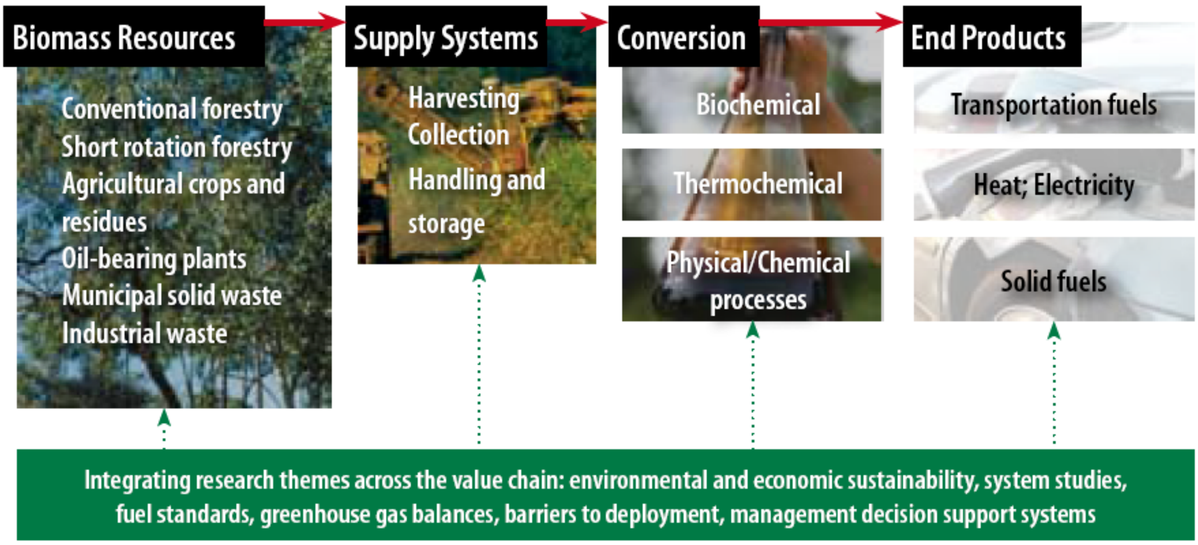

Figure 6. Schematic representation of the biomass supply chain. For mallee development the current focus is on understanding the **biomass resource** and developing efficient **supply systems** (image: redrawn from IEA Bioenergy[5]).

The biomass resource

There are many estimates of the potential for biomass production in Australia for energy purposes. Approaches can be from a 'top-down'/global assessment (Bauen *et al.*, 2010)) or from a 'bottom-up' approach where growth data is extrapolated via modelling (Bartle *et al.*, 2007; Polglase *et al.*, 2008). More recently the potential area for SRC woody crops was estimated at 2.3

[4]Image sourced from http://www.oilmallee.org.au/2009-Site/wood_processing.html; accessed 20/5/11.

[5] http://www.ieabioenergy.com/OurWork.aspx; accessed 12/2/2011

Mha (Farine *et al.*, 2011). In this report we focus more on energy crops than available residues from existing native forests and plantations.

Recent estimates indicate at least 12,000 ha of mallees have been planted in Western Australia (Bartle and Abadi, 2010). Of these plantings *E. loxophleba* ssp *lissophloia* accounts for nearly 40% of plantings, *E. kochii* (ssp *gratiae*, *plenissima* and *borealis*) 43% and *E. polybractea* 8% (Shepherd *et al.*, 2011). Other states such as New South Wales (NSW), may have a greater potential (Bartle *et al.*, 2007), but large-scale planting and associated industry development has not yet occurred with mallee plantings estimated in the hundreds of hectares. Whilst there have been significant trials, for example in NSW Delta Electricity with the NSW government co-funded the establishment of 200,000 mallee seedlings to provide biomass for co-firing[6], Farine *et al.* (2011) estimate it would take at least two to three decades of establishing approximately 100,00 ha per annum to fulfil industry potential. Significant planting programmes are required and these will not occur unless a commercial basis is established.

Identifying suitable species for biomass production in low rainfall areas

Whilst the focus in this report is in relation to the production of biomass for energy in many production systems it is likely that co-products will occur and/or be required to derive a financial return on investment. This is particularly important whilst energy prices in Australia are relatively cheaper than comparative countries and competition from existing fossil fuels remains strong.

Species selection is critical in establishing a viable biomass volume for large-scale industry development. The *Search* project focussed on what *products* could be developed and commercialised and then matched these characteristics with suitable *native species* (Figure 7). Thousands of species were considered and eventually a select few identified in different categories of products (e.g., species suitable for pulp and paper products included *Taxandria juniperina*, *Grevillea leucopteris*, *Alyogyne huegelii* and *G. candelabroides*). A similar approach, to understanding some of the product orientated characteristics of short-rotation species including eucalypts, was undertaken in New Zealand in the late 1990s (Senelwa and Sims, 1999).

Utilizing the framework and selected species identified in the *Search* project (Olsen *et al.*, 2004), the *FloraSearch* programme investigated species for the low to medium rainfall areas in Australia (Figure 8) including: *Acacia spp.*; *Eucalyptus cladocalyx*, *E. globulus* ssp. *bicostata* and mallees including *E. polybractea*, *E. loxophleba* ssp. *lissophloia* (Hobbs and Bennell, 2008; Hobbs *et al.*, 2009c).

Product opportunities identified included: existing forest products such as pulp and paper and composite wood (Hobbs, 2008); fodder; extractives including eucalyptus oil and bioenergy (Hobbs *et al.*, 2009a).

This identification of species capable of growing in a variety of soil and climatic conditions is critical in meeting the opportunities presented in the various product forms. In the *FloraSearch* project the species priority list started with 392 nominations and some 140 taxa were tested for various wood properties to match potential products (Hobbs and Bennell, 2008). Further testing developed a 'focus species' list including: *Atriplex nummularia*, *Acacia saligna*, *E. polybractea* and *E. rudis*. However, careful consideration of the weed risk assessment limits use of some species (e.g., *A. saligna*) in significant areas of eastern Australia (Hobbs *et al.*, 2009b).

After establishing species availability, survival and growth, in conjunction with physicochemical tests for wood products, a series of species that had good potential were identified for southern Australia (Table 1).

[6] http://www.de.com.au/About-Us/Corporate-profile/Corporate-profile/default.aspx; accessed 25/5/11.

There are several common physiological traits for species with significant potential for growth in the target areas of Southern Australia including:

1. species need to be drought tolerant yet capable of significant growth when water is available;
2. root development should be significant to capture available water (laterally and at depth), a characteristic of mallee species (Bartle, 2009);
3. species should be able to coppice when cut to minimise replanting and promote re-growth (Sims *et al.*, 2001; Wildy *et al.*, 2003);
4. frost and salinity tolerance (McMahon *et al.*, 2010).

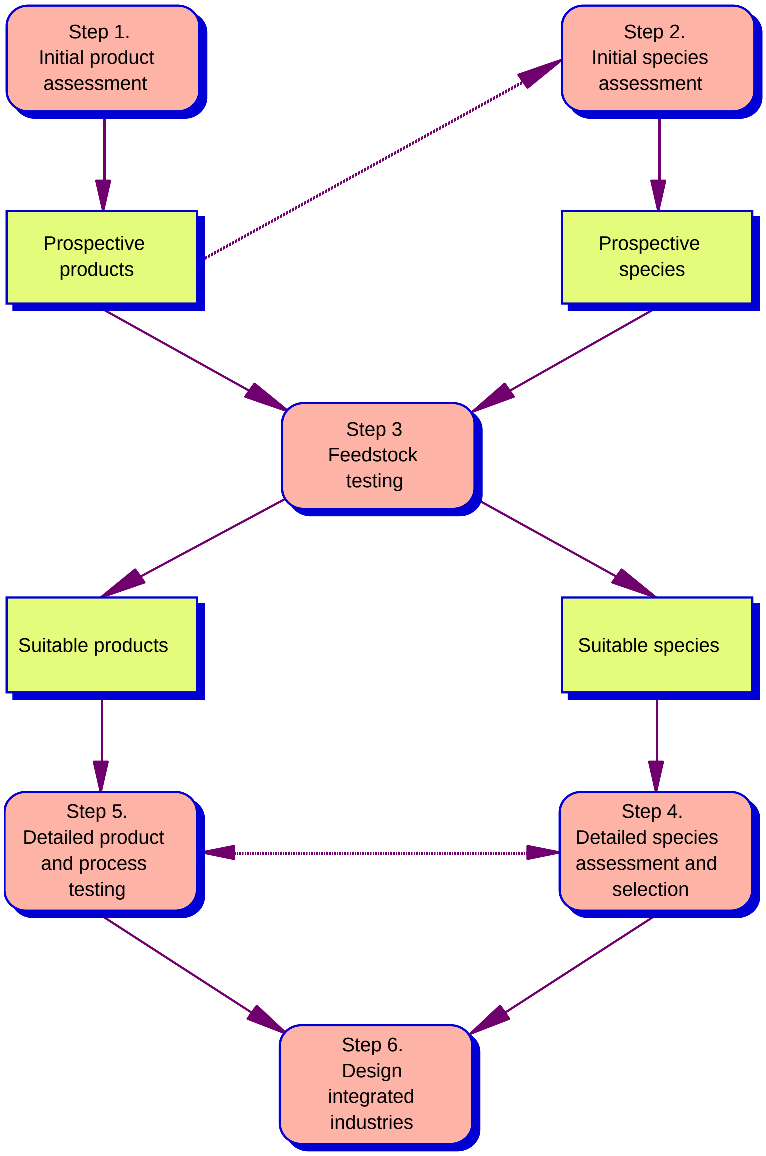

Figure 7. The framework established in the *Search* project (image: Olsen *et al.* (2004), applied and developed through *FloraSearch* (Bennell *et al.*, 2009) to identify products and match suitable native species. The process begins with an assessment of potential products and then consideration of available native species.

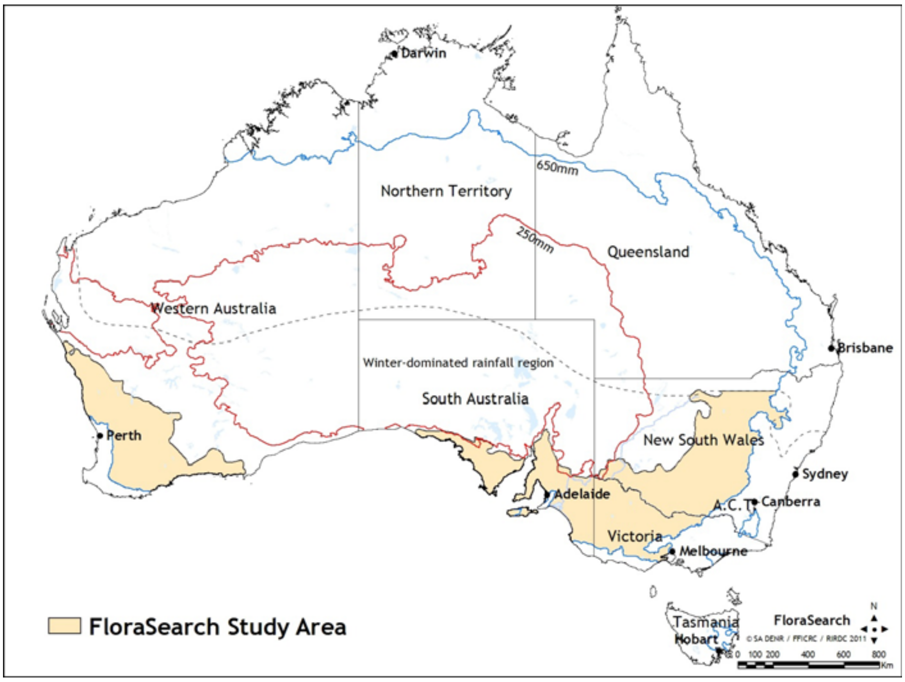

Figure 8. The area of interest for the *FloraSearch* programme in Southern Australia. The focus area is in the 'sheep-wheat' belt (300 – 650 mm rainfall per annum) of Southern Australia (image: T. Hobbs (June 2011) updated from Hobbs *et al.* (2009a)).

Table 1. Species identified through the *FloraSearch* programme that have suitable characteristics for bioenergy-based products and are suited for survival and growth in lower rainfall conditions across southern Australia (Bennell *et al.*, 2009).

Taxa	Stem wood production (m^{-3} ha^{-1} yr^{-1})[7]	Basic density (kg m^{-3})	Wood chip production (bdt[8] ha^{-1} yr^{-1} @500mm)	Pulp yield (%dm at Kappa 18)	Oil Yield (%dm)
Bioenergy					
Eucalyptus cladocalyx	22.0	753	12.1	49.6	0.05
Acacia retinodes	22.5	639	11.4	49.1	
Eucalyptus leucoxylon	19.3	773	9.9	43.0	1.65
Eucalyptus chloroclada	20.3	621	9.8	39.9	
Eucalyptus globulus ssp. *Bicostata*	22.4	656	9.6	46.7	1.15
Eucalyptus viminalis ssp. *Cygnetensis*	17.5	532	6.0	44.3	1.36
Eucalyptus camaldulensis	19.2	502	7.5	38.3	1.50
Oil/Bioenergy					
Eucalyptus porosa	6.4	641	3.0	49.9	2.10
Eucalyptus incrassata	5.0	768	3.1	48.6	2.80
Eucalyptus aromaphloia ssp. *Sabulosa*	25.5	540	7.8	44.5	2.95
Eucalyptus dives	7.4	603	3.5	39.4	3.81
Eucalyptus polybractea	2.5	770	1.5	54.0	2.35

[7] Site productivity data were linearly correlated with mean annual rainfall observations standardised to an equivalent stemwood productivity for 500mm of annual rainfall.
[8] bdt – 'bone dry tonnes', wood dried at 100°C to a constant weight and considered to have no moisture.

Biomass production

Maximising biomass production is paramount in developing a commercial large-scale bioenergy industry. Precipitation and the roots ability to 'capture' soil water across the site will significantly impact on expected growth as will nutrient availability and species suitability. Biomass production therefore is difficult to generalise; the species will have an impact as shown in Table 1 (column 2), but this can be highly variable.

Predicting growth rates is difficult and Peck *et al.* (2012) conclude: "*An overriding finding from this study was the high spatial and temporal variability in mallee yields and patterns of growth in belt planting layouts*." They continue: "*Yield differences of 50% or more over relatively short belt distances (i.e. tens of meters) were observed at all study sites. These observations are consistent with other published studies*". The results of Peck *et al.* (2012) and recently reported studies, where coppice regrowth was measured, are summarised in Table 2. Note the large difference between the value estimated for *E. cladocalyx* in Table 1 (2.5 m^{-3} ha^{-1} yr^{-1}; approximately 1.9 dry t ha^{-1} yr^{-1}) and the annualised (green) yield from other sites in Western Australia in Table 2. Milthorpe *et al.* (1994) reported yields within these ranges in coppiced *E. polybractea* plantings in southern NSW.

Table 2. Biomass yield for coppiced species and different ages for low rainfall woody species widely planted in Western Australia.

Data Source	**Taxa**	**Age**	**Annualised yield**[9] **(green t ha^{-1} yr^{-1})**
Liew (2009)	*E. polybractea*	4	6
		9	10
(Wildy *et al.*, 2003; Wildy *et al.*, 2004a; Wildy *et al.*, 2004b)	*E. kochii* subsp. *plenissima*	1	2 - 6
		2	7 - 10
Peck et al. (2012)	*E. loxophleba* subsp. *lissophloia*	4	8 - 13
		3	5 - 10
	E. kochii subsp. *plenissima*	3	11 - 17
		4	13 - 16
	E. polybractea	3	12 - 27
		4	11 - 33

Silvicultural considerations for woody species including mallees

There are regional and site specific silvicultural processes for successful establishment of woody species including mallees for energy crop production. As outlined above species selection is critical. Once species are selected the establishment of woody crops is similar to other agricultural enterprises. Site preparation is important and weed control essential. As with many plantation forestry systems the site needs to cleared of weeds (George and Brennan, 2002) and

[9] Mean annual increment since establishment unless age interval specified

soil prepared (generally ripped to a selected depth) to improve survival, establishment and early growth (Lacey *et al.*, 2001). Water availability, either conserved or supplemented, is also critical during early establishment (Graham *et al.*, 2009). 'Prescriptions' are often employed but need to be adapted to specific conditions.

Harvesting is critical as it affects the coppicing of the mallees and also is an important cost in the supply chain. Trial work from Western Australia indicates that allowing the trees to become well established with an initial harvest at 5 – 7 years, followed by a 3 – 4 year cut will allow for optimum yields (Wildy *et al.*, 2003). Other research in New Zealand supported the increased growth from coppiced stands but use earlier harvests (Sims *et al.*, 1999). It is likely that the appropriate time for initial and ongoing harvest of coppicing will be determined by the species, the average and seasonal rainfall, and management goals of the production system.

In coppicing mallee systems Wildy *et al.* (2003) highlight some of the characteristics for manipulation of the biomass to facilitate quick recovery for increased growth (Table 3). The ability to coppice is important in increasing production whilst minimising re-establishment costs. Frequent harvests will reduce root development negatively impacting on vigour and growth. In their spatial characterisation of mallees Hobbs *et al.*, (2009a) indicated an increase of 30% in growth rates between first and subsequent harvests was likely due to the already established root systems.

Table 3. Some of the important physiological considerations of mallee and the impact of harvest (adapted from Wildy *et al.* (2003)).

Physiological consideration	Key points	Desirable rotation length
Harvestable shoot production	• age of first cut is not overly important • first year after cutting incurs 'penalty year' of slow growth • early growth is near-exponential[10]	Ideally 3–4 years. Possibly longer
Rootstock vigour	• slow for first 1.5–2.5 years until shoot is restored • lack of new root growth if cut on short intervals may cause decline in rootstock vigour	at least 2–3 years
Season of harvest	• ideally harvests would be timed so that new canopy is formed at natural time of shoot formation coppice growth occurs (i.e., cut in late winter/spring)	increase next rotation length if cut out of preferred season (e.g., late summer/autumn)
Starch reserves	• no large impact on harvest regime	nil
Bud sites for new shoots initiation	• no large impact on harvest regime	nil

[10] However, Wildy *et al.* (2003) did not quantify how many years after cutting this effect would last.

Integration into farming systems

There are biophysical, environmental and economic[11] reasons underpinning the integration of mallee plantings into existing farming systems (Bell, 2005). The most common pattern of planting of mallees within existing farming systems is via a series of alleys with trees planted in 1 – 6 row belts and the area between utilised for existing agricultural production (see Figures 1 and 8 as examples). Optimal planting density, row number and inter-row spacing will require a balance of the: hydrological consideration including an understanding of the soil type and infiltration and lateral water transmission capacity; the species and expected growth from the mallee planted; the farming system rotations and practical machinery requirements; and other environmental considerations (including habitat benefits (Smith, 2009)).

Water is generally limiting in most Australian agricultural enterprises, particularly in the 'wheat-sheep' zone in southern Australia. The woody species, with deep roots, also compete for water in the soil profile and can utilise more than annual crops (White *et al.*, 2002). The increased capacity to intercept water below the annual crop root zone is important to promote survival and increase productivity and potentially enhance environmental benefits. But this increased water use enhances competition with other agricultural crops. A suitable site selection for mallee planting, especially on slopes, needs to consider the local hydrology (e.g., the capacity of sub-surface horizontal and lateral flow of water) as well as practical aspects of farm management such as the width of seeder and harvester. Early research with the nascent mallee farming systems focussed on the capacity to utilise sub-surface water for increased biomass production whilst reducing salinity impacts across local catchments by minimising water movement (Berry, 1997; Bell *et al.*, 2001; Olsen *et al.*, 2004). During this period the capacity of woody species to utilise 'extra' water in the soil profile was investigated (Barrett-Lennard, 2002; Vertessy *et al.*, 2003; Wildy *et al.*, 2003; Wildy *et al.*, 2004a; Robinson *et al.*, 2006). The water use efficiency (WUE) of coppiced mallee systems indicates the potential for 1.5 – 1.8 g biomass per L water in Western Australia (Wildy *et al.*, 2004b; Cooper *et al.*, 2005). However, linking the WUE to specific sites with confidence is problematic due to species responses to site, climate and management variation.

A general conclusion that 'trees use more water than pasture and annual crops' is widely accepted (e.g., Zhang *et al.*, (2001)). How to effectively and efficiently integrate woody crops, including mallees, into an IFES remains difficult to determine; especially at a local (e.g., paddock) scale. The competition for water is complicated and will require adaptive site-specific management to balance the hydrological competition between mallees and agricultural crops. The recent comprehensive work of Peck *et al.* (2012) estimate that on average the spatial impact of competition between mallees and annual crops was about 10 – 12 m, decreasing yields by ≈50%, with significant intra-row competition for water between the mallees. This has significant implications for the biomass production of the mallee system as well as competition across the farm and in integration with other production systems. Peck *et al.* (2012) found that competition increases with tree age as the roots develop and is greater in low rainfall years. Importantly, the harvest of the re-growing mallee coppice will decrease the competition for approximately three years. This harvest cycle has been shown by Wildy *et al.* (2003) to work well with mallee biomass production.

Nutrients are generally limited in many Australian farming systems as most soils have low nutrient hold capacity and availability and a balance of availability for production and retention on site is critical to sustain biomass energy systems (George and Cowie, 2011). Mendham *et al.* in Chapter 5 of Peck *et al.* (2012) report significant uptake and utilisation of nutrients in mallee biomass systems (Table 4).

[11] Volume 2 of this report will focus on economic considerations of integrating woody energy plantings.

Table 4. The biomass production and nutrient export from mallee harvest at 10 sites studied by Mendham *et al.* (Table 5-5 in Peck *et al.* (2012)). The numbers in parenthesis are the range in export rates.

	Harvest at 3 years age	**Harvest at 4 years age**
Biomass (t ha^{-1} y^{-1})	5.89 (1.54-11.79)	7.48 (4.07-16.39)
Macronutrients (kg ha^{-1} y^{-1})		
Nitrogen	46.7 (11.7-89.7)	50.1 (24.3-105.5)
Phosphorus	3.85 (1.33-6.88)	4.73 (2.74-8.67)
Calcium	32.2 (10.9-61.1)	46.6 (29.8-80.2)
Magnesium	5.78 (1.53-13.54)	7.58 (3.94-18.35)
Potassium	20.7 (6.6-38.5)	22.8 (13.3-45.6)
Sulphur	3.34 (0.95-6.66)	4.16 (2.36-8.43)
Micronutrients (kg ha^{-1} y^{-1})		
Boron	0.23 (0.04-0.60)	0.37 (0.12-0.94)
Copper	0.03 (0.01-0.06)	0.03 (0.02-0.07)
Iron	0.32 (0.11-0.68)	0.38 (0.19-0.75)
Manganese	0.66 (0.30-0.94)	0.97 (0.48-1.27)
Zinc	0.07 (0.02-0.11)	0.08 (0.04-0.14)

The concentration of the nutrients varied according to the biomass component (i.e., partitioned differently between the wood, bark, twig and leaf fractions). And a species effect was evident with certain nutrient uptake. For example, in *E. polybractea* Mg was higher in the bark compared to other species. Tree age affected the fractions of biomass, that is, older trees had a higher wood component compared to leaves, and this is important in the physical properties of the material for processing following harvest. Older trees will be more suited to bioenergy production. But they may be more difficult to harvest and also lead to larger losses of associated crop production due to increased competition. Importantly Mendham *et al.* (in Peck *et al.* (2012)) report that 30 – 60% of the mallee biomass is below ground with much of it present in fine roots. At harvest Wildy *et al.* (2004b) reported root senescence due to harvest leading to decomposition and increased nutrient availability. This will be important for continued biomass production.

The nutrient removal during harvest will need monitoring over time to ensure that specific deficiencies do not develop. Whilst the average removal of nutrients from the mallee sites studied by Mendham *et al.* was similar to those reported for a typical wheat crop there were sites where significant N was removed and special consideration of Ca and Mg is warranted due to their concentration in the woody fraction. For optimum management, nutrients need to be maintained and during harvest the woody fraction preferred with leaf material retained where practical. This may lead to a reduction in biorefinery products and economic losses; there is a tension between production and sustainability. Nutrient management is an ongoing issue for food and energy crops (Blanco-Canqui and Lal, 2009; George and Cowie, 2011).

If mallees are to be integrated into existing farming systems (e.g., Figure 9) then a comprehensive understanding of the biophysical capacity to grow, harvest, collect and process biomass is required. The water and nutrient impacts, especially due to planting formation and continued harvest, will influence the area required to achieve industry targets and the transport distance from producer to processor. And these imperatives need to be balanced with potential competition for site resources with other agricultural crops.

Figure 9. The integration of mallee plantings into a farming system in Western Australia. This is a six-tree wide belt – later plantings favour fewer rows with more space in between rows. Note the low habit and multi-stem nature of the mallees providing particular challenges in the design of efficient harvesting systems (image: B.H. George).

CONCLUSIONS

The woody crop IFES could develop into a large market-based industry through integrated plantings in farming systems in Australia. Over the last 20 years significant research, development and extension has occurred to understand and promote the opportunities for farmers in southern Australia. However, the industry remains fragmented.

Some Australian native species, including mallees, have been identified as providing biomass suitable for energy production. Species characteristics including drought tolerance, coppicing capacity and suitable wood properties provide the basis for the development of a commercially competitive industry with multiple markets whilst improving options for farmers in an integrated farming system (IFES). The ability to coppice can reduce the ongoing site disturbance, desirable for carbon management, whilst increasing the opportunity for production in water limiting environments.

There remain important issues that need to be resolved including:

1. Species, site selection and planting designs that account for efficient production whilst recognising competition for site resources with other crops and other environmental considerations such as hydrology and carbon dynamics.

2. Integration of woody crops, including mallees, into farming systems will require further understanding of the important physiological characteristics of the utilised species (e.g., capacity to intercept water and competition with other crops). This will impact on the required silvicultural management systems for optimum production.

3. A better understanding of the long-term nutrient balance for sustained production (and recognition of soil carbon) where continuous removal of biomass occurs with short-rotation harvests is required.

4. Planting density and spacing between rows will require a balance of the: hydrological consideration (including an understanding of the soil type and infiltration and lateral water transmission capacity); the species and expected growth; the farming system

rotations and requirements (e.g., spacing for machinery); and other environmental considerations.

The key message from Volume 1 of this report - we require a clear understanding of the species physiology and biomass characteristics that will allow for the development of management systems that maximise mallee production whilst recognising and managing the competition impacts on other crops.

Volume 2 will focus on the efficacy of the supply chain and summarise some of the recent attempts to model the important biophysical and economic parameters that will help determine site suitability and identify industry development opportunities.

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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.

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (2012) has 14 participating countries: Australia, Canada, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, USA.

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