



Integrated Tree Processing of Mallee Eucalypts

**A report for the RIRDC/Land & Water
Australia/FWPRDC
Joint Venture Agroforestry Program**

by Enecon Pty Ltd

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Foreword

In 1996 the RIRDC/ Land & Water Australia /FWPRDC Joint Venture Agroforestry Program published a resource kit titled *Commercial Farm Forestry in Australia, Development of a Strategy Framework* which identified a number of impediments to the widespread adoption of commercial farm forestry. To address some of these impediments the Joint Venture Agroforestry Program (RIRDC/ Land & Water Australia /FWPRDC) commissioned four projects designed to address key impediments. The four projects were designed to:

- strengthen links between farm forest growers and the forest industry
- identify policy reforms for farm forestry
- identify opportunities for harvesting trees on farms
- identify opportunities for processing wood products on farms.

One such opportunity identified is the planting of mallee eucalypts in the Western Australian wheatbelt. This area is suffering from degradation caused by rising saline water tables, as a result of extensive conversion of the perennial native vegetation to annual crops and pastures over the last one hundred years. The Western Australian Department of Conservation and Land Management (CALM) identified that new perennial crops such mallee eucalypts would help to mitigate this, but recognised that planting on the scale necessary could be achieved only if wheat growers had sufficient financial resources and incentive to plant. CALM initiated extensive planting in 1994. The Oil Mallee Association (OMA) formed in 1995 to represent growers' interests in development of an industry, initially focused on eucalyptus oil as a possible commercial product. In 1997 OMA sponsored the formation of the Oil Mallee Company (OMC), to undertake the harvest, processing and marketing aspects of the proposed industry. To streamline industry development OMC has recently absorbed the OMA responsibilities in managing the logistics of planting. OMA retains a role in promotion and publicity.

Enecon identified that the CSIRO process for converting wood to activated carbon, with co-production of electricity, was complementary to the proposed eucalyptus oil industry, and had the potential to make mallees into a commercial crop for farmers. Western Power Corporation was approached as a potential buyer of the electricity.

This report investigates the feasibility of building a commercial-scale mallee processing plant in Western Australia. The report follows preliminary engineering, cost estimating, testing of carbon made from mallees, and assessment of the likely returns to growers. On the basis of investigations to date, it is expected that satisfactory returns can be achieved, both to growers for tree planting, and to potential factory investors.

RIRDC's involvement in this project and in the Joint Venture Agroforestry Program, is part of the Corporation's Agroforestry and Farm Trees R&D Program which aims to foster integration of sustainable and productive agroforestry within Australian farming systems.

This report, a new addition to RIRDC's diverse range of over 700 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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- downloads at www.rirdc.gov.au/reports/Index.htm
- purchases at www.rirdc.gov.au/eshop

Peter Core

Managing Director

Rural Industries Research and Development Corporation

Postscript to Study Report

Following successful completion of this JVAP/Western Power funded study in 2000, funding has been finalised for a small, full scale plant to demonstrate the ITP concept. Based on a throughput of 20,000 tonne/year of green, whole tree feed, this plant is to be built near the town of Narrogin and is expected to commence operating trials mid 2002. The plant is funded by Western Power Corporation, with support from the Australian Greenhouse Office and Ausindustry. The Oil Mallee Company and Enecon will be involved in the provision of feed material and engineering/operation respectively.

Acknowledgments

This report has been prepared by Enecon Pty Ltd as part of a study administered by the Oil Mallee Company. Study funds were provided by the Joint Venture Agroforestry Program through the Rural Industries R&D Corporation, and Western Power Corporation. The authors gratefully acknowledge the valuable support provided by these organisations.

The Integrated Tree Processing project includes contributions from the following organisations:

Western Power Corporation (WPC)

Department of Conservation and Land Management (Western Australia) (CALM)

Oil Mallee Company (OMC)

Oil Mallee Association (OMA)

Enecon Pty Ltd

CSIRO - Forestry & Forest Products

Author's Disclaimer

This report has been prepared to assist with the appraisal of opportunities for integrated processing of mallee eucalypts. While care has been taken in its preparation, no responsibility will be taken by the authors for omissions or inaccuracies, or for the use of this information by any other party. It is recommended that any interested party undertake its own investigations on which commercial decisions may be based.

Abbreviations

abs	absolute
AC	Activated carbon
ATO	Australian Taxation Office
BOD	Biological oxygen demand
CALM	Western Australian Department of Conservation and Land Management
CAWP	CSIRO activated wood pellets
CRC	Co-operative research centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CW	Cooling water
EIS	Environmental impact statement
EPC	Engineering, Procurement and Construction
EW	Eastern Wheatbelt (region of WA)
GAC	Granular activated carbon
GST	Goods and services tax
hazan	Hazard analysis
hazop	Hazard and operability study
HTHO	High-temperature hot oil
HV	High voltage
ITP	Integrated tree processing
JIT	Just in time
LP	Low pressure
MC	Moisture content
MCC	Motor control centre
ODP	Ozone depletion potential
OMA	Oil Mallee Association
OMC	Oil Mallee Company
PAC	Powdered activated carbon
PV	Photovoltaic
QC	Quality control
QRA	Quantitative risk assessment
RO	Reverse osmosis
S	Southern (region of WA)
STC	Steam-turbine condenser
UGS	Upper Great Southern (region of WA)
WBP	World's best practice
WPC	Western Power Corporation
WSAC	Wet-surface air-cooled (condenser)

Executive Summary

This study has analysed the economic potential for an integrated tree processing plant in Western Australia, taking coppiced, chipped mallee biomass as feed and producing activated carbon, renewable energy and eucalyptus oil as products. Work has been undertaken by a study team comprising personnel from Department of Conservation & Land Management; Oil Mallee Company; Enecon Pty Ltd; CSIRO Forestry & Forest Products; and Western Power Corporation.

The overall finding of the team is that the proposed ITP plant is financially viable, offering commercial returns to plant investors while based on adequate prices to justify planting, harvesting and transporting mallee trees. The work of each group may be summarised as follows:

Work by CALM has focused on quantifying costs and yields for mallees planted to support a full-scale ITP plant. Chipped mallee biomass can be delivered to the factory gate for \$28 - \$40 per green tonne¹. This cost includes an opportunity cost to the farmers for the land planted to mallees and also harvest and transport costs. It thus reflects what is considered to be a sufficient commercial incentive to the farmers to stimulate large scale planting needed to support Integrated Tree Processing (ITP) plants. Pricing does not include revenue from land care benefits or from carbon sequestration.

CSIRO has made granular and pelletised activated carbon from mallee wood. Results from testing by CSIRO, other laboratories, and major international dealers/buyers are very positive for use of these activated carbons in water treatment and gold recovery. Granular and pelletised carbons made from mallee have been found to perform as well as or better than high-quality commercial carbons. The results indicate that mallee carbons could be sold for \$3000/tonne or more at the factory gate.

The yield of activated carbon per tonne of mallee tree varies according to the carbon products made (granules or pellets). For the mix of products investigated in this study a yield of one tonne of activated carbon per 24 tonnes of fresh mallee tree was assumed, based on CSIRO test work and leaf, twig wood fractions identified by CALM. Given that the carbon is made only from the wood fraction, the yield may also be stated as one tonne of carbon products per 10 tonnes of wood.

Work by Enecon has focused on developing the plant design in sufficient detail for capital and operating cost estimates to be completed.

For the purpose of the study a full-scale plant has been sized at 100,000 tonne per year of chipped mallee biomass. The capital cost for this plant has been estimated at A\$28.4 million, based on several assumptions on mix of carbon products, site and civil costs and feed storage.

Financial analysis has been carried out based on the above capital cost and carbon selling prices. The calculated internal rate of return (IRR) is 18.8% after tax. Sensitivities to changes in a range of variables have been calculated (typically +/- 10 to 20%) and IRR varies between 8.2 and 25.7%. However, much greater IRRs can be obtained if the project is not 100% equity financed. The table below summarises the financial analyses undertaken.

Key plant parameters	
Feed consumed	100,000 t/y
Feed composition	40% wood, 25% bark and twig, 35% leaf, with 50% (including all the wood) going to the activated carbon plant, 50% to the oil extraction plant (including all the leaf).
Capital cost $\pm 15\%$	\$28.4 million for a plant based on a steam turbine with an air-cooled condenser
Key plant parameters (cont.)	

¹ \$30/t has been used for financial analysis

Annual opex (includes feed purchase and interest payments)	\$7.9 million
Annual revenues	\$17.3 million
Feed cost, delivered to factory gate	\$30/t
Activated carbon products	GAC 2,720 t/y @ \$3000/t ex works CAWP 1,090 t/y @ \$3000/t ex works PAC 294 t/y @ \$1000/t ex works
Eucalyptus oil produced	1,050 t/y @ \$3000/t ex works
Electricity produced for export	5 MWe “green” electricity at \$60/MWh, 8000 h/y
IRR (15 years)	18.8%
NPV (12.5% discount rate for 15 years)	\$7.8 million
Debt to equity ratio	0 / 100%

Key sensitivities	
IRR is very sensitive to:	Debt to equity ratio Exchange rate Plant availability Granular activated carbon price Proportion of wood in feed Capex Opex Assumed escalation scenarios for costs and revenues
IRR is moderately sensitive to:	CAWP price Feed cost Eucalyptus oil price Electricity price
IRR is not very sensitive to:	Depreciation rate Company tax rate “Ralph report” recommendations PAC price Interest rate on borrowings

There are several areas of the study still under discussion. They include:

a) Seasonal availability of mallee feed. Long term storage of wood carries considerable capital and operating costs. Long term storage of leaves is not considered feasible This has cost implications if the leaf processing plant is to be oversized to effectively process 12 months supply of leaves in 9 months or less and would probably reduce return on investment for the oil section of the plant. OMC is investigating options to achieve all weather access for harvest and transport. b) The cost of the site could have a major impact on capital cost, depending on whether a rural site may be rezoned or an industrial site must be purchased. Civil works for water, sewerage and drainage management on the site can also potentially cost more than \$1 million.

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1. Introduction

1.1 Background

The large scale planting of oil mallee eucalypt trees in Western Australia is being promoted actively by the WA Department of Conservation and Land Management (CALM) as a key strategy in the reduction of major salinity problems in Western Australia's dryland agricultural area. Some 10% of WA's 18 million ha of agricultural land is already showing salt damage. The State Salinity Action Plan (1996) predicts that salt damage will increase to over 30% in the next few decades if nothing is done. Tree planting in parallel with annual cropping provides an excellent method of managing the water table and thereby the salt problem. After some years of testing, CALM has selected high leaf-oil yielding mallee eucalypts (oil mallee) as the most prospective "tree crop" for the low-rainfall (less than 500 mm annual rainfall) wheatbelt portion of the agricultural area. The wheatbelt comprises some 75% of the agricultural land in WA. Planting of oil mallee commenced in 1994. By winter 2000 more than 17 million mallees have been planted by several hundred participating farmers. The farmers have formed a 'representative growers' association (Oil Mallee Association) and an independent company (The Oil Mallee Company - OMC) to further their interests.

An important reason for the selection of mallee was its commercial potential. Mallee produces eucalyptus oil that initially has markets in the fragrances and pharmaceuticals industries. In the longer term it is hoped that economies of scale in production will allow the oil to be produced at less than half traditional costs and to penetrate low-priced but large-volume industrial solvent markets. The oil has excellent solvent properties and can be marketed as a natural alternative to the recently banned halogenated hydrocarbon solvents, such as trichloroethane, that damage the ozone layer.

Independently of the work by CALM, CSIRO Forestry and Forest Products has for some years been developing processes for energy recovery and the manufacture of charcoal and activated carbon products from wood. These processes have been developed initially at the laboratory scale and more recently at a pilot plant constructed by CSIRO in Victoria. Preliminary product trials of activated carbon produced have shown it to perform very well when compared with commercial carbons.

The CSIRO technology was licensed to Enecon Pty Ltd in 1998. Discussions with CALM commenced in 1998 and have lead to an understanding of the particular benefits of utilising the CSIRO technology with the mallee industry. These benefits are described in more detail below

1.2 Integrated Tree Processing

Production of eucalyptus oil alone utilises only the leaves of the mallee trees. To make better utilisation of the whole tree an Integrated Tree Processing (ITP) plant has been proposed by Enecon. Such plants would be located in each mallee growing area and would operate as follows:

- a) Mallee trees are mechanically harvested on a short-rotation (2-4 years) coppice system, and the entire chipped biomass is transported to the processing plant.
- b) The wood and the leaves are separated.
- c) The leaves are crushed and the oil is extracted via distillation (using steam from the wood processing).
- d) The wood is carbonised to charcoal. The combustion of volatiles in the wood during this stage releases much of the energy in the wood as heat, which may in turn be used to raise steam.
- e) The charcoal may be sold, or processed further and then activated with steam to produce activated carbon. During the activation step most of the energy remaining in the wood is released as water gas, which may be used for heat, steam or as a fuel for a gas engine or turbine.

2. Feed Supply

2.1 *The biomass resource*

This section considers the characteristics of a developed mallee biomass resource supplying a full-scale plant with 100,000 tonnes per year (fresh weight) of biomass.

Mallees will be considered harvestable when the average weight per plant exceeds 15 kg fresh weight. At this size, preliminary surveys indicate that the proportion of wood reaches approximately 40% of the total biomass. It has been assumed that all of the wood and approximately half of the bark and twig will be fed to the activated carbon plant, so that approximately 50% of the total feed is available for conversion to activated carbon. Smaller mallees have a lower proportion of wood and a higher proportion of leaf.

Mallees are grown in rows with an intra-row spacing of 1.5 metres. Rows are most commonly in pairs, known as hedges, with an inter-row spacing of 2 metres. Belts of mallees are commonly established with one, two or three hedges to the belt, with 30 m to more than 100 m between belts. The open land between belts is cropped and grazed according to conventional agricultural practice. Where site conditions are suitable, for example on moisture gaining sites, hedges may be planted at close spacings of about 10 m to form a block planting, with only grazing available in the spaces between belts. The compact hedge configuration is intended to concentrate mallee biomass production into narrow belts for efficient continuous 'row crop' harvest. This also leaves as much land as possible for conventional agriculture between the belts, while achieving relatively high perennial leaf areas over the whole paddock. A well-grown hedge typically displaces pasture and cropping from a 5 metre wide strip of land, so 2 km of hedge is considered to occupy 1 hectare of land. Harvesting involves cutting a single row at a time and is discussed in more detail below.

At 15 kg per mallee and 95% survival to harvesting, 1 km of hedge (1260 mallees) will yield 19 tonnes of biomass, which equates to 38 tonnes per hectare. An annual plant requirement of 100,000 tonnes of biomass will require mallees from about 5300 km of hedge which will occupy about 2650 hectares. However, mallees will be harvested on a 2, 3 or 4 year cycle. Assuming a three-year harvest interval, a 100,000 tonne plant could be supplied from 20 million mallees in 16,000 km of hedge, occupying 8,000 ha and growing on 1% of the land within 50 km of the plant.

To place an ITP plant in perspective in relation to the problems of salinity and land degradation, it is widely recognised that more than 20% of cleared agricultural land will have to be planted back to perennial woody plants. If 90% of the land around an ITP plant is cleared and 20% of that was to be planted to mallees, a 100,000 tonne plant could be supplied all its biomass from an 11 km radius, an area equivalent to less than 20 average wheatbelt farms.

State-wide, approximately 17 million mallees have been planted to winter 2000. Even in the absence of an established market, the level of farmer support for the mallee project is continuing to grow. It is anticipated that the establishment of a 20,000 tonne demonstration-scale plant will consume most of the established mallees within about 400 km of the plant over the first few years of operation. As the plant is expanded over a five year period to 100,000 tonne capacity, its presence must stimulate increased planting closer to the plant, which will provide the long-term biomass resource. The more concentrated plantings will improve the efficiency of harvest and transport, and so improve the returns to the growers.

2.2 *Security of supply*

Plantings up to 1996 are secured by Profit a Prendre that ensures that CALM, or some other suitable body (OMC), has the right to harvest. After 1996, a contract between the Oil Mallee Association (OMA) and the farmers has been signed to ensure that farmers understand their obligation to supply the mallee biomass for processing. When the ITP proponents have determined a price for the biomass, OMA and OMC will be able to set up forward selling contracts to secure the supply in advance.

2.3 Seasonal factors and other influences upon biomass supply

Year-round continuity of biomass supply to the plant is an important requirement. Apart from the cost of storage, maximising the period of utilisation of the plant has a major influence upon economic performance, so the strategies and costs presented in this report are based upon biomass supply to the plant for 12 months of the year. However there are a number of seasonal and other factors that will influence biomass supply and a harvesting strategy to minimise interruptions to supply must be developed.

2.3.1 Soil conditions

Wet soil conditions will be the principal influence due to the potential for bogging of harvesting machinery and cutting up of paddocks and creek crossings. The Mediterranean climate delivers rainfall in excess of evaporation across the wheatbelt in winter and this typically causes some soil types to become unstable for weeks or months. Strategies to cope with infrequent high-rainfall events such as summer and autumn tropical depressions and cyclones will also need to be developed.

Strategies to ensure continuous supply fall into several categories:

- Reducing machinery ground pressure using tracks and bogey axle systems will be an important part of machinery development for mallee harvesting and there are many precedents in agricultural and forestry machinery to follow. Achieving maximum flotation for the harvester working along the rows of mallees with their underlying root systems will be important, but more challenging will be the flotation of the chaser bins used to haul chipped biomass from the mallee rows out to the road transport. These bins will have to travel relatively fast and frequently over distances of up to several kilometres across cleared paddocks. Key points in the landscape such as creek crossings and water logged concave lower slopes will present potential problems.
- Low cost civil engineering solutions will become feasible where large quantities of mallee biomass will be hauled for many harvest rotations across specific problem areas such as creek crossings. The use of tyre matting and geotextiles to support soft soils will be required in some instances and will become economically justifiable when farmers are receiving a regular return from supplying biomass to full-scale ITP factories.
- Scheduling harvesting to take advantage of mallee stands on well-drained country with secure access to roads for a winter resource will be a very important technique for ensuring continuity of supply. In the short-term, supplying biomass to the demonstration ITP plant in winter will incur extra costs because the harvesting operation will have to travel through some mallee growing districts twice a year, harvesting some stands in dry soil conditions and leaving others nearby for a winter harvest. This is effectively an increase in the dispersal of the resource. When the industry is supplying full-scale ITP factories, the concentrations of mallee stands will increase, travel between mallee stands will decrease, and passing twice through a district in a year will not represent such a significant cost.
- The net returns to the farmers appear likely to be high enough to justify some large high-density plantings on well-drained sites near bitumen roads. The planting program necessary to be able to meet full ITP demand can specifically target all weather locations. These mallee stands would provide a concentrated resource to keep the ITP plant operating during the depths of winter and in the aftermath of extreme weather events. A 30 day supply for a 100,000 tonne per year plant would occupy about 900 hectares if mallees were in 4 row belts spaced at 40 metre intervals. Cropping and grazing would still be practical between the belts. On a three year harvest rotation, three of these reserves would occupy only 0.3% of the land within 50 km of a plant.
- While developing strategies for supplying the demonstration ITP plant, the concept has emerged of averaging the costs of transport and harvesting over the entire year's biomass supply. Under such an arrangement, all farmers would receive the same price per tonne at the factory gate, with the option of bonuses for high-quality feedstock and penalties for rough harvesting conditions. The farmers would be acting cooperatively, in the interests of a reliable market, to share the burdens of dispersed harvesting operations and long-distance transport. Examples of similar "crop pools" for

marketing and materials handling systems already exist in Australian agriculture, particularly in grain industries.

- This strategy could be applied to the provision of long-term continuous supply to ITP factories. For example, if soil conditions in southern regions deteriorated severely during an unusually wet winter, biomass could be hauled from northern regions where seasonal and soil conditions were suitable for winter harvesting. Similarly, autumn cyclonic rain in the northern and eastern regions would see biomass hauled from southern regions unaffected by the extreme weather.
- Allowance could be made, in the factory gate price, for a proportion of the annual biomass requirement to be supplied from remote sources. If over a year some of the budgeted allowance for these remote feedstocks was not used, the surplus funds could be distributed to farmers in the form of a small second payment.

2.3.2 Road conditions

In a similar way to soil conditions in the paddocks, there will be times in every district during winter when gravel road conditions will deteriorate. The condition of some roads during the crop seeding period in early winter demonstrates that some of the public road system does not provide all weather access for heavy transport.

Harvest scheduling will have to employ some of the strategies presented in 3.3.1 to cope with road access problems and use of alternative, longer, haul routes may be an option in many cases. In addition, ITP factories may need to hold an additional few day's biomass in storage during winter to allow for sudden deterioration in road conditions that can occur after a few hours of heavy rain. Moving the harvesting operation around in response to such short-term problems may not be cost effective.

2.3.3 Mallee dormancy

Mallee dormancy in late autumn and winter is a potential problem on a proportion of sites. Harvesting at these times is likely to be followed by a very slow regeneration response until the following spring and the stumps are vulnerable to weed competition and waterlogging during this dormant phase.

Harvest scheduling must avoid winter or autumn harvesting on sites at risk of seasonal waterlogging where the cut stumps may be immersed for even short periods.

Sites where mallees are young and heavy weed burdens are expected will need to be treated with residual herbicides at the first rains if they have been harvested in autumn and coppice regeneration is very slow due to drought stress. Winter harvesting may need to be followed up with knock-down herbicide, after the tops of the stumps have dried out, to prevent weed growth smothering the early coppice growth in late winter. A bonus payment could be considered for biomass harvested in winter to compensate for the extra management required by the farmers.

2.3.4 Shallow soils

On shallow soils, harvesting in autumn may cause significant mallee death from the combined impacts of harvesting and drought stress. Shallow soils may be the result of impeding rock layers or shallow saline water tables and are a problem for a small proportion of mallee sites, particularly in the earlier mallee plantings. They are typically less productive sites, which combined with the small proportion in number, makes their contribution to the total resource relatively small.

These sites should be harvested in spring to maximise coppice regeneration before dry soil conditions develop.

2.3.5 Vehicle movement bans

In summer during periods of high temperatures and strong winds, vehicle movement in paddocks may

be banned for part of the day due to the risk of fire. Bans may be applied from early to mid morning to the late afternoon or evening and will typically interrupt harvesting on about 10 to 20 days during a summer. Harvesting can continue at night, but the flow of biomass will be reduced if harvesting is already operating for 16 – 24 hours a day. A week's additional storage of biomass at the plant should be adequate to cover the risk of reduced supply in summer if harvesting is in progress more than 16 hours a day.

Due to the high cost of seasonal processing at the plant, the complexities of all-year harvesting must be dealt with. Year round harvesting will make better use of machinery capital, but it will also effectively increase resource dispersal by making the harvest operation pass over many districts twice a year for the same total biomass yield. In the start-up phase of the industry, dispersal will be a serious burden upon the cost of harvest and transport and adding to that problem will further reduce farmer returns. However as the industry develops and substantial plantings of mallees become established relatively close to one another, the costs of dispersal will diminish.

2.3.6 Fire, pests and disease

The mallees that will be used are mostly local or regional native species. They are well adapted to the wheatbelt environment, and experience since first large scale planting in 1994 indicates that they are will make the transition to the agricultural environment without difficulty.

Fire is a concern mainly during the late spring and early summer when there is an abundance of dry pasture and crops in the paddocks. During this period farmers are constantly on high alert and have well established fire protection and fire-fighting arrangements. Also the landscape is generally very flat and has less than 10% native bush. Damaging fires are rare and usually only run for the peak of the afternoon. Mallee crops will be widely dispersed and the amount lost in any fire event will be a small proportion of the resource supply. Fire is unlikely to destroy the stem wood and this could be readily harvested post-fire. The mallee habit is an adaptation to fire and crops will readily coppice after being burnt.

The only pest likely to cause extensive damage to established mallee crops is the locust. This insect occurs in plague numbers every decade or so and can be so damaging to crops and pastures that it is the object of major regional spaying programs. While mallee might be grazed by locusts it is only vulnerable to significant damage when young or newly coppicing. At such times it would be included in local control operations.

No serious pathogens have yet been observed. Oil mallee species occur in extensive natural stands comparable to the proportion of landscape cover that is envisaged in cultivated stands. Also cultivated stands will commonly consist of three or four species and this diversity could be increased if disease became a factor. Hence the risk of disease in farmland monocultures is not expected to be large.

2.4 Harvesting and transport

2.4.1 Introduction

Elsewhere in agriculture or forestry, there are few comparable crops in terms of harvesting strategies and product values. The greatest similarity is found in the sugar industry where the chopped cane has a similar value per tonne and similar ex-harvester product density and handling characteristics. The harvesting and transport system design described below is an adaptation of the cane harvesting and transport system recently developed for the Ord River sugar industry. Cane is typically harvested and loaded onto trucks for about \$5.50 per tonne and transport over a typical 15 km haul distance is \$2.50 per tonne.

A significant difference between sugar cane and mallee crops is the concentration of the resource. Cane is grown on small farms and each cane paddock is in close proximity to the preceding and following paddocks. Cane crops can yield up to 200 tonnes per hectare and harvester production can exceed 100 tonnes per hour and average 60 tonnes per hour over a whole season. Mallees are a much more dispersed crop than sugar cane and yields will be about 35 to 40 tonnes per hectare, so mallee harvesting will not be as cost effective as cane harvesting for the foreseeable future.

Harvesting will be a highly mobile contract operation with great reliance upon good communication and coordination, high-quality maps based on a geographical information system and accurate global positioning system navigation. For perhaps the next decade, a typical mallee site will produce 150 to 500 tonnes of biomass and take a few hours to two days to harvest. Mallee sites will be between a few hundred metres and 20 km apart. Even in the long term, rapid movement from site to site will be essential for overall efficiency.

Farmers will not own their own harvester in the foreseeable future because:

- The capital required will be very high, probably in well in excess of \$500,000 until they are mass produced.
- A harvester built on the scale proposed will supply a 100,000 tonne capacity ITP plant by itself and typically harvest all the mallees on one farm in a matter of hours.

The harvesting operation will initially be established by the OMC, but it will presumably be sold to a contractor at the earliest opportunity so that as the industry develops additional contractors will enter the industry and provide competitive pricing for the harvest operation.

2.4.2 Harvesting and transport operation and equipment

The harvesting operation will involve a self-propelled harvester supported by a chaser bin which will haul harvested biomass from the paddock to the road transport trucks. Truck trailers in road train configurations will be left as close as possible to the harvest site and will be filled by tipping the chaser's bin over the side of the trailer bins. One prime mover will work a number of trailer units in rotation so that empty trailers are always waiting to be filled and the harvester and chaser can work continuously.

A pre-commercial prototype mallee harvester is currently under development because no suitable "off the shelf" machine could be found for this crop. Detailed reports of this development are available. The mallees are chipped by the harvester to produce a material suitable to be handled in large containers and transferred efficiently by throwing with air, conveyors or bulk tipping.

The self-propelled harvester has been designed to travel at about 3 to 5 km/h, depending upon mallee size, straddling and harvesting a single row. The harvester will have a 7.5 tonne capacity bin which will accumulate the chipped mallee biomass and the chaser bin will be the same size. Both bins will have a high side-tipping action for emptying, so that the harvester can empty into the chaser or the truck and the chaser can also empty into the truck. The chasers and high side-tipping bins are routinely employed in the sugar cane industry and present no technical difficulty in adaptation to mallee.

The truck trailers will be worked in pairs, with three 7.5 tonne capacity bins per trailer, giving a payload of 45 tonnes per load. Emptying will be by side-tipping action using an overhead crane at the ITP plant to tip the bins into a receival pit.

A balanced operation will involve:

- One harvester cutting 300 tonnes per day to meet the annual requirements of a 100,000 tonne ITP plant.
- Cutting rate will be 35 to 40 tonnes per productive machine hour.
- Allowing one third of its time for maintenance and relocating from site to site, the harvester will supply one plant with an average 75 to 80 hour week.
- One chaser travelling at 20 km/h transferring chipped biomass up to 2 km from the harvester to the truck.
- Three road trailer units of two trailers each.
- One prime mover hauling 50 km to the plant.

This simple harvest and transport system is only a demonstration of how balance could be achieved. There is excess capacity in the harvester, but the system described is focussed upon supplying only one ITP plant. Though not directly relevant to this feasibility study, the development of harvesting systems will inevitably be influenced by the full range of opportunity the biomass industry presents, not just that likely to flow from the initial ITP plant. For example, increasing the local region's biomass production capacity to meet the full demand of the first ITP plant at the earliest date requires plantings that will subsequently take production beyond that plant's demand. This surplus production will form the supply base for further processing developments that will see harvesters fully utilised.

3. Process Plant Overview

This section describes the components of a full-scale ITP plant.

The plant comprises the following sections:

- Feed receiving and storage
- Eucalyptus oil extraction
- Leaf combustion
- Charcoal making
- Granular Activated Carbon (GAC) and CSIRO Activated Wood Pellets (CAWP) making
- Utilities.

The plant's nominal capacity is:

- 100 000 t/y of feed (35% leaf, 15% twig and bark, 50% wood (includes some twig and bark), 40% MC wet basis)
- 7240 t/y charcoal as an intermediate
- 4100 t/y of activated carbon, based on 2720 t as granular activated carbon, 1090 t as pellets, with the balance as powder.
- 1050 t/y eucalyptus oil
- 5 MW electricity

3.1 *Feed receiving and storage*

Chipped material is delivered in side tipping trailers of about 60 m³ capacity, which are tipped into a sunken receiving bin. The material is conveyed either to the plant, or to storage. Short-term storage facilities are provided for up to 2,000 t of feed in unsegregated form, under cover, on a concrete pad, so as to reduce the effect of minor fluctuations in feed supply on the plant, and vice versa.

It may be necessary to separate the wood and leaf fractions prior to storage, as the presence of leaf may accelerate deterioration of the wood. This has not been costed into the project at this stage, but the cost would be significant.

Material entering the plant is winnowed into leaf and wood fractions. It is assumed that approximately 50% of the feed will end up in the wood fraction. This will include all the wood, and approximately half the bark and twigs. The remainder of the bark and twigs will remain with the leaf fraction.

3.2 *Eucalyptus oil extraction*

Leaves are mixed with recycled hot water and fed to the extraction vessel. Live steam is used to bring the leaf/water mixture to 100°C. Vapour from the extraction vessel is condensed and the condensate separated in a gravity decanter into water and oil fractions. The crude oil fraction is stored in a tank and exported by road tanker. Leaves are separated from the water in a vibrating screen and sent to the leaf combustor.

3.3 *Leaf combustion*

Leaves from the oil extraction plant (including twig fraction) are burned in a combustor or gasifier. The technology to be used is not critical to the success of the project, but budget pricing from various manufacturers indicates that gasification followed by combustion of the gases is the most cost-effective route. The hot combustion gases are fed to a waste heat boiler where superheated steam is produced.

Technical factors affecting selection of the leaf combustion process will include:

- Deterioration of the refractories caused by salts in the feed, which may contribute to lower than expected slagging temperatures.
- Completeness of combustion, affecting emissions of particulates, carbon monoxide and NO_x.
- The temperature and composition of the gas leaving the combustor, and any consequent handling problems.

3.4 Charcoal making

The wood from the winnowing step is sent to a CSIRO charcoal plant. The process produces charcoal in a fluidised bed, with a particle size similar to the feed. Heat of combustion is recovered by boiler tubes in the bed, which produce superheated steam, and by using the hot combustion gases to preheat boiler feedwater.

3.5 Manufacture of Granular and Pelletised Activated Carbon

Granular (GAC) and pelletised (CAWP) carbons require different processing steps and are targeted at different markets. The plant is not designed for full nameplate capacity production of pellets, and the quantity of pellets produced will depend on market penetration. If sales success permits, pellet production could be expanded. Room has been left in the plant for the necessary equipment, but the cost of this equipment is not included in the estimate.

The details of the activated carbon manufacture are confidential to CSIRO. They may be summarised as:

The charcoal is milled in an adjustable mill. Granular activated carbon requires a coarser particle size, with minimisation of fines. CSIRO activated wood pellets (CAWP) requires a fairly fine maximum size, with minimal restriction on fines. Milled charcoal for granular activated carbon is fed in batches directly to a fluidised bed where it is activated with steam. The heat needed for activation is supplied by burning both the water gas produced during activation, and the leaf gasification gas. The heat leaving with the combustion gases is used to preheat boiler feed water.

Granular activated carbon from the fluidised bed is cooled and packed in bulk bags for sale to customers.

Milled charcoal for pellets is mixed with a binder and extruded into pellets. The pellets are calcined and then activated and packaged in the same way as granular activated carbon.

3.6 Utilities

The plant is a net exporter of electricity. Steam is produced from heat or combustible gases produced in the charcoal, activated carbon and leaf combustion plants, and is fed to a steam turbine at 450°C and 45 bar abs. In most sites for these plants there will be a shortage of low-price water for the operation of a water-cooled condenser. Therefore the turbine is assumed to have an air-cooled condenser, enabling a condenser pressure of 0.2 bar abs to be maintained for much of the year. On warm and hot days (> 20°C), the condenser pressure will rise, with a consequent reduction in output. Approximately 10% of the electricity generated is used internally, leaving 5 MW for export at design conditions, and 4.4MW with an ambient of 40°C. The number of hot days will vary from site to site. For example:

Table 1: Ambient temperatures at possible sites

Site	Operating hours per year when ambient temperature is ²	
	above 20°C	above 30°C
Esperance	1800	minimal
Merredin	2900	540
Narrogin	2100	100
Wongan Hills	3000	700

The plant does require some cooling water, primarily for cooling hot charcoal and activated carbon. A small cooling tower is included on the estimated cost.

The boiler requires demineralised water, which is supplied by a reverse osmosis unit. Conventional deionisation is also acceptable on technical grounds. Recirculated condensate may require treatment in a polishing plant.

Some form of auxiliary fuel is required for start up and to recover from major process upsets. Due the likely absence of mains gas, diesel has been chosen to meet this need. LPG is an alternative.

Compressed air is needed for operating pneumatic valves. An air compressor and receiver are included for this purpose.

² Inferred data from Bureau of Meteorology records.

4. Process Technologies

4.1 Activated Carbon

Technology for converting wood to charcoal and from there to activated carbon has been scaled-up by Enecon from CSIRO pilot plant data. While CSIRO has operated a continuous pilot plant for charcoal-making at wood feed rates of up to 250 kg/h, the proposed ITP plant would require a wood feed rate of 6.25 t/h. A demonstration-scale plant (one-fifth of the nominated ITP capacity) is planned for construction prior to construction of the ITP plant, so that the technology can be brought up gradually to full scale, at lower risk.

The charcoal process uses temperatures of up to 500°C and operates at atmospheric pressure. The activated carbon processes utilise temperatures up to 900°C, and again operate at atmospheric pressure.

The process conditions and preliminary mass and energy balances for mallee feedstocks have been developed by CSIRO, based on pilot plant-scale manufacture of charcoal and activated carbon from *Eucalyptus loxophleba lissophloia* (mallee).

4.2 Eucalyptus Oil

Technology for extracting eucalyptus oil from mallee leaves has been developed by the Oil Mallee Company, using pilot-scale facilities at Curtin University. It is planned to reuse this pilot facility in the proposed demonstration plant and develop considerably more information on its efficient operation.

4.3 Renewable Energy

Electricity is made by a conventional steam cycle process. The main components are:

- A deaerator for ensuring that the boiler feedwater is free of oxygen. Oxygen would cause corrosion problems within the steam system, and undesirable reactions in the steam activation process for activated carbon manufacture.
Pumps to bring the boiler feed water to the required pressure.
- Heating equipment to boil and superheat the steam. Steam conditions have been selected as 45 bar abs and 450°C, which is a commonly-used combination. It allows the use of ANSI 600 flanges. Lower pressures and temperatures (say, 30 bar abs, and 300°C) result in a reduction in electrical output of approximately 10% for the same energy input.
A condensing steam turbine to generate electricity. A condensing temperature of 60°C has been selected, on the basis that air temperatures of 20°C should be achievable for much of the year. Water cooling is not seen as a viable option, due to the large volumes of water that would be needed and the cost of such water in the dry areas of the wheatbelt - see discussion in section 10.3.1.

Heat is obtained from:

- | | | |
|-------------------|---------------|-------|
| • Charcoal plant | Fluidised bed | 500°C |
| | Flue gas | 500°C |
| • AC plant | Flue gas | 800°C |
| • Leaf combustion | Flue gas | 990°C |

These heat sources are used to:

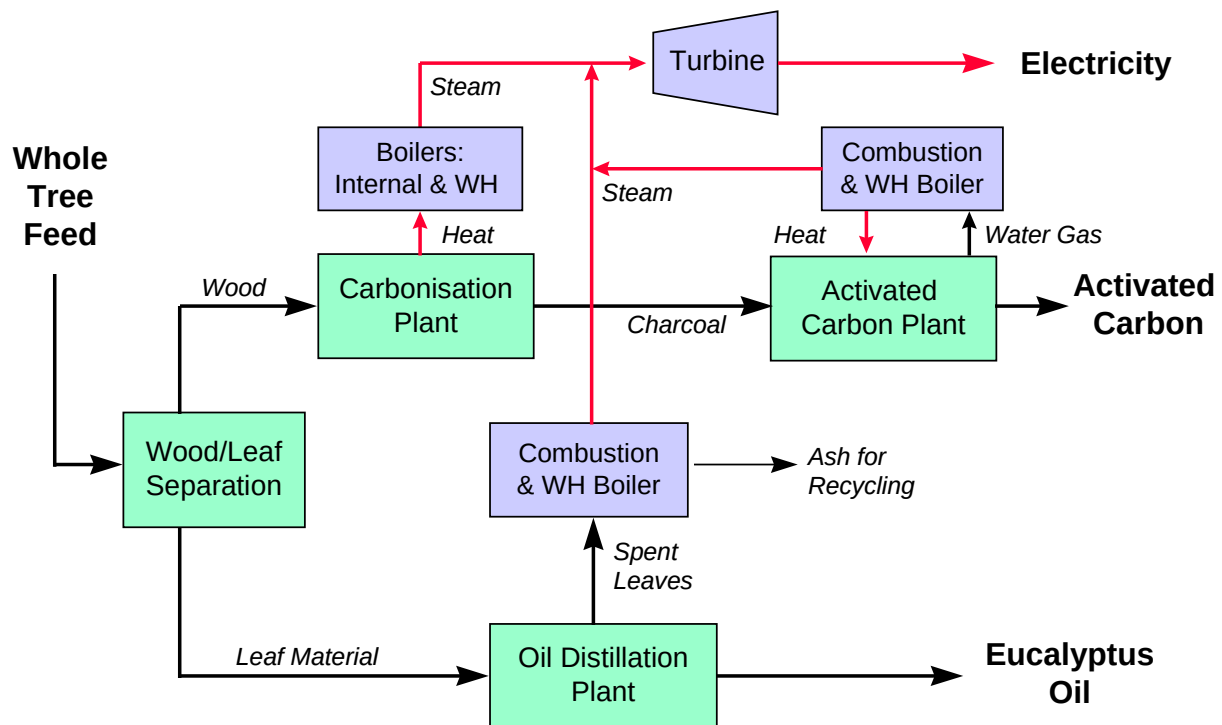
- Heat steam turbine condensate and make-up from condensing temperature (60°C) to deaerator temperature (105°C).
- Heat boiler feed water from deaerator temperature to boiling temperature (257°C).
- Boil boiler feed water
- Superheat the resultant steam (450°C).

It is expected that the electricity produced will be saleable as “green power”, on the basis that:

- The fuel is supplied from plantation timber, which is being managed in a sustainable way.
- The plant does not require import of energy, other than for start-up. At start-up the plant will need:
 - electricity to power the plant to enable motors to run to feed fuel into the plant, for lighting and for the control system.
 - diesel to preheat the charcoal fluidised bed, and to combust unburnt volatiles from the fluidised bed. Once normal operating temperature is reached, all volatiles will be burnt in or above the bed.
 - It is possible that some additional imported fuel may be needed in the AC plant to bring the fluidised beds up to temperature. This depends on developing a continuous process for making activated carbon in the demonstration plant. If a batch process is required, it should be possible to use some of the gas produced in the leaf gasifier to supply this need. If diesel must be used, the additional heat input would result in additional steam production, and so in additional (non-green) electricity.

Plant Schematic

A schematic for the processing plant is presented below:



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5. Site selection

A basic plant requires approximately 3 hectares of land, excluding any area required for long-term feed storage. If 25,000 t of storage were required, approximately 3 additional hectares would be required, enabling either 3 months' storage of wood and leaf, or 6 months' storage of wood alone. Short-term storage of feed is included in the basic 3 ha, and would enable the plant to cope with interruptions to feed supply caused by:

- total fire bans
- weekends and public holidays
- bad weather
- night
- minor breakdowns to the harvester

Conversely, short-term storage will enable the plant to continue to receive feed when it is shut down, running at low rates, or when several deliveries are made in a short period of time.

The site should be essentially level, have access to a main road, and not be in a residential or commercial area.

Close access to water supply, sewer and an electrical substation is assumed.

The plant will emit noise. Design targets will limit on-site noise to legislated requirements, typically, a maximum of 85 dBA in plant areas, with outside noise limits dependent on the zoning of the land surrounding those affected. Major sources of noise are expected to be fans, including those on the air-cooled steam-turbine condenser, mills and the rechipper (if needed). It may be necessary to install noise reduction equipment at the source, so that WA regulations are met. Locating the plant so as to create minimum impact on its neighbours will have a significant effect on the cost of noise reduction measures. Noisewise, a good site will have the following features:

- Be in an area zoned industrial, or next best zoned commercial
- Be close to a busy road or busy railway line.
- Have hills between it and residences or other neighbours.
- Be as far as possible from residences and other neighbours.

6. Safety and Environment

6.1 Regulations

The following is extracted from “A Guide To Environmental Impact Assessment in Western Australia”, from the Western Australian government website.³

West Australians have an environmental impact assessment process which looks at new development proposals to ensure the environment will be protected. The system also is based on the recognition that people want a say before the Government decides. As a result, the process is aimed at protecting the environment by ensuring development is environmentally sound and well managed.

The process is straightforward. Proponents, or project developers, are required to tell the Environmental Protection Authority and the community what they want to develop, what they expect the environmental impacts to be, and how they plan to manage their projects so the environment will be protected. They also are required to commit themselves to the environmentally responsible implementation of their proposals.

Proponents can be private developers, government departments or local authorities and each is treated similarly by the EPA which is obliged to assess all proposals which might have significant environmental impact.

Environmental impact assessment is not aimed at determining a balance between environment and development. In Western Australia, it is assumed that society wants both. Instead, impact assessment provides a way in which independent environmental advice can be given to the Government so it can properly decide the balance on the basis of a range of advice covering political, environmental, economic, social and cultural issues.

Environmental impact assessment is aimed at resolving questions of "how to" manage projects so the environment is protected rather than to say "yes" or "no" to development. The EPA provides independent advice to the Government and the community on ways to ensure environmentally acceptable development. The Government decides whether it accepts that advice.

The public expect to be told about what developers are planning. In Western Australia, people also expect to have a say about development, and to be heard before the Government makes a decision.

The process is designed to ensure this happens. In particular, the EPA will help, or require, developers to design projects that protect the environment and will recommend environmental approval if it can be shown that the environment will be protected. If proponents cannot show that the environment will be protected, the EPA will recommend against their proposals.

³ http://www.environ.wa.gov.au/pubs/eia/prt_eia1.htm

6.2 Emissions

The following tables describe the major emissions from the plant.

Table 2: Liquid effluents assuming air cooling

Assuming air-cooling is used, liquid effluents will comprise:

Source	Quantity	Temperature	Contaminants	Disposal means
Cooling tower blowdown	0.5 m ³ /h	< 35°C	increased dissolved solids, antiscaling / anti-corrosion agents (phosphonates, zinc salts and organics), biocides (isothiazolins)	Trade waste
Boiler blowdown	0.5 m ³ /h	< 100°C	increased dissolved solids, oxygen scavenger (diethylhydroxylamine), scale inhibitor (liquid polymer / phosphate), alkalinity builder (sodium hydroxide)	Trade waste
Demineralised water plant	6.5 m ³ /d (batch discharge)	ambient	increased dissolved solids	Trade waste
Polishing plant	5 m ³ /d (batch discharge)	ambient	increased dissolved solids, possibly significant deviations from neutral pH	Trade waste
Storm water runoff	-	ambient	Potentially: Wood chips Leaves Dissolved tannin Charcoal Activated carbon	Solids will normally be recovered in the “first flush” containment system or in the triple interceptor pit, and returned to the feed system to the plant, or sent to landfill. Water will be cleared of wood, leaves, charcoal, and activated carbon before discharge off site to the town’s storm water system or to a local creek. Water containing dissolved tannin is not expected, as any feed material requiring storage will be kept under cover.
Laboratory	tba	ambient	Small selection of waste common laboratory chemicals, including acids, alkalis, indicators, and alcohols.	Trade waste, or by special collection and disposal by approved contractor.

Table 3: Atmospheric emissions

Emissions to the atmosphere include:

Source	Quantity of Gas	Temperature	Contaminants	Proposed treatment
Charcoal plant flue gas	18.8 t/h	250°C	Charcoal particulates NO _x SO _x Methane	Prior to discharge, will be passed through cyclone to remove particulates, and through afterburner if temperature drops below 500°C to incinerate volatiles. Due to low combustion temperature (500°C), formation of NO_x (NO and NO₂) should be minimal. The formation of N₂O is favoured by low (< 500°C), and needs to be assessed. Sulphur is a minor component of the feedstock, but can be as high as 0.02% (dry basis) in wood grown in high-sulphur soils. Approximately 10% of the sulphur in the feedstock will be emitted to the atmosphere, the rest will go out with the ash. Due to the low combustion temperatures, formation of methane at a level of around 90 ppm is likely. It is expected that most of this will be incinerated directly above the fluidised bed.
			Carbon monoxide	Due to the low combustion temperatures, formation of carbon monoxide at a level of around 2500 ppm is likely. It is expected that most of this will be incinerated directly above the fluidised bed.
Charcoal milling area	17 m ³ /min	ambient	Charcoal fines	Passed through reverse pulse dust filter prior to discharge.
AC plant flue gas	16.8 t/h	250°C	Particulates NO _x	Any particulates carried over from the activation fluidised bed will be incinerated when the water gas is combusted at around 950°C. Due to low combustion temperature (950°C), formation of NO_x should be minimal.

Source	Quantity of Gas	Temperature	Contaminants	Proposed treatment
			SOx Methane Carbon monoxide	Sulphur is a minor component of the feedstock, but can be as high as 0.02% (dry basis) in wood grown in high-sulphur soils. Approximately 10% of the sulphur in the feedstock will be emitted to the atmosphere, the rest will go out with the ash. Any methane formed in the activation fluidised bed will be incinerated when the water gas is combusted at 950°C. Large quantities of carbon monoxide are produced in the activation fluidised bed. These will be burned at 950°C, and only minor levels of carbon monoxide emitted to the atmosphere.
Extrusion area	Relatively small	200°C	Tarry volatiles	Will be captured by fume extraction, and fed into water gas combustion system
Calcining flue gas	Relatively small	800°C (may be reduced if heat recovery is economic)	Tarry volatiles	Will be captured by fume extraction, and fed into water gas combustion system
Eucalyptus oil condenser non-condensables	small nominal quantity, saturated with oil and water	30°C	Eucalyptus oil fumes	No action planned. If an odour problem, fumes will be fed into water gas combustion system
Eucalyptus oil storage tank	<200 l/h air, saturated with oil and water	ambient	Eucalyptus oil fumes	No action planned. If an odour problem, fumes will be fed into water gas combustion system
Deaerator vent	small nominal quantity	105°C	Steam, with a little air	No action planned
Leaf combustion	23 t/h	250°C	Charcoal particulates	Prior to discharge, will be passed through cyclone to remove particulates.

Source	Quantity of Gas	Temperature	Contaminants	Proposed treatment
			NO _x	Due to low combustion temperature (1000°C), formation of NO _x should be minimal.
			SO _x	Sulphur is a minor component of the feedstock, typically around 0.02% (dry basis). Approximately 10% of the sulphur in the feedstock will be emitted to the atmosphere, at a concentration of around 7 ppm (wet basis, as SO ₂).
			Methane	Most of the methane formed in the gasification process will be combusted at 990°C before discharge at minimal concentrations.
			Carbon monoxide	Most of the carbon monoxide formed in the gasification process will be combusted at 990°C before discharge at minimal concentrations.

Table 4: Solid wastes

Solid wastes produced by the plant will include:

Source	Nature	Contaminants	Quantity	Proposed treatment
Leaf combustion	Ash	The ash will contain principally oxides of silicon, aluminium, iron, calcium, magnesium, sodium and potassium, plus other chemicals depending on what minerals are present in the soil.	approx 500 t/y	It is expected that ash will be sold to farmers, possibly being delivered by backhaul on the feed delivery trucks. See note below.
Administration	Office waste	Paper, packaging materials, food scraps.	tba	On-site combustion (with the leaves) could be investigated. Otherwise, municipal waste collection to landfill.
Workshop	Used oil and solvents	Used lubrication oil and machinery-cleaning solvents (kerosene and similar)	tba	Will be collected and removed by approved contractor.
	Scrap metal	Pipe and structural steel offcuts. Worn-out machinery and components. Drums and pails.	tba	Will be collected and removed by approved contractor or sent to landfill.

Source	Nature	Contaminants	Quantity	Proposed treatment
	Other scrap	Gaskets, plastics, cables, electronic components, dirty rags, broken pallets, broken bags. n.b. asbestos is not expected to be on site.	tba	Will be collected and removed by approved contractor or sent to landfill.
	Office waste	Packaging materials, paper and food scraps.	tba	On-site combustion (with the leaves) could be investigated. Otherwise, municipal waste collection to landfill.
Laboratory	Office waste	Paper, packaging materials, food scraps.	tba	On-site combustion (with the leaves) could be investigated. Otherwise, municipal waste collection to landfill.
Laboratory	Chemical solids	Tested activated carbon	tba	On-site combustion (with the leaves) could be investigated. Otherwise, municipal waste collection to landfill.

It is likely that the ashes produced by the charcoal-making and leaf combustion processes could be sold to the farmers. Ash production is likely to be very low, but there appears to be considerable interest from the farmers in purchasing it. The alternative is incurring a disposal cost. The trailers used to deliver feed are likely to have light bins partially made of weldmesh, and so will not be able to backload material like ash. A local transport operator with a conventional tipper is probably the best way of moving the ash.

Ash production is likely to be around 0.1 - 1% of feed, or 100 - 1000 t/y. Facilities for storing ash, or loading trucks with ash have not been included in the estimate, but would not be expensive, and the investment should be returned rapidly by ash sales.

Refer to Table 25 in Section 11.1 below.

Table 5: Risk Assessment

The following general hazards have been identified:

Hazard	Examples	Consequence	Protection provided
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Hazard	Examples	Consequence	Protection provided
Feed storage	Leaves Wood Twigs	Fire	Fire water storage tank Fire pumps Ring main Fire hydrants Local fire brigade.
High temperatures	Up to 1000°C in leaf combustor and AC plant. 500°C in charcoal plant Steam temperatures up to 450°C	Burns	Exposed areas will either be: insulated to reduce surface temperatures to below 65°C guarded to prevent accidental contact
High pressures	45 bar in steam system	Rupture of pipe or vessel	Pressure relief valves. Design to AS4041.
		Splashing of pipe contents	Properly-selected sample and drain valves Knock-out pots
Flammable gases	Hydrogen Carbon monoxide Methane	Fire, explosion Toxic (CO only)	Gas detectors Ventilation Flameproof electrical equipment
Flammable liquids	Eucalyptus oil ⁴	Fire, explosion Poisonous	Gas detectors Ventilation Flameproof electrical equipment Minimal inventory in processing plant Storage tank blanketed with inert gas Fire extinguishers
Combustible liquids	Diesel	Fire	Fire extinguishers
Dust	Charcoal AC	Fire, explosion	Housekeeping Earthed equipment Conductive packaging
Product storage	AC	Fire	Earthed equipment Conductive packaging Fire extinguishers

⁴ The flash point of eucalyptus oil depends on the species and purity, and is variously reported for medicinal oil from *E. citriodora* as 74°C, and 44°C for *E. globulus*. Liquids with a flash point below 60°C are generally regarded as flammable.

Hazard	Examples	Consequence	Protection provided
Spillage of solid product	Charcoal AC	Environmental	First-flush system for storm water Housekeeping
Spillage of liquid product	Eucalyptus oil	Environmental	Bunded areas around storage tanks.
Acids/alkalis	Sulphuric acid Caustic soda	Environmental Chemical burns	Safety showers, eye washes Bunded areas around storage tanks
Boiler and cooling water chemicals	Biocides Anti-corrosion and anti-scaling agents Alkalinity builders Oxygen scavenger	Environmental Toxic Toxic, corrosive Toxic	Bunded storage and handling areas Handling procedures Training of staff Personal protective clothing Medical emergency procedures
Laboratory chemicals	tba	Toxic Corrosive	Secure, appropriate storage areas Handling procedures Training of staff Personal protective clothing Medical emergency procedures
Workshop welding gases	Acetylene Argon	Flammable Asphyxiants	Proper storage and handling facilities Training of staff Medical emergency procedures

7. Activated Carbon Products

7.1 Summary

CSIRO has made activated carbon from mallee wood supplied by CALM:

- Granular carbon has been optimised for water treatment applications
- Pelletised carbon has been optimised for gold recovery.

Test work to date indicates that both carbons perform well against other commercial carbons. Water treatment test work has been particularly good. Gold recovery test work indicates the carbon pellets perform as well as some commercial carbons but still have room for improvement.

The world markets for these two applications alone are estimated to be almost 200,000 tonne/year, in a total world market for activated carbon of more than 700,000 tonne/year.

Selling prices quoted for carbon include post production costs such as storage, transport, marketing and profit. The factory gate price will therefore be lower than the retail price. The table below summarises testing to date and its impact on likely ex-factory selling prices. Based on work to date, an average ex-factory selling price of A\$3000 per tonne is considered realistic.

Table 6: Preliminary mallee carbon tests - water and gold

Use	Reference carbon	Preliminary mallee carbon performance
Water - taste and odour	Norit ROW 0.8 Supra	Better
Water - taste and odour	Calgon Filtrasorb 300 - granules	Better
Water - taste and odour	Calgon WPL – powder	Better. Up to twice as good
Water	Low grade powder	
Gold	Norit 3515 pellets	Not as good
Gold	Pica G210 AS	Similar

These results, particularly for water treatment applications, are very encouraging. A better estimate of ex-factory price in relation to retail price will indicate whether the selling price estimates may be increased. Note that the initial market for gold carbons will be local to Western Australia, and this is expected to have a significant positive effect on the price for the carbon because of avoided transportation and other overseas costs.

Preliminary testing has also been carried out to investigate performance in chemical and food applications. It was not expected that the carbons would perform well as they had not been prepared for such work. The initial results below indicate that more work needs to be done for these applications to see whether satisfactory results can be achieved.

Table 7: Preliminary mallee carbon tests - food and chemical

Use	Reference carbon	Preliminary mallee carbon performance
Chemical - solvent extraction	Sutcliffe Carbons DCL 12X40 US	Not as well
Food decolourisation	Sutcliffe Carbons DCL 12X40 US	Not as well

Samples of the mallee carbons produced by CSIRO are being sent to several activated carbon companies in Europe, the UK and the USA. Response to tests and commercial comments are expected to be received from these companies over the period September 1999 to February 2000.

7.2 Testing

7.2.1 CSIRO

a) Granular carbon tests

CSIRO carried out seven iterations of granular activated carbon manufacture. In each case the carbon was tested for its ability to adsorb phenol and tannin from water, as a measure of the carbon's ability to remove taste and colour from water. Norit ROW and Calgon Filtrasorb 300 were used as reference carbons in each test. CSIRO's processing parameters were modified to optimise the mallee carbon's ability to remove phenol and tannin. The final carbon was made to optimise yields, but still performed better than both reference carbons for tannin adsorption and as well as or better than both for phenol adsorption. If carbon yield was reduced the activity of the carbon increased significantly.

Further tests carried out by the Co-operative Research Centre for Water Quality in Adelaide (see below) add to the data which suggests that the mallee granules are an excellent general purpose water treatment carbon.

b) Pelletised carbon tests

CSIRO carried out several trials with activated carbon pellets. For gold industry applications the production of pellets from wood is essential to give the wood carbon the physical hardness required to withstand the rigours of use in a gold extraction plant. CSIRO therefore optimised the carbon for hardness, to achieve a level of 97 or greater as measured in a standard industry test.

CSIRO achieved this hardness level and better, and tested the pellets against a reference carbon (Norit RO 3515) to assess the kinetics of gold adsorption. It was found that the effectiveness as an adsorbent for the mallee carbon decreased with increased hardness. At the industry minimum of 97, the CSIRO carbon was close to, but still slightly less effective than the Norit reference.

7.2.2 CRC for Water

The Cooperative Research Centre for Water Quality and Treatment (or Australian Water Quality Centre) was engaged to carry out three tests on the granular activated carbon:

a) Methylisoborneol (MIB) adsorption

MIB adsorption is a common test for taste and odour compound removal from potable water. The MIB molecule is small in comparison with the tannic acid molecule (168 versus approx. 1000) and so good performance in both MIB and tannic acid tests indicates a broad ability to remove water contaminants.

b) Microcystin adsorption

This test shows the ability of the activated carbon to remove toxins associated with contamination by blue green algae.

c) Atrazine adsorption

Atrazine is one of the more commonly used pesticides in the northern hemisphere and is routinely removed from potable water in Europe and the USA via activated carbon.

In all cases a reference carbon was also tested. The carbon recommended by the CRC was Calgon WPL, which is generally available around Australia for taste, odour and algal toxin removal.

Test results have been provided and in all cases the mallee activated carbon showed good adsorption overall and considerably better performance than the Calgon WPL. Results may be summarised as follows:

Table 8: Adsorption test results

% removal of:	Calgon WPL	Mallee carbon	% improvement
MIB	57	97	70
Microcystin	43	86	100
Atrazine	78	96	23

The CRC commented that the CSIRO mallee sample was highly active for both MIB and microcystin, which is not common and may be an additional attribute for sales into the water treatment market.

Additional testing is possible: microcystin against a higher grade granular carbon and saxitoxin removal (which has yet to be seen to be very successful with activated carbons).

7.2.3 CRC for Hydrometallurgy

This CRC is based in Perth, and is very experienced in analysis of activated carbons for the recovery of gold from ore slurries via the CIP process, the process used by almost all Australian gold mines, with annual carbon use of around 5,000 tonnes in Australia for this activity.

The CRC was commissioned to carry out several tests to measure the quality of the mallee pellets against two premium carbons used by the industry:

- Pellets - Norit RO 3515 - market share estimated between 5% (by Pica) and 10-15% (by Jim Avraamides from the CRC).
- Granules - Pica G210 - market share given as 25 - 35 % by Pica.

The gold industry is currently experiencing a period of low product prices and financial hardship. Prices for activated carbons in the gold industry are reported to have fallen by as much as one third over the past ten years.

Test results from the work by the CRC may be summarised as follows:

- Activity - CSIRO carbon was similar to Norit and lower than Pica.
- Ball pan hardness - CSIRO carbon was lower than Norit and Pica at 98.6 was but still at a hardness level acceptable to the industry.
- Contamination - the CSIRO carbon was found to be more prone to contamination by the organic materials that may be found in gold recovery streams.
- Pulp attrition - carbon weight loss was measured against attrition with sand, as an indicator of the likelihood that some of the carbons will be lost because of attrition in the CIP tanks. The CSIRO carbon showed slightly more attrition than the Norit carbon. The Pica carbon performed better than both Norit and CSIRO.

Thus, while the CSIRO activated carbon shows good commercial potential, there needs to be some

improvement in its general characteristics before it can compete fully with two of the industry leaders. Note that there has been very little opportunity thus far to optimise the CSIRO carbon for all required attributes. By comparison, activated carbon pellets made from jarrah by CSIRO have shown excellent general characteristics, indicating that further improvement of the mallee carbons may be quite possible with additional test work.

7.2.4 Sutcliffe Speakman

Sutcliffe Speakman is the largest activated carbon company in the UK. Colin Stucley (Enecon) met with their managing director in June 1999. Sutcliffe Speakman markets activated carbons from a range of producers and also buys in low-grade carbons for additional processing to suit particular markets. Their UK facility includes extensive testing laboratories.

100 gram each of granules and pellets was sent to Sutcliffe Speakman for the following tests:

Table 9: Sutcliffe Speakman carbon test results

Test	Background
Bulk density	General test to determine characteristics of the carbon
Iodine number	Measure of the ability to adsorb iodine, a common industry test to show adsorptivity.
Surface area	General test to determine characteristics of the carbon.
Pore size distribution	Shows the ratios of large, medium and small pores, which in turn indicates the ability to adsorb contaminants (into the smaller pores) and the speed with which this will occur (via transport through the larger pores).
Ash content	General test to determine characteristics of the carbon.
Molasses decolourisation	Common test for use in food industry.
Methylene blue	Common test for colour adsorption.
CTC	CTC is carbon tetrachloride, an industrial solvent. This is a common test for the ability of the carbon to adsorb solvents from contaminated air.

These tests were chosen to provide general information about the carbons and to assess their performance in two areas not examined by others: food decolourisation and solvent recovery.

Results from Sutcliffe Speakman's testing program indicate that the samples tested had moderate attributes for solvent recovery or food decolourisation. Given the preliminary nature of these tests the results are not surprising. Further examination of these markets should include review for precedents of other wood-based carbons performing well in such applications, and should allow CSIRO the opportunity for multiple iterations to optimise manufacture for the necessary physical attributes.

7.2.5 Other Carbon Companies

Once activated carbon had been made and tested by CSIRO it was offered to several large activated carbon companies for independent testing. These tests and their results were still being organised and interpreted at time of preparation of this report. They will therefore be reported separately.

The companies that will probably participate in testing include:

- Pica, France (<http://www.pica.fr>)
- Norit, Holland (<http://www.norit.com>)

- Calgon Carbon Corporation, USA (<http://www.calgoncarbon.com>)
- CPL Industries, UK. (<http://www.cplindustries.co.uk>)

7.3 Discussion

7.3.1 Multiple Products

Activated carbon is sold as powder, granules and pellets. Powder is often generated as a byproduct from granular activated carbon production - when activated carbon is processed to make size fractions preferred for granular applications, significant quantities of activated carbon powder may be generated. This powder is usually sold at a lower price than the granules, and so plants producing mainly granular carbon must select their sizing equipment carefully to maximise granules and minimise powders.

CSIRO pellets are made by pelletising the charcoal prior to activation, and so powder generated after activation is not necessarily suitable as a feed for activated carbon pellets. However, if charcoal sizing is managed properly the majority of the charcoal will either be powder suitable for pellet manufacture or pieces that, when activated, are appropriately sized for the granular markets. In this way powdered activated carbon can be kept to a minimum and the average product selling price is increased.

7.3.2 Production and Selling Costs

The prices shown for reference carbons above are selling prices to customers, and include costs for:

- manufacture
- packaging
- storage
- transport
- marketing

for the manufacturer and any marketing organisation (related or independent).

Data collected from a range of sources suggest that carbons from an ITP plant will sell ex-works for a range of prices, with granules and pellets normally at \$3000 or better and any powder produced selling between \$1200 and \$1700 per tonne. It is intended that all powdered charcoal produced will be used as feed for activated carbon pellets, keeping the average price of the carbons as high as possible. The current state of the gold industry will possibly have a negative impact on carbon prices but, as this also represents a major Australian use for carbon, the opportunity to sell directly to Australian customers may increase the ex-factory returns.

Because the plant has the ability to size charcoal prior to activation it should be able to minimise production of powdered activated carbon to a few percent. In a full-scale ITP plant the powdered charcoal produced can be used as feed for activated carbon pellets.

7.3.3 Market Shares

In each major market, such as water treatment and gold recovery, activated carbons will be sold at a range of prices as shown above. Some customers want the cheapest carbon available, while others are prepared to pay premium prices for high performance or particular attributes.

The activated carbon market for gold recovery in Australia is estimated at approximately 5,000 tonne/year (or about 10% of the world gold market of around 50,000 tonne/year). The Norit RO3515 pellets are at the premium end for these carbons and the bulk of the market is serviced by cheaper, lower grade carbons made from coconut shell. For example PICA have indicated that they hold around 30% of the market with their carbon.

We believe that the water treatment and other markets follow similar trends, namely that high-value, premium carbons command a small market share relative to the middle priced carbons. This has two effects for the ITP industry:

- In the short term the premium markets will allow higher selling prices for ITP products. This suggests a premium for sales of activated carbon from the demonstration plant that will help provide an adequate return for its investors and operators.
- In the longer term, production of larger quantities of carbon possibly will force its sale into lower value markets. This should not be a problem once full-scale ITP plants are built. The positive financial analysis carried out to date indicates that full-scale plants will still be viable on these lower selling prices.

7.4 Market sizes

7.4.1 Australia

The Australian market for activated carbon is estimated to total approximately 7,500 tonne/year, comprising approximately 5,000 tonne/year for gold recovery and 2,500 tonne/year for water treatment, food and beverage and other miscellaneous uses.

These figures are based on import statistics from the Australian Bureau of Statistics (Reported commodity number 3802100008) and communication with the two companies in Australia that make activated carbon from coal. Imports comprise 5,000 to 6,000 tonne/year and are largely coconut shell and pelletised peat carbons for the gold industry.

7.4.2 Worldwide

A market review in 1998 (BM Coope & Partners) has estimated a total world market for all activated carbon of some 700,000 tonnes. Market growth over the period 1988-1998 was estimated by Coope at 4-6% per year. Consumption is estimated to be on the following geographical basis:

Table 10: World activated carbon consumption

Country	Consumption (‘000 tonne/year)
United States of America	175
Western Europe	155
Japan	145
China	85
Asia	65
Other	75
Total	700

The majority of production in the USA and Europe is by six or seven manufacturers in each region, with two companies, Calgon and Norit, being the largest producers.

Figures for United States in 1990 (Kirk Othmer) provide an indication of the range of uses for activated carbon:

Table 11: Uses for activated carbon

Application	% utilisation
<i>Liquid Phase</i>	
potable water	19.2
wastewater	16.9
sweetener decolourisation	16.9
chemical processing	6.8
food, beverages, oils	5.1
Pharmaceuticals	4.6
Mining	4.4
Groundwater	3.4
Household uses	2.4
Other	1.8
<i>Gas Phase</i>	
solvent recovery	4.8
petrol recovery	4.4
industrial off gas control	3.4
Catalysis	2.9
Other	3.0

7.4.3 Water treatment and gold

The figures for carbon usage in the USA indicate approximately 20% is used for potable water

treatment. Extended over world consumption this suggests a potential potable water market of some 140,000 tonne/year for the mallee carbons, that have been shown to perform well in several water-treatment applications. It is expected that the market for potable water treatment will expand as more water treatment facilities are built in Asia.

The above figures apply only for potable (or "drinking") water applications as tested. Additional testing is needed to confirm whether performance by the mallee carbon in wastewater treatment is equally good.

The Australian gold industry produces approximately 10% of the world's gold each year, and uses some 5,000 tonne/year of activated carbon to do so. If one assumes that all gold recovery follows similar a process to that used in Australia, this would suggest a world market for gold recovery activated carbon of some 50,000 tonne/year. In practice, other techniques (such as zinc dust precipitation in South Africa) are used for gold recovery and the activated carbon usage world wide is not accurately known.

8. Eucalyptus Oil

8.1 Introduction

A few species of Australian Eucalyptus trees, mainly “mallees” (plants with multiple stems, woody lignotubers and the ability to regenerate or coppice after repeated harvesting) produce a leaf oil for which there is existing world trade as a pharmaceutical product and a large potential market as an industrial solvent. These oils are composed of mixtures of volatile organic compounds including hydrocarbons, alcohols, aldehydes, ketones, acids, ethers and esters. Most are monoterpenes and sesquiterpenes, which consist of two or more isoprene (C_5H_8) units. They are products of photosynthesis, with functions for the plants that are still poorly understood. Currently the most important of these is 1,8-cineole, but even in high-cineole eucalyptus oil there are small quantities of other compounds which have existing or potential specialised uses.

The Australian industry peaked in the mid-1940's when annual production was about 1000 tonnes. Since then the establishment of eucalypt plantations in countries with lower labour costs has reduced our competitiveness. Although some mallees (particularly *Eucalyptus polybractea*, “blue mallee”) are still harvested exclusively for oil in eastern Australia, most of the world's production is derived as a by-product of wood production from plantation *Eucalyptus globulus* (Tasmanian blue gum) in China. However, this yields an oil with a lower cineole proportion than in the oil mallees, and the oil must be refined or blended with a cineole-rich product to meet most pharmaceutical standards.

Currently somewhere between three and five thousand tonnes are traded each year on international markets, with only two or three hundred tonnes being produced by Australia. Prices fluctuate widely (depending on many factors including type of oil, quality, demand) from US\$2 to about US\$10 per kilogram.

The following sections discuss the chemistry of eucalyptus oil (cineole) and the existing and potential markets that are available to it.

8.2 1,8-Cineole

1,8-Cineole (often called just “cineole”) is the pharmaceutically active component of eucalyptus oil. It occurs in complex mixtures with numerous other terpenoid compounds in the leaf oils of many eucalypts, but to differing extents - usually 60 to 70% in the case of bluegums and up to 95% in some oil mallees.

Cineole (see Figure 1 below) is a cyclic ether with the empirical formula $C_{10}H_{18}O$ and systematic name 1,3,3-trimethyl-2-oxabicyclo[2.2.2]octane. It is sometimes traded commercially as “eucalyptol”. The carbon atoms linked to the ether oxygen are fully substituted, and this fact plus the chemical saturation (no carbon-carbon double bonds) endow cineole with stability and low chemical reactivity. These properties include resistance to oxidation, polymerisation and thermal decomposition, in contrast to most other terpenoid compounds.

It is a colourless liquid over the temperature range 0 °C to 177 °C with a vapour pressure of 69 mmHg at 20 °C and a strong characteristic odour. Its flash point is reasonably high (48 °C). It is slightly less dense than water (0.927 g mL⁻¹ at 20 °C). Cineole's ether oxygen atom is moderately polar, making it either fully or partly miscible in a wide range of other liquids from hydrocarbons to polar organics. Cineole has a limited solubility in water (0.4% by weight at 20 °C).

Carboxylation and hydroxylation of cineole have been described by various processes, including enzymatic, biological and metabolic routes. It has an odour which at low concentration is considered pleasant by most people and is used in aromatherapy applications as well as for deodorising waste sludges. Cineole's combination of cleaning properties and pleasant odour have resulted in its incorporation into a wide range of household cleaning products.

Cineole therefore has a future as an industrial and commercial solvent in addition to its existing use in pharmaceuticals. In particular, in many situations cineole may well replace 1,1,1-trichloroethane,

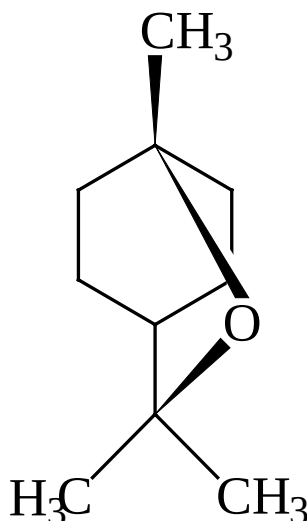
previously widely used for metal degreasing and other cleaning operations.

8.2.1 Bioactivity of Cineole

Cineole and other components of eucalyptus oil are readily biodegradable, unreactive and relatively non-toxic. Eucalyptus oil carries the US Food and Drug Authority classification GRAS (Generally Regarded as Safe) and is approved for incorporation into foods such as chewing gum and throat lozenges at low concentrations.

Cineole can readily penetrate tissue, one of the reasons for its efficacy in various decongestants and pain relief products. It also has mild bactericidal properties and has been used in herbicidal, insecticidal and allopathic applications. All these properties are presumably associated with its unique compact chemical form, with the cyclic ether linkage spanning a structure based on cyclohexane (Figure 1).

Figure 1. Molecular structure of 1,8-cineole, showing the system of “fused rings”: the cyclohexane ring with 6 carbon atoms and two cyclic ether rings of 5 carbon atoms and an oxygen atom.



Essential oils containing cineole demonstrate antimicrobial and pesticide qualities, including effects demonstrated by cineole on its own as well as synergistic effects when cineole is used as a carrier solvent. For example:

- *Eucalyptus* trees with a high cineole content show less susceptibility to herbivory by Christmas beetles, and cineole is a mosquito feeding and egg-laying repellent.
- Treating the western honey bee for the parasitic mite *Varroa jacobsonii* with a terpene based solution containing cineole gave a mite mortality of 96.7% against a 4.4% mortality in the control colonies.
- Cineole is a natural repellent to the American cockroach and results of tests for the use of eucalyptus oil and cineole as a mosquito larvicide also indicate it has insecticidal potential.
- Cineole has been investigated as a fumigant against stored-product insects.

8.3 Existing Markets

The existing world market for eucalyptus oil is mainly for pharmaceutical and domestic cleaning uses and is approximately 4000 tonne each year. China produces some 3500 tonne of this. Half the Chinese production is from blue gums and the rest is from camphor trees. Quality of the latter oil is variable. Production in China is expected to decline. The major importing countries are:

Table 12: Major eucalyptus oil importing countries

Country	Tonnes
France	800
Germany	400
UK	400
USA	400
Australia	300
Total	2,300

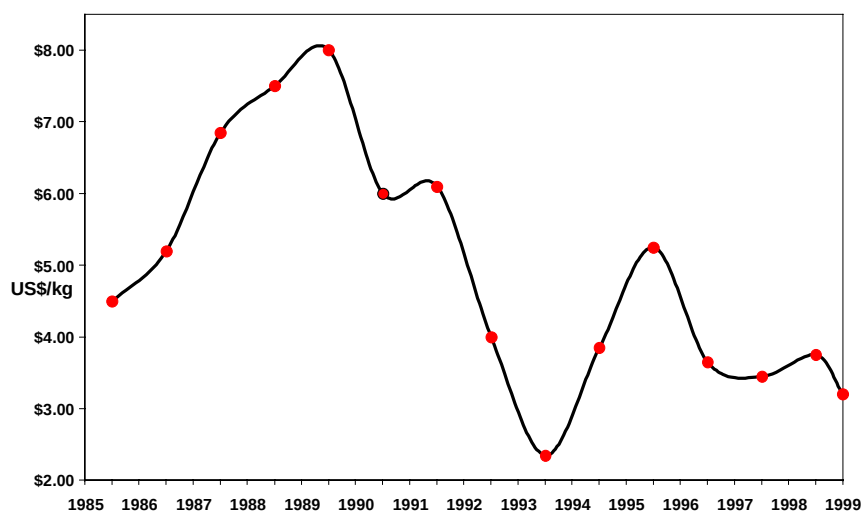
Eucalyptus oil is used as a fragrance in soaps, detergents, as a wool wash component, as perfumes and as a flavouring in food. It has been used as a flotation agent in the mining industry. Other uses include:

- Bottled Eucalyptus Oil
 - In Australia a large quantity of bottled eucalyptus oil is sold to consumers for a multitude of household uses, including as a spot and stain remover. Some oil is sold in bottles in Asia and New Zealand, but no other country has a similar pattern to the Australian consumption.
- Rubs, Liniments, etc.
 - Traditionally liniments, rubs and balms have been used for the relief of the pain, stiffness and soreness of muscles whether from sports or arthritis. Historically and therapeutically these products have been effective and used extensively around the world. Chest rubs are also popular.
- Asthma
 - Allergens from dust mites are a major cause of asthma. Studies have shown 80% of asthmatic children have been sensitised to house dust mites.
 - Reducing house dust mites reduces the risk of asthma. The lower the dust mite population the lower the number of attacks. Tests have shown that eucalyptus oil kills dust mites, suggesting a substantial potential market for oil in this application.
- Other Pharmaceutical Uses
 - Other pharmaceutical uses for eucalyptus oil include mouthwashes such as Listerine, cough drops, cough syrups, nasal decongestants, antiseptics, disinfectants, soaps and insect repellents.
- Inhalants
 - Overseas vaporiser and humidifier manufacturers do not recommend the use of inhalants but if current trials are satisfactory there is potential of a large international market for eucalyptus inhalants.

Prices

The price movements of Chinese eucalyptus oil since 1986 are shown in the table. The price during the last six years has generally been between US\$3.00 – 4.00 kg.

Price of Chinese Eucalyptus Oil (US\$/kg) 1986-99



Eucalyptus oil revenue for the integrated processing plant has been based on a selling price of A\$3/kg ex works. This provides a substantial margin below prevailing market prices and opens potential to develop new markets.

8.4 Eucalyptus Oil as a Natural Solvent

8.4.1 1,1,1-Trichloroethane

To put cineole's chemical properties in the context of the future of this compound as an industrial solvent, it is necessary to consider briefly the background of the solvent trichloroethane. The vapour of the chlorohydrocarbon 1,1,1-trichloroethane (CCl_3CH_3) is now known to be both an ozone-damaging and a "greenhouse" gas and this solvent has been effectively phased out for all but essential purposes. Worldwide annual production has fallen dramatically from its peak in the early 1990's. Trichloroethane has a relatively low ozone depletion potential (ODP) of approximately 0.11. (The ODP is the ratio of the impact due to the release of a particular molecule on global ozone loss compared to the impact of a molecule of CFC-11, CFCl_3 .) However trichloroethane's stability in the lower atmosphere (atmospheric lifetime of about 6 years) and widespread use as a degreaser and general all purpose solvent since the late 1950's means that it has been a significant contributor to ozone layer depletion. Despite its adverse environmental record and poor occupational health standing, trichloroethane was the degreasing solvent of choice, with annual international sales of the order of a million tonnes in 1993.

8.4.2 Industrial Solvents

High-cineole eucalyptus oil has a combination of chemical and physical properties that makes it suitable for several solvent applications. It is:

- a good solvent for a wide range of materials
- chemically stable, not deteriorating on storage or heating
- liquid over a wide range of temperatures with a moderate vapour pressure at ambient temperature
- slightly soluble in water and has the ability to steam distil
- relatively safe, with minimal environmental and occupational health implications
- a "familiar" but unexploited product worldwide.

Several market sectors have been identified:

- solvent degreasing: low price and high volume. Although there is significant competition from petroleum-based solvents, there is a growing popular demand for “natural” solvents, and high-cineole eucalyptus oil has advantages over other natural solvents like pinene and limonene. Both have development and production constraints as by-products of other industries (wood products and orange juice, respectively), and cineole has an inherent chemical stability compared with the unsaturated terpenoids such as pinene and limonene.
- carrier solvent: medium price and moderate volume. Synergistic efficiency improvement and more controlled application of pesticides have been demonstrated but not yet fully explored.
- extraction solvent: medium to high price and moderate volume. Cineole has been investigated for a few specific applications, but again there is considerable scope for further investigation.

There is a significant market opportunity for eucalyptus oil in industrial degreasing and solvent applications. Best practice is changing rapidly in response to the phasing out of trichloroethane under the Montreal Protocol 1987, an international convention to arrest ozone depletion. Trichloroethane consumption has been replaced by:

- solvent-free systems
- various new and established hydrocarbon solvents
- aqueous detergent systems
- natural products which have other industrial ecological advantages over petrochemical products.

8.5 Measurements of Degreasing Ability

High-cineole eucalyptus oil has been successfully trialed as a workshop degreaser and has been used routinely as a degreaser in the Kwinana workshops of Alcoa Australia. Blends have been used, with reports indicating improved degreasing and a favourable response from workers to their less pronounced eucalyptus odour. The other components in the blends are also botanically derived.

Although it is unlikely that any one solvent will replace trichloroethane in its full range of applications, cineole has great potential to replace it as a degreaser. Biodegradability and ease of recovery from grease-contaminated solvent through steam distillation are also desirable properties in this solvent. The total size of this potential market is as much as three hundred times the size of the existing world eucalyptus oil market, so replacing even a small proportion of the degreasing solvent market would dramatically change the situation for eucalyptus oil.

In tests at Murdoch University in Western Australia, high-cineole eucalyptus oil formulations have shown solvent capabilities comparable to those of trichloroethane. While solvent properties can be assessed by a variety of theoretical and semi-empirical methods, it is desirable to be able to measure degreasing ability directly. The University has developed a method for measuring dissolution characteristics of semi-solid materials in non-aqueous solvents and has applied it to the dissolution of several industrial greases. The method utilises the rotating disc concept popular in dissolution and electrochemical reactions.

An inverted circular brass “cup” is used to accommodate the grease. The upper face of the disc has a centrally mounted vertical spindle for connection to the rotating shaft. The cup is filled with grease and its surface smoothed to allow laminar flow of the solvent over the grease surface. The disc is lowered into the solvent which is in a water jacketed container that has water at constant temperature circulating around it. The solvent volume and the speed of disc rotation are such that laminar flow is approximated. Solvency properties are determined by measuring the mass of grease lost as a function of time during rotation of the cup in the solvent.

The rotating cup method can provide a means for more rigorous comparison of the degreasing ability of solvents, which can facilitate the development and selection of solvents for particular degreasing situations.

Several greases have been tested:

- Mobilith SHC 220 is described as a lithium complex grease with over 75% naphthenic and petroleum hydrocarbons.
- Mobilgrease HP is a high-pressure grease with greater than 85% refined mineral oil. Other ingredients include nonanedioic acid dilithium salt (<10%) and lithium-soap thickener (<10%).
- Molub-alloy 860/220 grease has a high content of petroleum hydrocarbons.

Table 13: Comparative data for several degreasers

Solvent	S-Code			Flash Point, °C
	Mobilith SHC	MobilgreaseHP	Molub-alloy	
1,8-Cineole	27	65	34	48
Limonene	38	104	29	48
Blend 1	66	81	32	-
Blend 2	71	61	-	-
Hydrocarbon degreaser	27	<0.1	-	84
1,1,1-Trichloroethane	100	100	100	Nonflammable
<i>p</i> -Xylene	-	-	-	27
Ethylbenzene	-	-	-	15
Ethyl acetate	716	114	-	-3
Toluene	-	-	-	4
<i>m</i> -Xylene	-	-	-	27
<i>o</i> -Xylene	-	-	-	17
Ethyl lactate	1	17	-	48
N-Methyl-2-pyrrolidone	0.6	<0.1	-	86

Trichloroethane is the most effective solvent, and the commercial hydrocarbon degreaser (containing more than 60% naphthenic hydrocarbons) is the least effective of those tested. The degreasing endurance of trichloroethane was lower than for the other solvents. Blend 1 showed no decline in degreasing endurance over the range tested, while results for cineole were generally constant. These data yield the S-codes reported above (based on a benchmark value of 100 for 1,1,1-trichloroethane). Ethyl lactate and N-methyl-2-pyrrolidone, sometimes advocated as trichloroethane substitutes, both returned low values in these tests.

The results for the dissolution of the greases presented here for the range of solvents tested show that

- it is unlikely that a single replacement solvent with a wide range of applications similar to that of 1,1,1-trichloroethane will be found. It is more probable that solvent blends will be developed for specific applications
- cineole is as effective a degreaser as the hydrocarbons solvents being used as replacements for trichloroethane (except perhaps with greases like Molub-alloy)
- the blending of cineole with suitable liquids can result in a solvent with degreasing ability close to that of trichloroethane and other substitute degreasers currently being used (again, perhaps not the case for Molub-alloy).

The suitability of cineole and its blends as degreasers will also require investigation of other properties

like flashpoints, as well as the costs of the recovery of the oil and the other liquids. The table above provides a comparison of various liquids as potential substitutes for 1,1,1-trichloroethane: the S-codes and the flash points both as high as possible. The flash point of cineole compares favourably with those of most of the hydrocarbon solvents shown here. The blending of small amounts of other sustainably produced liquids reduces the flash point, but not to those of the xylenes and the other aromatic hydrocarbons.

8.6 Other Markets

In the preceding pages, the existing market for eucalyptus oil has been summarised, followed by the large potential market as a degreasing solvent. The attributes which make eucalyptus oil suitable for these markets are also applicable to a range of other opportunities. Some of these are noted below, based generally on the use of eucalyptus oil in its “whole” form. Other potential uses will be developed around specific components of the oil (apart from the cineole).

Solvent extraction: This is a diverse market with good volume potential. Solvents are commonly used for the extraction of a variety of products. In its simplest form, solvent extraction involves choosing a solvent that will dissolve the target product, allow the dissolved target and solvent to be separated from unwanted contaminants, then separation of the target from the solvent which is recovered and reused repeatedly. Equally diverse is the range of solvents used in the process. Examples include:

Vitamins	using	limonene, canola oil
Essential oils	using	hexane
Wool grease	using	hexane/isopropanol

Eucalyptus oil, either refined or simply distilled has good potential in this industry. It has better biodegradability, higher flash point and preferred occupational health characteristics when compared with hexane.

Health care and cleaning products: The bioactive nature of cineole, together with the good cleaning properties of eucalyptus oil, suggest significant potential as an ingredient in a wide range of cleaning products for both personal and institutional use. The solvent abilities of the oil coupled with its natural origins should also bring opportunities from specific industries where regular equipment or parts cleaning is required and an environmental emphasis is present - for example the printing industry.

Animal care products: Eucalyptus oil has been used in the past as a component of veterinary products for sheep in Australia. The oil was present as an *active ingredient* as distinct from a *carrier solvent*. The importance of this distinction from a manufacturer’s viewpoint is one of cost. The carrier solvent imparts no perceived value to the product and only contributes to the cost of manufacture, packaging, distribution and warehousing, regardless of the fact that it is necessary for the effective utilisation of the product at its point of use.

The oil-containing product became a victim of the newer chemicals which actually killed the offending insect, rather than repelled it as the eucalyptus oil did. More recently, the presence of chemical residues in wool has prompted a resurgence of interest in oil based products. This and other animal care products have been identified for investigation, which must include normal ethical and National Registration requirements.

Aroma chemicals: This industry has seen significant growth in recent years as a result of increased popularity of aromatherapy. A wide range of specific chemicals of botanical origin are used in the therapy, many of which exist as minor components in eucalyptus oil.

Gasohol: Eucalyptus oil has been demonstrated to have potential as a fuel component and cineole used as an additive in ethanol-gasoline fuel blends (“gasohol”) prevents phase separation in the presence of water. This is another potentially large application, likely to attract interest after world petroleum production peaks, which is predicted to occur in the first decade of the twenty first century.

9. Project Schedule

The plant is expected to have a design and construction period of 20 months, followed by 3 months of commissioning. The critical path is equipment delivery, with equipment such as calciners and steam turbines taking up to 52 weeks to arrive on site from date of order. EPA approval could become critical if delayed significantly.

10. Costs and Revenues

10.1 Feed Costs

10.1.1 Introduction – mallee production configuration

The cost of growing and delivering oil mallee biomass to an ITP plant is composed of three separate costs; agricultural production, harvest and transport. These costs are derived from a number of variables, some of which are not clearly defined or relate to technology still under development. Therefore feed costs have been estimated using a simple economic model summarised in Table 14.

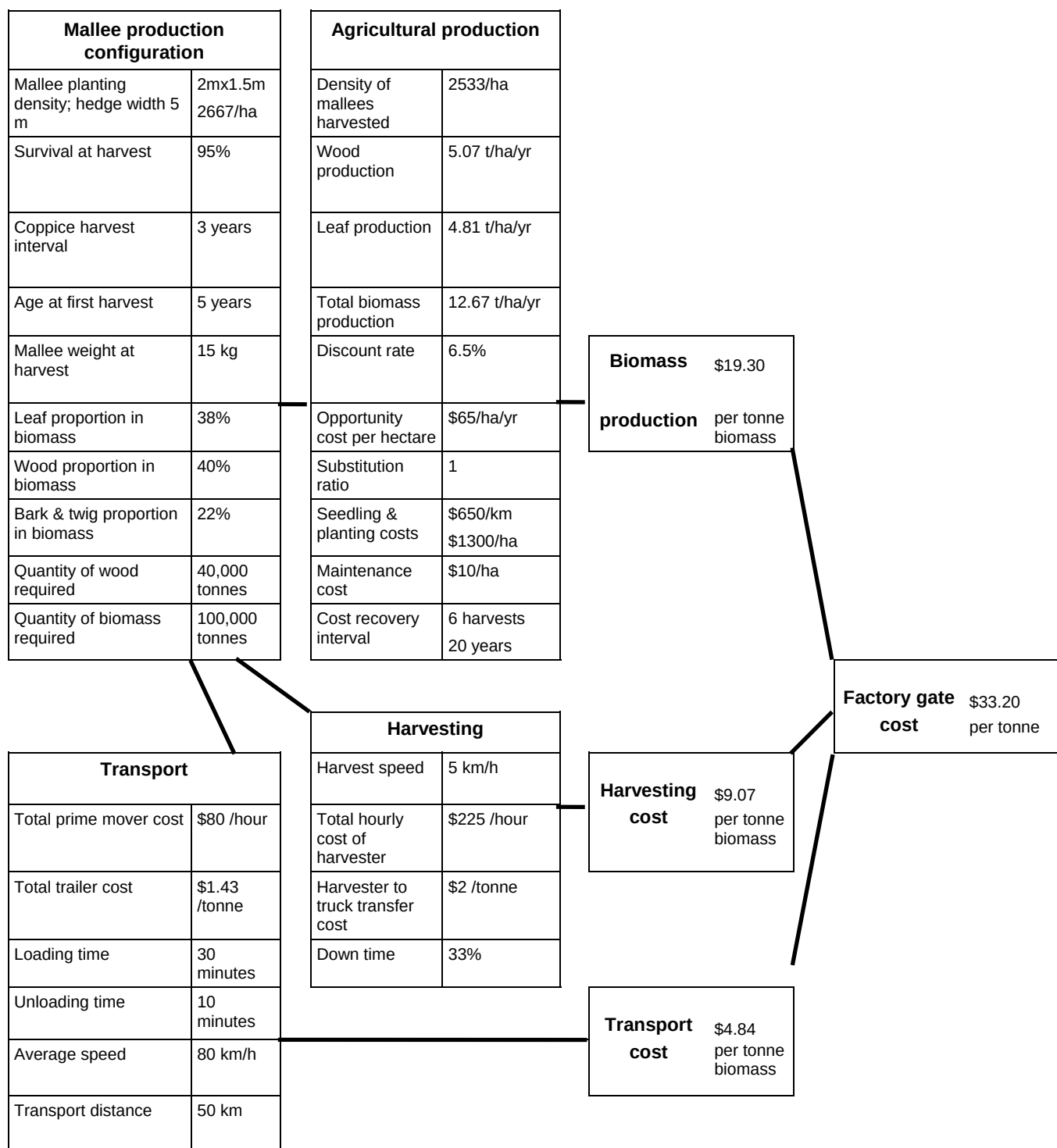
The configuration of the mallees in the paddock is fundamental to many other variables. The table below outlines the main configuration variables.

Table 14: Configuration of the mallee crop

Variable	Range of values in used feed cost model	Derivation
Planting density – per km of hedge	2m between rows, 1.5 m spacing within the rows	Standard practice
Planting density – per hectare	Hedge occupies 5m wide strip 2km of hedge = 1 hectare	Standard practice
Mallee survival at harvest	95%	Typical of good establishment practices
Coppice harvest interval	2, 3 and 4 years	Anticipated time taken for coppice to exceed harvestable weight.
Age at first harvest	4, 5 and 6 years	As for coppice harvest interval
Mallee weight at harvest	15 kg fresh weight biomass	15 kg is the minimum average weight at harvest to ensure a sufficiently high proportion of wood in the biomass for ITP viability.
Leaf proportion in biomass feed	38%	Estimated from field measurements
Wood proportion in biomass feed	40%	Estimated from field measurements
Bark & twig proportion in biomass	22%	Estimated from field measurements
Quantity of wood required	40,000 tonnes per year	Minimum to achieve economies of scale.
Quantity of biomass required	100,000 tonnes per year	Minimum to achieve economies of scale.

Harvesting schedules are described in terms of age at first harvest, coppice harvest interval and average mallee weight. For example 4,2,15 is first harvest at age 4 years, 2 year coppice harvest interval and 15 kg per mallee. As 15 kg per mallee is the minimum harvestable weight, the harvest schedule is a reflection of growth rate.

Table 15: Feed cost model, including typical values for each variable



10.1.2 Agricultural production

It is assumed that the mallees are grown on arable land. Therefore the mallees occupy land that would otherwise be cropped or grazed, and to quantify this substitution of one enterprise with another, an average whole farm opportunity cost is included in the cost of mallee production.

Table 16: Variables influencing cost of agricultural production

Variable	Range of values used in feed cost model	Derivation and comments
Density of mallees harvested	2533 mallees per hectare	Density planted x survival
Wood production	3.8 – 7.6 tonnes per hectare per year for coppice	(Density of mallees harvested x mallee weight at harvest x wood proportion in biomass) divided by the harvest interval in years
Leaf production	3.6 – 7.2 tonnes per hectare per year for coppice	(Density of mallees harvested x mallee weight at harvest x leaf proportion in biomass) divided by the harvest interval in years
Total biomass production	9.5 – 19.0 tonnes per hectare per year for coppice	(Density of mallees harvested x mallee weight at harvest) divided by the harvest interval in years
Discount rate	6.5%	Based on typical return expected for agricultural investment
Opportunity cost per hectare of the land planted to mallees Equivalent to the 10 year average gross margin of current conventional agricultural enterprises.	\$20, \$65, \$80 and \$100 per hectare per year	\$20 assumed as a lower bound for low rainfall regions where sheep numbers are low and land not under annual crops has very low production. Land available for the farming enterprise is assumed to be more than that required for annual cropping program. \$65 typical 10 year farm average for arable land in the low rainfall (<400 mm) wheatbelt \$80 typical 10 year farm average for arable land in medium rainfall (450 – 600 mm) wheatbelt. \$100 typical 10 year farm average for the most productive land in medium rainfall wheatbelt.
Substitution ratio	1	Index of the net influence of the mallees, beyond the area they occupy, upon other farm enterprises. If <1, the mallees enhance productivity of other enterprises; if >1, the mallees suppress the productivity of other enterprises.
Seedling and planting costs	\$650 – \$750 per km of hedge	Range of costs observed across the wheatbelt under current good practice.
Maintenance cost	\$10 per hectare per year	Assumed. Little maintenance required at present.
Cost recovery interval	20 years equivalent to between 4 and 9 harvests depending upon growth rates	Period over which the costs of establishment are recovered from sale of biomass.

10.1.3 Harvesting

Estimating the cost of harvesting is based upon a number of assumptions because the mallee harvester is currently under development and we have no direct experience of its productivity and costs of ownership and maintenance. A number of variables are based upon estimates of operating harvesters in the sugar cane industry. The diesel motor and hydraulic components of the mallee harvester prototype are ex-cane harvester and it is anticipated that costs of owning and maintaining the two harvesters should be similar.

Harvesting includes the transfer of the mallee biomass from the harvester to the road transport trailers. This transfer cost has also been estimated from observed practices in the sugar cane industry.

Table 17: Variables influencing the cost of harvesting

Variable	Range of values in used feed cost model	Derivation and comments
Harvester speed	5 km/h	Assumed from prototype performance. Speeds in excess of about 7km/h are assumed to be difficult due to the close proximity of the harvester's saw to the ground.
Total hourly cost of harvester	\$225 per shift hour to own, operate and maintain	Estimated from sugar cane harvesting. Assumes that two thirds of harvester time is productive. Balance spent on travelling from site to site and maintenance.
Harvester to truck transfer	\$2 per tonne	Estimated from sugar cane harvesting and assuming similar productivity.
Biomass production	9.5 tonnes biomass (fresh weight) per km of row	Planting density x survival x mallee weight at harvest.

Sugar cane harvesting has been reviewed in some detail, particularly the harvesting system in the Ord River region. This sugar industry is the most recently developed and is a combination of the best elements of the Queensland industry. The Ord River sugar mill crushes 120 tonnes of cane an hour every hour for the entire 6 month harvest season. One contractor conducts all the harvesting.

The contract harvesting cost in the Ord River sugar industry is approximately \$5.60 per tonne loaded onto the road trailers. This \$5.60 per tonne cannot be applied directly to the mallee industry as a cane crop yields more per hectare than a mallee crop, but the per tonne rate can be used to estimate a combined hourly cost for a harvester and two self-propelled chaser bins. A harvester and its chasers cut and load 60 tonnes per hour, which equates to about \$335 per hour, 24 hours a day, over a whole season.

The cost of hauling sugar cane out to the road trailers is assumed to be about one third of the \$5.60 per tonne. From this, an estimate of \$2 per tonne has been used in this study as the cost of hauling mallee biomass from the harvester to the road trailers using a similar chaser bin to those used for sugar cane. As the harvester cutting rate is less for mallees than for sugar cane, only one chaser bin will be required per mallee harvester, but the same per tonne rate should still apply to both crops.

Of the \$335 per hour, approximately two thirds, or \$225 per hour, relates to the capital recovery plus operating and maintenance of the harvester, and this hourly rate has been applied to the mallee harvester for estimating harvesting costs per tonne.

However in addition to the different yields for cane and mallee, the mallee crop is also more dispersed and travel from site to site will take more of a mallee harvester's time. It has been estimated that about one third of a harvester's time will be down-time spent on travelling and maintenance. This is a pessimistic estimate, especially for the medium to long term when the density and size of mallee plantings will both be greater than at present, but there is no experience in broad scale mallee

harvesting to base the estimate upon.

Cane farms being smaller, the distance from one paddock to the next is short. However cane harvesting has just-in-time delivery to the sugar mill to contend with, which reduces harvester production by about one third and increases the capital invested in machinery by 50%.

- As sugar cane is perishable, there is no stockpiling at the sugar mill. Delivery to the Ord River mill is strictly just-in-time in 24 tonne (one truck trailer load) increments and trucks can spend a large proportion of their time waiting to unload. This causes unavoidable hold-ups in the harvesting process and harvesters which can cut 90 tonnes per hour in average crop conditions, with instantaneous rates of over 150 tonnes per hour, have a whole of season average of 60 tonnes per hour.
- Two harvesters and four chaser bins supply the sugar mill with 120 tonnes of cane per hour, 24 hours a day. A third harvester and two additional chasers are kept in reserve to allow for maintenance and breakdowns – an extra \$800,000 in capital.

With a stockpile at the ITP plant of at least a week's feedstock, a mallee harvesting and transport system will be able to operate at its own pace without having to conform to the demands of strict JIT delivery to the plant. Maintenance of harvesters would not require the support of additional machinery on standby.

It has therefore been assumed that a mallee harvester will cost the same per shift hour, or per productive machine hour, as a cane harvester. With an average mallee yield of 15 kg, the harvest cost is estimated to be \$9.07 per tonne fresh weight loaded onto the trucks.

10.1.4 Transport

The transport system is conceptually the same as that employed in the Ord River sugar cane industry. In that industry, 500,000 tonnes per 6 month season is transported on 7 road trains which are moved in rotation by four prime movers. Empty road trailers are parked near the cane harvester to be filled while full trailers are hauled to the mill.

Table 18: Variables influencing the cost of transport

Variable	Range of values in used feed cost model	Derivation and comments
Transport distance	50 km	Assumed realistic distance for medium term supply of 100,000 tonnes per year of biomass.
Total prime mover hourly cost	\$80 per hour	Industry standard contract rates. Full cost of owning and operating.
Total cost of owning and maintaining trailers	\$1.43 per tonne	50 km transport distance. Tri-axle trailers with tandem dollies. Purpose built and owned by mallee industry.
Average speed	80 km/h	Assumed the transport distance
Loading time	30 minutes	Estimated time to drop empty road train and drive a few kilometres to hitch to a full one.
Unloading time	10 minutes	Receival hopper capacity of at least 45 tonnes. Side tipping trailers that do not require unhitching to tip.

Cost of transport is determined primarily by distance and the efficiency of loading and unloading.

Distance will vary over time as the industry develops and planting concentrates around ITP factories, but 50 km has been assumed for this study.

Loading is effectively part of the harvesting operation, as the chaser will transfer biomass from the harvester into the road trailers. However with the dispersed nature of the mallee resource, a truck will have to drop empty trailers close to the harvester and then travel a short distance back to find the full trailers left behind by the harvester. Unloading is by side tipping and assumes a large capacity receival hopper so that a whole road train may be tipped quickly. Hopper length is assumed to be 12 metres or one trailer length.

For a 50 km distance, transport is estimated to cost \$4.84 per tonne fresh weight, which is in line with log transport costs in the timber industry.

10.1.5 Total cost of biomass production delivered to the factory gate

Table 18 presents a range of costs of production for selected production scenarios and harvesting schedules. The costs of production vary from \$28.10 to \$36.50 per tonne of biomass (fresh weight) at the factory gate.

Assumptions include:

- A transport distance of 50km assumed to represent a reasonable average in the medium term (to 2010) Average haul distance could be less in the long term, but a small proportion of biomass may be hauled very long distances, even in the long term, to supply some of the winter feed from drier regions of the wheatbelt.
- The cost of establishment is repaid over a 20 year term
- A discount rate of 6.5%
- Other variables as specified in Tables above

Table 19: Variation in delivered biomass cost as a function of planting site

Production scenarios and harvesting schedules	Cost component	Cost per tonne of biomass (\$/t)
1(a) Low rainfall low production	Agricultural production	21.70
Harvest schedule 6 yrs, 4yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$20/ha/yr	Factory gate cost	35.60
Establishment cost \$650/km hedge		
1(b) Low rainfall medium production	Agricultural production	19.30
Harvest schedule 5yrs, 3yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$65/ha/yr	Factory gate cost	33.20
Establishment cost \$650/km hedge		
1(c) Low rainfall medium production	Agricultural production	14.20
Harvest schedule 5 yrs, 2yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$65/ha/yr	Factory gate cost	28.10
Establishment cost \$650/km hedge		
2(a) Medium rainfall medium production	Agricultural production	20.80
Harvest schedule 5 yrs, 3yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$80/ha/yr	Factory gate cost	34.70
Establishment cost \$650/km hedge		
2(b) Medium rainfall medium production	Agricultural production	22.60
Harvest schedule 5 yrs, 3yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$80/ha/yr	Factory gate cost	36.50
Establishment cost \$750/km hedge		
2(c) Medium rainfall high production	Agricultural production	14.60
Harvest schedule 4 yrs, 2yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$80/ha/yr	Factory gate cost	28.50
Establishment cost \$750/km hedge		
2(d) Medium rainfall high production	Agricultural production	15.90
Harvest schedule 4 yrs, 2yrs, 15kg	Harvesting & transport	13.90
Opportunity cost \$100/ha/yr	Factory gate cost	29.80
Establishment cost \$750/km hedge		

The results of a sensitivity analysis are presented in Table 19. The assumed standard scenario is described by production scenario and harvesting schedule 1(b) in Table 18 and Table 14.

Table 20: Sensitivity analysis

Variable	Range	Total cost of production at the factory gate (\$/t)	% variation in cost of production
Growth rate age at 1 st harvest 15 kg fresh weight biomass yield	4 years	\$32.02	- 3.5%
	5 years	\$33.20	
	6 years	\$36.71	+ 10.6%
Growth rate coppice harvest interval 15 kg fresh weight biomass yield	2 years	\$28.07	- 15.4%
	3 years	\$33.20	
	4 years	\$40.56	+ 22.2%
Growth rate combined age at first harvest and coppice harvest interval	4 yrs, 2 yrs, 15 kg	\$26.36	- 20.6%
	5 yrs, 3 yrs, 15 kg	\$33.20	
	6 yrs, 4 yrs, 15 kg	\$42.30	+ 27.4%
Opportunity cost of land ($\pm$ 20%)	\$52 per ha per yr	\$31.89	- 4.0%
	\$65 per ha per yr	\$33.20	
	\$78 per ha per yr	\$34.51	+ 4.0%
Establishment cost per km of hedge ($\pm$ 20%)	\$520 per km	\$30.82	- 7.2%
	\$650 per km	\$33.20	
	\$780 per km	\$35.58	+ 7.2%
Substitution ration ($\pm$ 20%)	0.8	\$31.89	- 4.0%
	1	\$33.20	
	1.2	\$34.51	+4.0%
Mallee weight at harvest ($\pm$ 20%)	12 kg	\$39.79	+ 19.9%
	15 kg fresh weight	\$33.20	
	18 kg	\$28.81	- 13.2%
Harvester cost per shift hour ($\pm$ 20%)	\$180	\$31.79	- 4.3%
	\$225	\$33.20	
	\$270	\$34.62	+4.3%
Harvester operating speed ($\pm$ 20%)	4 km per hr	\$34.97	+ 5.3%
	5 km per hr	\$33.20	
	6 km per hr	\$32.02	- 3.6%
Harvester downtime ($\pm$ 20%)	26%	\$32.52	- 2.0%
	33%	\$33.20	
	40%	\$34.03	+ 2.5%

Variable	Range	Total cost of production at the factory gate (\$/t)	% variation in cost of production
Prime mover hourly cost ($\pm 20\%$)	\$64	\$32.52	- 2.1%
	\$80 per hour	\$33.20	
	\$96	\$33.88	+ 2.1%
Loading and unloading time per load ($\pm 20\%$)	32 minutes	\$32.97	- 0.7%
	40 minutes	\$33.20	
	48 minutes	\$33.44	+ 0.7%
Distance ($\pm 20\%$)	40 km	\$32.63	- 1.7%
	50 km	\$33.20	
	60 km	\$33.77	+ 1.7%
Distance ($\pm 40\%$)	30 km	\$32.06	- 3.4%
	50 km	\$33.20	
	70 km	\$34.34	+3.4%

The most influential variable is mallee growth which is determined to a large extent by the quality of the land, the standard of mallee establishment and standard of management practices. The non-linear response of cost of production to mallee productivity is significant.

Well-managed mallee crops grown on the best land will result in the first harvest occurring relatively soon after establishment and short intervals between coppice harvests. Such scenarios are predicted to produce the highest returns relative to other agricultural enterprises on the same land, despite the high productivity of the conventional agriculture displaced by the mallees. This is demonstrated by scenarios 2(c) and 2(d) in Table 18, where a factory gate payment of \$30 per tonne equates to an opportunity cost (equivalent to a gross margin) in excess of \$100 per hectare per year. In contrast, the use of low productivity land with a very low opportunity cost, for example scenario 1(a) in Table 18, is not economically viable because the cost of mallee establishment is still high and over a 20 year term biomass production cannot produce a satisfactory return on that investment. The same low levels of mallee productivity could also result from poor management of mallees planted on good land.

Mallee weight at harvest is also very influential upon total cost of production, but 73% of this influence is due to the fact that larger mallees have grown faster, so reducing the cost per tonne of biomass of establishing and growing the crop. The balance (27%) of the influence of mallee weight acts through the cost of harvesting. Larger mallees increase the throughput of the harvester and so reduce the cost of harvest per tonne of biomass.

If the influence of growth rate is removed from mallee weight, the cost of harvesting becomes more apparent as shown in Table 20. For this table, it has been assumed that the mallees will take 3 years to reach 5 kg in weight and then grow at 5 kg per year until first harvest. Coppice growth is assumed to be 5 kg per year at all times. These data demonstrate the influence of short harvest rotations in reducing the cost of agricultural production, but the increased cost of harvesting small mallees is the dominant influence upon the total cost of production.

Table 21: Sensitivity analysis – mallee weight

Harvest rotation and mallee weight	Cost of agricultural production (\$/t)	Cost of harvest (\$/t)	Cost of transport (\$/t)	Total cost of production at the factory gate (\$/t)
6yrs, 4 yrs, 20kg	\$21.27	\$7.30	\$4.84	\$33.43
5yrs, 3 yrs, 15 kg	\$19.30	\$9.07	\$4.84	\$33.20
4yrs, 2 yrs, 10kg	\$18.68	\$12.60	\$4.84	\$36.12
3yrs, 1yr, 5kg	\$18.09	\$23.21	\$4.84	\$46.14

Establishment cost is the next most influential variable. The cost of seedlings account for about two thirds of the establishment cost. However the extent to which seedling cost can be reduced is limited because high-quality seedlings are fundamental to rapid growth and growth is the most important variable. The balance of the cost of establishment relates primarily to weed control which must be of a high standard for rapid growth and satisfactory survival. Varying the planting density offers the best prospect for reducing establishment cost. Due to the trend towards harvesting bigger mallees, mallee spacing trials have commenced to determine the optimum spacing along the row. Preliminary evidence indicates that wider spaced mallees (perhaps 2 to 2.5 m apart) may be as productive per kilometre of row per year as the present spacing of 1.5 m. A 20% reduction in the cost of establishment may be readily achieved in this way.

Harvester cost per hour and speed of operation are also important variables and will become the focus of future harvester development. Once the principles of mallee harvesting are established by development of the prototype machine, the size and power of the machine must be optimised, bearing in mind the trend towards cutting larger mallees. Optimising the machine is constrained by the need to cut close to the ground, which limits the maximum practical speed, and single row harvesting, which limits the tonnes cut per hour to the product of mallee weight and harvester speed. Two row harvesting is considered unlikely as the machine would become very large and cumbersome. The influence of harvester downtime is relatively small, but poor harvest system design could see downtime increase beyond the maximum value of 40% presented in Table 19.

The opportunity cost of the land, which is the long-term average gross margin of conventional agricultural enterprises, is significantly less influential than mallee productivity. This reinforces the importance of good land and proper management to low cost biomass production.

Transport variables are relatively minor influences upon the total cost of production, but like harvester downtime, the $\pm 20\%$ variations modelled in Table 19 could be exceeded if system design is inadequate. Haul distance is the variable most likely to cover a wide range. In the long term, some biomass is likely to be hauled long distances to overcome temporary shortages at individual factories. Factories in southern and western regions are liable suffer from shortages caused by wet soil conditions in winter and in northern and eastern regions, drought stress in autumn may cause similar problems. Consequently, a small proportion of any plant's annual feed may be hauled very long distances, and the total cost of biomass transport to each plant averaged over the annual feed. For example, if a plant is supplied from local resources for 11 months of the year and remote sources for 1 month:

11 months supply	average haul distance of 30 km	\$ 3.70 per tonne
1 months supply	average haul distance of 275 km	\$17.50 per tonne
Average cost for 12 months supply		\$ 4.85 per tonne

This estimated average cost is equivalent to a year-round average haul distance of 50 km. This form of cost averaging depends upon farmers statewide supplying biomass co-operatively to all ITP factories.

Gross margins of good mallee crops should be similar to the long-term gross margins of conventional wheatbelt agriculture. When comparing the gross margin of annual cropping with that of a perennial

mallee crop, it is important to consider that the annual crop gross margins must support substantial capital investment in farm machinery. Mallee gross margins are net of all machinery capital costs as these are included in the cost of harvesting. In addition, annual crops demand considerable labour annually from the farmer, whereas after initial establishment, mallees will require relatively little farm labour in harvesting and maintenance.

This analysis indicates that an average payment of about \$30 per tonne fresh weight would cover the costs of a well-managed mallee growing, harvesting and transport system.

10.2 Plant Capital Costs

Capital costs are shown in Appendix A, broken down by area. Details of what is included in each area are shown also.

Several scenarios were investigated, with the financial results being reported against Scenario 8, which is the preferred scenario for development and has a capital cost of \$28.4 million. Details of the scenarios are provided in Section 11.2.

A capital cost estimate for the complete ITP plant has been developed via the following steps:

- Develop processes to the point that all major equipment items may be nominated and budget prices obtained from vendors.
- Carry out similar work for services, utilities.
- Develop cost estimates for plant electrics and controls.
- Develop cost estimates for piping and valves.
- Estimate costs for equipment installation.
- Develop cost estimates for all civil and structural work, concrete, steel, drainage, fire protection, etc.
- Add costs for engineering, project management, and contingencies.

General note

The cost is an estimate only, not a quotation for a job, and as such includes no profit margin for a turnkey contractor. The estimate, however, does allow for normal overhead recovery on engineering and trades hours. This estimate is what the plant owner might expect to spend if they took the role of turnkey (or EPC) contractor for the job.

To convert this estimate to an estimate of EPC contract value, an additional amount of at least 7% would need to be added, dependent on the level of risk allocated to the contractor in the commercial conditions.

10.3 Plant Operating Costs

10.3.1 Water Supply and Effluent Disposal

10.3.1.1 Options available

The export electricity from the plant is produced via a steam turbine and generator. For optimal efficiency in conversion of steam energy to electrical energy the steam leaves the turbine at less than atmospheric pressure and is condensed under vacuum before being returned to the boiler. The quantity of water required by the ITP plant depends primarily on the method of cooling the steam turbine condenser, as this provides around 90% of the total cooling load. Given the shortage of water in many areas of WA and the high costs quoted for water as a result, several options for condensing were considered:

Option 1 Cooling water for all cooling loads.

This requires a large cooling tower, and large cooling water pumps. Large amounts of

water are evaporated into the atmosphere, and discharged to the plant effluent in the form of blowdown.

Option 2 Air cooling for steam-turbine condenser; cooling water for other loads.

Cooling water requirements are approximately 10% of those for Option 1, equipment is consequently smaller, and effluent production is reduced greatly. To provide cooling for the steam-turbine condenser, an air cooled condenser is used. This item is generally more expensive than the equipment for option 1, consumes more electricity, produces less electricity, and is noisier.

Option 3 Cooling of steam-turbine condenser using treated effluent water from the Narrogin effluent treatment plant; cooling water for other loads.

In this option, a wet-surface air-cooled (WSAC) condenser is used on the steam turbine. Water is sprayed onto the condenser tubes, and air is drawn over the wet tubes. Water consumption is greatly reduced, and clean water is not essential. The capital cost is greater than for conventional cooling towers, and using treated waste water from an effluent treatment plant will almost certainly create an odour problem.

Option 4 Air cooling followed by supplementary water cooling for steam-turbine condenser; cooling water for other loads

This option provides additional cooling to the steam-turbine condenser, so that electricity output is not reduced. The bulk of the load is provided by the air cooler, but water is used to reduce the condensate temperature to that achieved by cooling water.

The following table shows the relative costs of the various options. Costs are indicative only, and do not include associated engineering, civil installation and electrical/instrument costs. The connection and consumption costs of water, effluent supply, and effluent disposal have been obtained from Water Corporation.

Table 22: Cooling options

	Option 1 Water cooling	Option 2 Air cooling	Option 3 WSAC	Option 4 air + water cooling
Capex				
Cooling tower(s)	\$165,000	\$15,000	\$15,000	\$20,000
Steam-turbine condenser	\$350,000	\$670,000	\$500,000	\$700,000
Cooling water pumps	\$47,000	\$10,000	\$10,000	\$15,000
Cooling water piping	\$210,000	\$41,000	\$41,000	\$60,000
Steam turbine exhaust ducting		\$100,000	\$100,000	\$120,000
Water connection cost	\$3,500,000	\$750,000	\$750,000	\$850,000
Treated effluent supply connection cost			\$150,000	
Sewer connection cost	\$702,000	\$147,000	\$581,000	\$172,000
Total	\$4,970,000	\$1,740,000	\$2,150,000	\$1,940,000
Opex				
Fresh water ⁵	\$104,000	\$12,000	\$12,000	\$16,000
Treated effluent ⁶			\$70,000	
Effluent disposal ⁷	\$77,000	\$16,000	\$31,000	\$19,000
Electricity production ⁸	45,360 MWh/y \$2,720,000/y ⁹	45,040 MWh/y \$2,700,000/y ¹⁰	45,360 MWh/y \$2,720,000/y	45,360 MWh/y \$2,720,000/y
Electricity consumption				
Cooling tower fans	45 kW	5 kW	5 kW	7 kW
Cooling water pumps	300 kW	15 kW	15 kW	20 kW
STC fans				
Total		220 kW	48 kW	220 kW
	3,000 MWh/y \$180,000/y	1,920 MWh/y \$115,000/y	540 MWh/y \$32,000/y	1,980 MWh/y \$120,000/y
Total ¹¹	\$360,000/y	\$160,000/y¹²	\$150,000/y	\$160,000/y
Capex + 5 years' opex	\$6.8 million	\$2.6 million	\$2.9 million	\$2.7 million

⁵ Quoted by Water Corporation at \$0.40/m³

⁶ Quoted by Water Corporation at \$0.35/m³

⁷ Quoted by Water Corporation at \$0.671/m³ + additional charges for suspended solids and BOD; assumed total cost of \$1.0/m³

⁸ Assumed to be worth \$60/MWh

⁹ Assumes condensing temperature of 60°C all year round.

¹⁰ Assumes condensing temperature of 72.5°C for 100 h/y, 67.5°C for 900 h/y, 62.5°C for 2,100 h/y, 60°C for 4,900 h/y. The distribution was obtained by analysis of Narrogin's temperature records.

¹¹ Assumed to cost \$60/MWh. There are other consumers of electricity that are common to all options, and which are not shown.

¹² Includes \$20,000 for shortfall in electricity production compared with options

It is evident that:

- The reduction in output from the power station caused by using air cooling is not significant.
- The operating costs and capital cost of the water-cooled option are by far the highest.
- There is not much to differentiate the other three options, although air cooling appears to be the best, based on current quoted prices. For this reason air cooling (Option 2) was taken as the base case, and developed into Scenario 8. The WSAC case (Option 3) was developed into Scenario 9, and is assessed briefly in Section 11.2.

10.3.1.2 Quantities

The quantity of water make-up required is highly dependent on the method chosen for cooling the steam turbine condenser. Peak summer rates are estimated at:

Table 23: Peak summer water consumption rates

	Peak summer water consumption m³/h	Annual water consumption m³/y
Option 1 - water cooling	37	260,000
Option 2 - air cooling	3.7	30,000
Option 3 - effluent cooling	3.7 m ³ /h fresh water + 28 m ³ /h effluent	30,000 m ³ /y fresh water + 200,000 m ³ /y effluent
Option 4 - air + water cooling	5.1	40,000

Comparison of Options 1 and 2 shows that the steam turbine condenser is potentially a major consumer of water. Other users are:

- small heat exchangers
- boiler make-up
- RO unit blowdown
- plant administration (toilets, changerooms, kitchens)
- plant washdown

Water should be clean and relatively free of dissolved solids. Boiler feed water make-up will be demineralised by either ion exchange or reverse osmosis. The capital and operating cost estimates are based on reverse osmosis, as this is likely to have both lower capital and operating costs.

10.3.2 Operating Labour

Operating labour will comprise (for Scenario 8 - refer section 11.2):

Area	Classification	Gross labour cost allowed per year per person
Shift crew	Boiler attendant	\$70,000
	Carbon plant / packaging operator	\$60,000
	4 shifts + 1 relief boiler attendant	
Day crew	Plant manager	\$100,000

Plant engineer (assistant mgr)	\$90,000
Maintenance tradesman	\$70,000
Laboratory technician	\$60,000
Clerk	\$50,000
Yard operator (2)	\$50,000 each

Total annual labour costs **\$1,060,000**

The above costs include all general overheads for superannuation, insurance, tax leave, shift loading, etc.

10.3.3 Maintenance

Maintenance costs are estimated at 6% of the capital cost of the plant, in addition to the maintenance tradesman employed. This amount includes labour, materials and subcontract services. It is envisaged that operators would conduct routine maintenance (checking of oil levels, breaking pipes to clear blockages, etc.), and the maintenance tradesman would do more specialised tasks, including minor mechanical improvements, welding, pipe fitting, and overhaul of defective machinery (pumps, fans, etc). Other tasks would require hire of specialists, such as electricians, crane drivers, and stainless welders. The steam turbine will require routine overhauls supervised by the manufacturer every few years. It is assumed that if these skills are not readily available at the town in which the plant is located, they can be readily obtained from larger centres such as Perth, Kwinana or Bunbury. The quantity of maintenance to be carried out routinely will be sufficient to justify crews coming in annually from such centres.

Maintenance costs for a plant such as this can be as low as 3% of capex. This represents world's best practice (WBP). It will not be practicable to achieve WBP on the ITP plant, due to its small size and remoteness, and it is felt that 6% plus one tradesman will cover a well-run, small-scale operation.

Table 24: Services and Utilities

Area	Item	Annual cost
Boiler	Chemicals	\$1 600
Cooling tower	Chemicals	\$1 300 (air-cooled option) \$21,000 (water-cooled option)
Polishing plant	Chemicals	\$2,000
Demineralisation (RO)	Chemicals Cartridges	minor minor
Start-up fuel	Diesel	\$10,000, assuming approximately 1 start-up/mo
Fuel for inert gas	Diesel	\$500 000 (if inert gas used)
Bags for product		\$350 000
Misc consumables	Laboratory, workshop, office	\$100 000

10.3.5 Other operating costs

General head office support

An allowance has been made to cover support from the operating company's head office for such items as:

• Engineering 4 hours per week, plus 6 visits per year to site	\$30,000
• Recruitment \$5000 for advertising	\$5,000
• Insurance \$100,000 for miscellaneous property insurance (preliminary allowance)	\$100,000
• Licensing (eg. EPA) \$20,000 (preliminary allowance)	\$20,000
• Market and product development 4 hours per week, plus \$70,000 product testing and travel	\$95,000
Total	\$250,000

Accounting

An allowance of \$30,000 per year has been included to cover accounting advice, auditing of the books and preparation of tax returns. It is envisaged that basic bookkeeping and preparation and payment of invoices would be handled on a daily basis by the clerk included in the day crew.

Rates

An allowance has been made for local government rates, but its validity is yet to be established.
\$100,000

Interest on borrowings

It is assumed that the commissioning cost and the working capital are not provided as a capital sum, and need to be borrowed. An overdraft interest rate of 10% has been allowed.

Technology licensing

A royalty of 3% of activated carbon sales has been included.

11. Financial Analysis

11.1 Assumptions

The following assumptions were used in the financial analysis:

Table 25: Financial analysis assumptions

Item	Value used
Discount rate	12.5% (note that this is a typical rate for an industrial investment, which is higher than the rate of 6.5% as used above in on farm financial analysis for tree planting)
Project life	15 years from first investment
Residual value of plant	Nil
Construction period	20 months, with equal expenditure in years 1 and 2.
Commissioning period	3 months, resulting in year 2 production of 10% of nameplate.
Inflation	Costs: 2% pa. Revenue: nil
Depreciation	Straight line over 8 years
Company tax rate	36%
Losses carried forward	max 7 years
GST	Not considered
Interest on borrowings	10%
Investment allowance	nil
Financing	100% on balance sheet, except for commissioning costs and working capital
Feed purchase price	\$30/t
Production	Electricity 5 MW (40,000 MWh/y) Activated carbon 2,720 t GAC 294 t PAC (GAC fines) 1,090 t CAWP Eucalyptus oil 1,050 t
Selling prices	Electricity \$60/MWh No carbon credits No green power premium Activated carbon \$3,000/t GAC \$1,000/t PAC \$3,000/t CAWP Eucalyptus oil \$3,000/t
Technology licensing	Activated carbon 3% of AC sales
Working capital	2 months' opex
Sustaining capital	1.5% of capex per year

11.2 Financial Analysis

Several scenarios are described in the table below. These consider the impact of certain feed, product and site changes on capital and operating costs for the plant. The preferred scenario is number 8, and sensitivities for this scenario are presented in Section 11.3.

11.2.1 Scenario Development

Scenario 1 was developed as a first pass. It assumed a water-cooled steam turbine condenser, production and use of nitrogen for cooling hot charcoal and activated carbon, 3 months' feed storage, and land purchase at \$30/m². Since the IRR was unsatisfactory, further scenarios were investigated.

Scenario 2 avoided manufacture of activated carbon pellets. Pellets require a lot of expensive equipment, so a significant reduction in capex was envisaged. However, making pellets adds significant value to the fine charcoal made as part of the granular activated carbon process. On the figures shown below, deleting pellet manufacture is beneficial, but it is very sensitive to the price differential between pellets and powder. Manufacture of pellets was retained for further analysis, but needs to be kept under review.

Scenario 3 deleted nitrogen production and use, with consequent capex and opex savings. It was felt that much cheaper options for cooling charcoal and activated carbon could be found during detailed engineering. Deletion of nitrogen improved the IRR, and so was not considered further.

Scenario 4 looked at avoiding 3 months' feed storage, with consequent savings in storage facilities, land requirements, drainage requirements, roads, lighting and site preparation. This had a major effect on IRR, and was therefore retained. The onus was placed on the feed supplier to be able to supply year round. Other difficulties such as whether feed could be stored for 3 months without deterioration were recognised, but not addressed.

Scenario 5 was variation on Scenario 4, when it became apparent that land costs were likely to be much lower than expected, and that free land was a possibility. The estimate for the civil work was also felt to be conservative, and was reduced by 10%. This reduction would be achieved by a reduction in the finish level of the plant, and by design changes that became apparent after the civil costing had been completed. This scenario was adopted as the base case for issue of the draft of this report in September 1999.

Following discussion of the draft report, water consumption and feed storage became major topics for further study. Scenario 6 was developed to investigate the possibility of burning all leaves in a 6 month period, to avoid both leaf storage and feed harvesting difficulties. Wood would still be stored for up to 6 months to enable year-round processing, but this did not present technical problems. This scenario did not produce satisfactory economics.

Scenario 7 was a minor variation to Scenario 5 which required a week's storage of feed under cover.

Scenarios 8 and 9 looked at the different water supply options discussed in Section 10.3.1, and were based on Scenario 7 (water-cooled steam turbine condenser). Scenario 8 used an air-cooled steam turbine condenser, and Scenario 9 used a WSAC cooled by treated effluent. As Scenario 8 is marginally better than Scenario 9, it was chosen as the base case.

Scenario 10 was a variation on Scenario 6 to see whether the benefits of air cooling could make a 6-month harvest season attractive. Although there was an improvement in IRR, this scenario was not considered further.

Table 26: Scenario Development

	Scenario 1	Scenario 2 ¹³	Scenario 3	Scenario 4	Scenario 5
Description	All items included	No pellets	No nitrogen	As per Scenario 3, but also with no feed storage	As per Scenario 4, but also with minimal civil peripherals, and free land
Adjustments to capex	nil	Delete costs for area 4	Delete 80% of costs for area 11	Scenario 3 changes Delete costs for area 112 (feed storage) Reduce area 113 costs (land purchase) by 50% Reduce area 110 costs (drainage) by 50% Reduce area 111 (misc site - fencing, lighting, roads, site prep, rock excavation) costs by 40%.	Scenario 4 changes Delete remaining costs for area 113 (land purchase) Delete 80% of costs for area 106 (amenities) Reduce remaining civil costs by 10%
Adjustments to opex ¹⁴	nil	Delete costs of binder for pellets	Reduce plant consumables by \$500,000	Reduce labour costs by replacing 1 operator per shift + 1 relief operator (k\$300/y) with 2 day shift operators (k\$100/y).	
Other adjustments		Some GAC fines to be sold			
Capex	\$38,792,000	\$37,063,000	\$38,076,000	\$33,354,000	\$31,745,000
Opex (incl. feed and interest)	\$9,412,000/y	\$8,617,000	\$8,861,000	\$8,370,000	\$8,272,000
Revenue	\$17,274,000	\$16,440,000	\$17,274,000	\$17,274,000	\$17,274,000
IRR	9.1%	9.9%	10.6%	14.3%	15.5%
NPV (12.5% discount rate)	-\$4,969,000	-\$3,753,000	-\$2,763,000	+\$2,448,000	+\$3,959,000

¹³ If CAWP is not made, the GAC fines need to be sold at a heavily discounted price. Deleting CAWP may not be beneficial if CAWP sells at a premium to GAC.

¹⁴ A reduction in capex will automatically result in a reduction in opex, as maintenance is a percentage of capex.

	Scenario 6	Scenario 7	Scenario 8 (base case)	Scenario 9	Scenario 10
Description	As per scenario 5, but with 1 week's dry storage and wood storage to suit 6 month harvest period. All leaves processed immediately.	As per scenario 5, but with 1 week's dry storage.	As per scenario 7, but with air-cooled steam turbine condenser.	As per scenario 7, but with a wet-surface air-cooled (WSAC) steam turbine condenser.	As per scenario 6, but with air-cooled steam turbine cooled condenser.
Adjustments to capex	Increase size of leaf processing and burning plant. Increase size of steam turbine, and power export equipment. Add in capital costs of dry storage, and of wood storage.	Add in capital costs of dry storage	Cooling tower, cooling water pipework much smaller. Replace water-cooled condenser with air-cooled condenser.	Cooling tower, cooling water pipework much smaller. Replace water-cooled condenser with WSAC condenser.	Cooling tower, cooling water pipework much smaller. Replace water-cooled condenser with air-cooled condenser.
Adjustments to opex ¹⁵	Increase labour costs by replacing 2 day shift operators (k\$100/y) with 1 operator per shift + 1 shift relief (k\$300/y)		Reduced water consumption and effluent production.	Reduced fresh water consumption and effluent production. Need a supply of dirty water (Narrogin town effluent).	Reduced water consumption and effluent production.
Other adjustments					
Capex	\$40,906,000	\$32,185,000	\$28,386,000	\$28,020,000	\$36,461,000
Opex (incl. feed)	\$9,033,000	\$8,299,000	\$7,892,000	\$7,987,000	\$8,587,000
Revenue	\$17,274,000	\$17,274,000	\$17,274,000	\$17,274,000	\$17,274,000
IRR	9.3%	15.2%	18.8%	18.4%	12.1%
NPV (12.5% discount rate)	-\$4,966,000	\$3,546,000	\$7,784,000	\$7,315,000	-\$577,000

¹⁵ A reduction in capex will automatically result in a reduction in opex, as maintenance is a percentage of capex.

11.3 Sensitivity Analysis

Sensitivities are shown with respect to Scenario 8. This scenario assumes that a year-round supply of feed will be available, and that water supply and effluent disposal problems will be minimised.

Table 27: Sensitivities

Item	Range	IRR	NPV
Capex	-10%	21.7%	\$10,451,000
	0	18.8%	\$7,784,000
	+10%	16.4%	\$5,118,000
Opex	-10%	21.0%	\$10,839,000
	0	18.8%	\$7,784,000
	+10%	16.5%	\$4,721,000
Feed cost	\$25/t	20.2%	\$9,723,000
	\$30/t	18.8%	\$7,784,000
	\$35/t	17.4%	\$5,846,000
GAC price	\$2400/t	14.7%	\$2,512,000
	\$3000/t	18.8%	\$7,784,000
	\$3500/t	22.0%	\$12,177,000
CAWP price	\$2400/t	17.2%	\$5,671,000
	\$3000/t	18.8%	\$7,784,000
	\$3500/t	20.1%	\$9,545,000
PAC price	\$800/t	18.7%	\$7,594,000
	\$1000/t	18.8%	\$7,784,000
	\$1200/t	19.0%	\$7,974,000
Eucalyptus oil price	\$2500/t	17.5%	\$6,047,000
	\$3000/t	18.8%	\$7,784,000
	\$3500/t	20.1%	\$9,521,000
Electricity price	\$50/MWh	17.8%	\$6,445,000
	\$60/MWh	18.8%	\$7,784,000
	\$70/MWh	19.8%	\$9,123,000
Green power premium	\$0/t	18.8%	\$7,784,000
	\$50/MWh	23.6%	\$14,478,000
Carbon credits	\$0/t	18.8%	\$7,784,000
	\$6.80/t	19.4%	\$8,535,000
Plant availability	10% less production	14.2%	\$2,003,000
	planned production	18.8%	\$7,784,000
	10% more production	23.0%	\$13,565,000

Item	Range	IRR	NPV
Proportion of wood in feed	40%	13.1%	\$716,000
	45%	16.1%	\$4,250,000
	50%	18.8%	\$7,784,000
Exchange rate ¹⁶	10% fall in A\$	22.6%	\$13,096,000
	no change	18.8%	\$7,784,000
	10% rise in A\$	8.2%	-\$5,852,000
Inflation - costs / revenue	0% / 0%	21.5%	\$11,945,000
	2% / 0%	18.8%	\$7,784,000
	0% / 2%	25.7%	\$20,123,000
	2% / 2%	23.5%	\$15,962,000
Interest on borrowings	6%	19.1%	\$8,117,000
	8%	18.9%	\$7,951,000
	10%	18.8%	\$7,784,000
	12%	18.7%	\$7,616,000
Debt / equity ratio	0% / 100%	18.8%	\$7,784,000
	50% / 50%	31.9%	\$13,360,000
	80% / 20%	60.2%	\$16,706,000
	90% / 10%	90.8%	\$17,821,000
Depreciation rate	12.5% (8 years)	18.8%	\$7,784,000
	10% (10 years)	18.3%	\$7,239,000
	6.67% (15 years)	17.3%	\$6,110,000
	5% (20 years)	16.5%	\$5,089,000
Company tax rate	33%	19.3%	\$8,492,000
	36%	18.8%	\$7,784,000
	39%	18.3%	\$7,076,000
Implementation of “Ralph report” recommendations	Depreciation rate / Company tax rate		
	12.5% / 36%	18.8%	\$7,784,000
	6.67% / 30%	18.5%	\$7,805,000
Effect of GST	See below		

¹⁶ Based on 25% of equipment, 50% of piping, and 35% of electrical/instrument being subject to exchange rate variation. For scenario 8, this means that \$5,495,000 (including contingency) of the estimate is affected. Assumption is that all production is either sold locally at an import competitive price, or sold overseas. Further assumption that the exchange rate variation happens prior to commencement of the project.

Table 28: Summary of sensitivities

IRR is very sensitive to:	a) Debt to equity ratio b) Exchange rate c) Plant availability d) GAC price e) Proportion of wood in feed f) Capex g) Opex h) Assumed escalation scenarios for costs and revenues
IRR is moderately sensitive to:	a) CAWP price b) Feed cost c) Eucalyptus oil price d) Electricity price
IRR is not very sensitive to:	a) Depreciation rate b) Company tax rate c) “Ralph report” recommendations d) PAC price e) Interest rate on borrowings

11.3.2 Effect of GST

The effect of the GST is not considered significant. Two aspects are relevant:

Capital purchases:

Advice obtained from the Australian Taxation Office (ATO) was that GST would need to be paid on all capital purchases; however, provided the equipment was used for a manufacturing purpose, it could all be claimed back. As such, the costs to the project would be the GST payable on non-manufacturing items, such as computers, telephones, and lighting. In some cases, the GST payable would be less than the amount of sales tax that is currently payable. The effect of the GST is therefore negligible. Possibly, the greatest effect will be that the tax will need to be financed from the time it is paid, until it is reimbursed by the ATO.

Operational expenses:

Again, GST will need to be paid on all purchases of goods and services for the plant. This includes feedstock, water, electrical services, maintenance materials, bags, diesel and office supplies. GST will need to be collected from customers for products sold. There will be a cost in financing the GST from when it is paid, until when customers pay for the finished product. This is not expected to be significant - it is of the order of a 10% increase in working capital, which would increase opex by 0.3%.

The effect of imposing the GST on product sales is the same for all companies with local sales, and therefore does not affect the competitiveness of the products. Overseas sales do not attract GST.

12. Project Risk

Key risks for this project are:

12.1 Cost risks

Costs, both capital and operating, may be higher than expected. Sensitivities are shown in Section 11.3. By constructing a demonstration-scale plant, the risks will be greatly reduced, in that:

- the scope of the costs will be almost completely defined, needing only scale-up and addition of items such as pellet production.
- a better database of equipment and installation costs will be available
- operating costs will be almost completely defined, needing only scale-up.

At this stage of the project, risks have been kept to acceptable levels, by use of proven estimating techniques. These include:

- Doing a significant amount of basic engineering to establish sizes of equipment.
- Obtaining budget prices for major items
- Preparation of basic flow sheets and layouts
- Estimating weights of major items
- Use of specialist subcontractors to estimate civil, electrical, instrument and installation costs

A contingency of 10% has been applied to the estimate to cover items that may have been omitted, or where the cost may vary from the estimate. The contingency is not intended to cover additions to the scope.

12.2 Feed supply risks

12.2.1 Planting of trees

If trees are not planted, the plant will not be able to operate as designed. The rate of planting of trees is affected mainly by:

- the cost of seedlings and of planting them
- the availability of a market for harvested trees
- the returns to the farmer from sale of harvested trees

The cost of getting trees planted is a major concern to farmers, particularly when the likelihood of a market is unclear. Some subsidies are available, but will provide a limited benefit only. Investment in plantings by organisations interested in acquiring carbon sequestration credits may assist the rate of planting. Project stakeholders may also be interested in investing in plantings to ensure the supply of feed to the project, and may be able to direct that they be planted in areas that can be harvested year-round. For a plant requiring 100,000 t/y of feed, approximately 20 million trees need to be in the ground, assuming 10 kg per tree and harvesting every 2 years), with associated investment of \$10 million. To provide a 6.5% return, the investor would need around \$15/t for harvested feed. If carbon sequestration benefits are included, this figure reduces by about \$0.65/t, assuming a payment of \$6.80/t of carbon sequestered.

It is expected that construction of the demonstration plant will provide a major boost to plantings in the Narrogin area, as a significant market develops. Expansion of the plant will occur only when it is apparent that sufficient feedstock will be available when the plant is ready to accept it.

The price paid for material harvested will be market-driven. A higher price will encourage more planting. If the price paid for feed for the demonstration plant does not encourage sufficient additional

planting for expansion, the expansion is unlikely to occur.

12.2.2 Harvester

The feed supply depends on having a machine that can harvest the trees at the required rate, and chip them to an agreed specification. The harvester is currently under development. During operation of the demonstration plant, any lack of capacity, reliability or ability to produce on-specification feed will become apparent. Expansion of the demonstration plant will not occur until all deficiencies have been sorted out. The ongoing cost of harvester development over the next few years is assumed to be covered by the feed cost.

It is considered that transport of the harvested material from the farm to the plant presents no great risk. The equipment that is envisaged will be identical to equipment used for harvesting sugar cane in the Ord River area, and alternative equipment exists.

12.2.3 Continuity of harvest

The design of the plant assumes that a continuous supply of feed is available, with no allowance in the design for any seasonal harvest variation. Refer to section 11.2, and the comparison between Scenarios 6 and 7, to see the effect on the viability of providing some long-term storage.

Short-term storage is available to cover interruptions caused by:

- total fire bans
- weekends and public holidays
- bad weather
- night
- minor breakdowns to the harvester

Conversely, short-term storage will enable the plant to continue to receive feed when it is shut down, running at low rates, or when several deliveries are made in a short period of time.

Any delays in excess of a few days will jeopardise production. Mitigation steps other than development of long-term storage facilities include:

- Sourcing feed from further away, where harvest conditions may be better - this will attract a cost penalty for transport.
- Encouraging planting of trees in areas that can be harvested over most of the year.
- Sourcing alternative feeds such as bluegum (*E. globulus*) that are harvested year-round. Such feeds are likely to be more expensive, as transport distances will be greater, there is a competing market for the wood, and no established mechanism for harvesting/collecting leaves. Eucalyptus oil from bluegum is likely to be less valuable than mallee-sourced oil, and no testing has been done of activated carbon made from bluegum. If oil is not feasible, it should still be possible to run the activated carbon section and substitute wood for leaf in the power section. Use of native species from old-growth forests may affect the “greenness” of the electricity produced.
- Developing a harvester that can harvest for more of the year. Use of a tracked harvester may be better than a wheeled one.
- Paying a premium for feed delivered in the suboptimum harvest season. For example, feed delivered during summer could attract \$25/t, autumn and spring \$30/t, and winter \$35/t. Alternatively, some sort of “delivery continuity” bonus could be paid.

12.3 Technology risks

There is a risk that the full-scale ITP plant may not work as expected. The plant is required to use feed to produce activated carbon, eucalyptus oil, and electricity of agreed quality, at agreed rates, and in

agreed annual quantities. In addition, it must provide a return to its owners, and maintain its “licence to operate”.

Any of these deficiencies found in the demonstration plant will be rectified before committing to an expansion. Design of both the demonstration plant and subsequent expansions will include hazop and hazan activities to identify potential problems. A “hazop” study, or Hazard and Operability study aims to identify potential safety and operating problems in a process plant at the detailed engineering stage. A “hazan” study, or Hazard Analysis study quantifies these risks, so that the cost benefit of addressing them can be calculated. Identification of potential problems at an early stage will enable cost-effective treatments to be implemented.

Note that it is not planned to make activated carbon pellets in the demonstration plant. The risk that there will be technical problems with pellet manufacture will be mitigated by commencing production at low rates, and expanding as market acceptance and operating experience are gained.

12.4 Environmental risks

Any environmental problems will be sorted out in the demonstration plant. Major problems are not expected as the pilot plant work has indicated that emissions are far less than for competing processes. An environmental management plan will be implemented during the construction phase of the demonstration plant project, and will be augmented as necessary afterwards.

The plan will detail procedures for monitoring environmental compliance, and handling of environmental accidents, during construction and operation of the plant.

12.5 Safety risks

Any safety problems will be sorted out in the demonstration plant. A comprehensive safety management plan will be implemented during the construction phase of the demonstration plant project, and will be augmented as necessary afterwards.

The plan will detail requirements for the safe construction, start-up, operation, shut-down and maintenance of the plant.

12.6 Sales risks

Again, market acceptance of the plant’s production will become evident during the demonstration plant phase.

12.6.1 Activated carbon

Work to date has focussed on making granular activated carbon for potable water treatment and carbon pellets (CAWP) for gold recovery. Risks exist that:

- There will be new entrants to the market. This will be managed by the plant’s marketing efforts, which will maintain knowledge of what the plant’s competitors are doing, so that decisions can be made with as much knowledge as possible.
- The value of the Australian dollar will rise, affecting sales prices overseas, and lowering the cost of imports. Hedging may provide some relief against short to medium-term fluctuations, but a long-term rise may have serious consequences.
- There will be an economic downturn that reduces demand for activated carbon. It is expected that demand for water-treatment activated carbons will grow as population growth puts pressure on water supplies, so that the plant’s proportion of the market will fall. Sale of pellets to the gold industry is likely to be more cyclical, but is not expected to exceed 25% of sales. It will not be difficult to make additional granular carbon, if the market for pellets declines.
- Alternative technology will be developed that reduces demand for activated carbon. This may have serious consequences and it is quite likely that alternatives using resins or molecular sieves are

being examined, however no such technology has been indicated as providing a significant threat in discussions to date with suppliers or users.

- Prices will fall in a “price war”. There will be a continual focus on cost reduction. The economic model used assumes that prices will fall in real terms by 2% pa. An alliance with an existing wholesaler or manufacturer of activated carbon will provide additional financial stability during any price war, as well as reducing the likelihood of its starting. It is understood that the entry of low-grade and low-cost activated carbon manufactured in China captured much of the bottom end of the water market several years ago. Similarly the entry of low-cost coconut shell carbon captured the lower end of the gold market. However these carbons are now established in the overall marketplace and it is felt that the middle and upper parts of the markets (where ITP carbons are focussed) are relatively stable.
- Low cost activated carbon will flood the market. Activated carbon from coconut shell is being manufactured in increasing quantities in Asia, however this carbon is often directed at markets of lower quality and cost than those targeted by the mallee carbons. It is not expected that it will have a significant impact .

12.6.2 Eucalyptus oil

The risks and strategies are generally the same as for activated carbon, with the additional problem that eucalyptus oil will need to be sold into non-traditional markets. As well, the plant will be the world’s largest producer of eucalyptus oil, and will be competing against Chinese production which is now sold below the traditional market price, apparently to ensure that the whole production is sold.

Testing the new markets will be essential during the demonstration plant phase. Marketing strategy is also important, with marketing by the ITP team offering potentially greater margins, but marketing by third parties such as the major world suppliers offering faster market penetration and greater security.

12.6.3 Electricity

The main risk is changes to government policy. Demand from customers for premium-priced “Green” power is minimal, and the utilities’ general renewable energy sourcing activities are currently government-driven because of the Mandated Renewable legislation for the Energy Target.

Policy changes that would affect the plant include:

- Changes to the requirement to provide an additional 2% of capacity from renewable sources.
- Imposition of a carbon tax.

The risk of cheaper, alternative, base-load, renewable-energy power stations being built in Western Australia is small, due to the lack of suitable hydro sites in populated areas. Tidal, wave and PV power are likely to be more expensive. Wind will not provide a base load, and landfill gas will never contribute significantly to the 2% target.

Appendix A - Capital cost estimate - 5 MWe ITP plant

A.1 Scope of estimate

The sections below describe what is included in each of the sections listed in the estimate.

Equipment cost

Exclusions freight (see area 114)

Inclusions import duties

instruments

control valves

Equipment installation cost

Piping cost (labour and materials)

Inclusions manual valves

insulation of piping

refractory lining of piping

Electrical and instrumentation work

Inclusions control system

MCCs

field wiring and marshalling boxes

cable ladder

programming

electrical and instrument engineering, project management and pre-commissioning

Exclusions flameproofing of any equipment other than around oil extraction plant and in water gas production area

Civil work

Inclusions Foundations, slabs, upper floors, steelwork, platforms, staircases, lighting, cladding, roofing, doors, ventilation, drainage, painting, signs, crushed rock on unpaved work areas.

Exclusions Permit fees

Sprinklers - it is assumed that these will not be required, due to the low quantities of flammable material within the plant.

Engineering

Inclusions: Mechanical and civil design, procurement and construction.

Project management

Pre-commissioning

Exclusions Environmental impact study

Contingencies

Inclusions Minor omissions and errors needed to complete the defined scope.

Exclusions Anything not included in the defined scope.

A.2 Description of plant areas

The following description applies to Scenario 8.

Area 1 - Feed handling

Equipment included:

- Gantry for tipping trailers
- Truck unloading
- Winnowing
- Leaf and wood hoppers
- Wood flow metering
- Screening of wood feed fraction
- Rechipping of oversize

Area 2 - Charcoal making

Equipment included:

- Charcoal production
- Boiler feed water heating
- Steam turbine condensate heating

Area 3 - Granular carbon making

Equipment included:

- Charcoal metering
- Charcoal milling
- Charcoal classification
- Activation
- Boiler feed water heater

Area 4 - Pellet making

Equipment included:

- Binder preparation
- Blending of binder with charcoal
- Extrusion of pellets
- Calcining
- Metering of flow of pellets to Area 3 for activation

Area 5 - Packaging

Equipment included:

- Pallet dispenser
- Bulk bag filling station to trade accuracy
- Accumulation conveyor to hold 5 bags
- Storage area (open air, on concrete) for one week's production (approx 80 bags).

Area 6 - Oil extraction

Equipment included:

- Leaf metering
- OMC extraction process
- Oil storage tank for 20 t of oil (1 tanker load, approx 1 week's production)

Area 7 - Leaf combustion

Equipment included:

- Leaf combustor
- Ash handling facilities

Exclusions:

- Ash storage and loading facilities.

Area 8 - Steam circuit

Equipment included:

- Demineralised water plant (reverse osmosis)
- Chemical dosing plant
- Deaerator
- Boiler feedwater pumps for 45 bar
- Waste heat boiler for leaf combustor
- Steam drum
- Headers on charcoal fluidised bed for steam and superheated steam raising
- Condensing steam turbine and alternator rated at 5 MWe
- Air-cooled steam-turbine condenser
- Condensate return pumps
- Condensate polishing plant

Exclusions:

- Supplementary water-cooling of steam turbine condensate to lower pressure in summer.

Area 9 - LP steam distribution

Equipment included:

- Pressure reduction station to produce low-pressure (6 bar) steam for activation, calcining, deaeration, oil extraction, and possibly cooling of charcoal and AC.

Area 10 - High-temperature hot oil (HTHO) circuit

A source of heat is required for the mixer used to blend charcoal with binder for pellet production. A temperature of more than 200°C is required. Steam is impractical due to the high pressure required. The mixer would be very expensive as it would need special high-pressure jacketing. HTHO can provide the heat required at much lower pressure, but using steam to heat HTHO is also expensive. It was therefore decided to use electric heating, and so area 10 was deleted.

Area 11 - Diesel, plant air, nitrogen

Equipment included:

- Diesel storage and pump
- Plant air compressor

Exclusions:

- Nitrogen plant. Stoichiometric combustion of air is used to produce an inert gas containing principally nitrogen and carbon dioxide. The gas is saturated with water, and contains a small amount of oxygen.

Nitrogen would be used for cooling of hot charcoal and activated carbon, and as a safety mechanism for inerting potentially hazardous situations, such as fires in fluidised beds.

The equipment required is expensive, however, and has high associated operating costs (diesel and cooling water), and so it was decided that jacketed screw conveyors, cooled with cooling water and/or steam, will provide an alternate means of cooling, and that water or stored flame retardants could be used to control fires.

Area 12 - Cooling towers

Equipment included:

- A small cooling tower
- 2 pumps each capable of handling 100% of full duty
- Distribution system to charcoal and AC cooling, water gas cooling and extruder.

Area 101 - Mobile plant

Equipment included:

- Ride-on forklift

Area 102 - Transformer yard

Inclusions:

- Civil works to transform plant power supply to 415V

Area 103 - Power export

Inclusions:

- Connection of alternator to grid
- Connection of grid to internal distribution system
- Associated civil works

Area 104 - Control room

Inclusions:

- Fire-rated civil works to house MCCs and control system

Area 105 - Administration building

Inclusions:

- Timber single-storey building approx 100 m² with offices, meeting room, kitchen and toilets
- Computers
- Office software
- Phones - “Commander”-style system

Area 106 - Amenities building

Inclusions:

- Addition to administration building to provide limited male and female changerooms, showers and toilets

Area 107 - Workshop

Inclusions:

- Steel-frame building with “colourbond” roof and walls
- Work bench
- Spare parts storage
- Basic tools

Area 108 - Laboratory

Inclusions:

- Steel-frame building with “colourbond” roof and walls
- Work bench
- Chemical storage
- Basic equipment for QC purposes.

Area 109 - Sewer and water connections

Inclusions:

- Connection to trade waste
- Connection to domestic effluent sewer
- Connection to town water supply (approx 3.7 m³/h - air cooled option).

Area 110 - Drainage

Inclusions:

- Storm water collection
- Triple interceptor pit to remove solids and floating material from storm water runoff
- “First flush” system to collect and store first 150 m³ of storm water falling on site (equivalent to 5 mm of rain over whole site).

Area 111 - Miscellaneous site

Inclusions:

- Footpaths
- Roller doors
- Car parking for 15 cars
- Fire protection - hydrants and rose reels, water storage tank, electric and diesel pumps, ring main around feed stockpile
- Fencing
- Roads
- Landscaping
- Signage
- Crossovers
- Exterior lighting
- Site preparation - assumes site is basically flat and easy to work.
- Rock excavation - \$100,000 allowance.

Exclusions:

- Effluent treatment

Area 112 - Feed storage

Inclusions:

- Small Caterpillar-type bulldozer with chip blade for stacking, reclaiming and shaping stockpile.
- Undercover, concreted area for storing 2,000 t of feed (1 week) to smooth out surges in feed supply.

Exclusions:

- Storage of larger amounts of feed

Area 113 - Site purchase

Inclusions:

- nil

Exclusions:

- Land cost is not included in this estimate. Land could cost around \$30/m² (\$300,000/ha). This price is generally applicable to industrial areas around major centres. In rural WA the alternative of purchasing farmland and rezoning could provide land at approximately \$1000/ha, however significant additional capital could be required for adequate road connections, power, sewerage, etc.

Area 114 - Freight

Inclusions:

- Allowance for freight of all items from source to Narrogin, WA.

Area 115 - Spare parts

Inclusions:

- Initial set of spare parts, including some capital spares for all items listed above

A.3 Capital cost estimate

Capital costs are shown for scenario 8. All costs are in \$'000.

Area	Description	Equipment	Installation	Piping	Elec/Instru incl eng'g ¹⁷	Civils	Engineering (mech and civil)	Contingency
1	Feed handling	\$ 653	\$ 18	\$ 2	\$ 47	\$ 48	\$ 85	\$ 77
2	Charcoal making	\$ 1077	\$ 52	\$ 63	\$ 84	\$ 272	\$ 168	\$ 155
3	GAC making	\$ 3321	\$ 108	\$ 197	\$ 255	\$ 558	\$ 485	\$ 444
4	CAWP making	\$ 815	\$ 81	\$ 60	\$ 67	\$ 374	\$ 148	\$ 140
5	AC packaging	\$ 171	\$ 29	\$ 2	\$ 14	\$ 184	\$ 41	\$ 40
6	Oil extraction	\$ 205	\$ 24	\$ 69	\$ 21	\$ 18	\$ 37	\$ 34
7	Leaf combustion	\$ 3,676	\$ 7	\$ 135	\$ 268	\$ 63	\$ 464	\$ 415
8	Steam circuit	\$ 3,843	\$ 82	\$ 569	\$ 316	\$ 401	\$ 575	\$ 521
9	LP steam distribution			\$ 170	\$ 12		\$ 20	\$ 18
11	Diesel, plant air, N ₂	\$ 62	\$ 1	\$ 71	\$ 2	\$ 6	\$ 17	\$ 14
12	CW	\$ 38	\$ 4	\$ 241	\$ 20	\$ 30	\$ 37	\$ 33
101	Mobile plant	\$ 35					\$ 4	\$ 4
102	Transformer yard					\$ 75	\$ 7	\$ 7
103	Power export	\$ 990				\$ 9	\$ 120	\$ 100
104	Control room					\$ 56	\$ 5	\$ 6
105	Admin	\$ 35				\$ 95	\$ 13	\$ 13

¹⁷ Pro rata amount in proportion to mechanical work.

Area	Description	Equipment	Installation	Piping	Elec/Instru incl eng'g ¹⁷	Civils	Engineering (mech and civil)	Contingency
106	Amenities					\$ 27	\$ 2	\$ 3
107	Workshop					\$ 41	\$ 4	\$ 4
108	Laboratory					\$ 41	\$ 4	\$ 4
109	Sewer, water connections					\$ 897	\$ 81	\$ 90
110	Drainage					\$ 272	\$ 25	\$ 27
111	Misc site					\$ 617	\$ 56	\$ 62
112	Feed storage	\$ 150				\$ 207	\$ 37	\$ 36
113	Site purchase					\$ 0		\$ 0
114	Freight							\$ 628
115	Spare parts	\$ 628						
	Total	\$ 15,699	\$ 407	\$ 1,579	\$ 1,105	\$ 4,289	\$ 2,433	\$ 2,873
	Grand total	\$ 28,386						

Appendix B - Existing and projected feed supply data

Table B.1 Standard planting data according to the OMA Development Plan of May 1998
Expected growth, survival and proportion of sites that are harvestable.

Region	Upper Great Southern region						Southern region						Eastern Wheatbelt region					
Planting year	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival
1992							40,000	70%	0%	80%	20%	70%						
1993	23,000	70%	0%	80%	20%	70%	18,000	70%	0%	80%	20%	70%						
1994	67,000	70%	0%	80%	20%	80%	79,000	70%	0%	80%	20%	80%	95,000	70%	0%	55%	45%	70%
1995	325,000	70%	10%	80%	10%	80%	144,000	70%	10%	80%	10%	80%	269,000	70%	0%	55%	45%	70%
1996	450,000	70%	10%	80%	10%	80%	170,000	70%	10%	80%	10%	80%	599,000	70%	0%	55%	45%	80%
1997	300,000	80%	20%	80%	0%	80%	139,000	80%	20%	80%	0%	80%	291,000	80%	0%	60%	40%	80%
1998	350,000	90%	20%	80%	0%	90%	160,000	90%	20%	80%	0%	90%	341,000	90%	0%	65%	35%	90%
1999	640,000	90%	20%	80%	0%	90%	236,000	90%	20%	80%	0%	90%	644,000	90%	0%	65%	35%	90%
2000	1,200,000	95%	25%	75%	0%	95%	500,000	95%	25%	75%	0%	95%	1,200,000	95%	0%	70%	30%	95%
2001	2,100,000	95%	25%	75%	0%	95%	1,200,000	95%	25%	75%	0%	95%	2,100,000	95%	0%	70%	30%	95%
2002	2,450,000	95%	30%	70%	0%	95%	1,750,000	95%	30%	70%	0%	95%	2,450,000	95%	0%	75%	25%	95%

2003	2,800,0 95% 00	30%	70%	0%	95%	2,000,0 95% 00	30%	70%	0%	95%	2,800,0 95% 00	0%	75%	25%	95%
2004	3,150,0 95% 00	30%	70%	0%	95%	2,250,0 95% 00	30%	70%	0%	95%	3,150,0 95% 00	0%	75%	25%	95%
2005	3,675,0 95% 00	30%	70%	0%	95%	2,625,0 95% 00	30%	70%	0%	95%	3,675,0 95% 00	0%	75%	25%	95%
2006	4,200,0 95% 00	30%	70%	0%	95%	3,000,0 95% 00	30%	70%	0%	95%	4,200,0 95% 00	0%	75%	25%	95%
2007	4,725,0 95% 00	30%	70%	0%	95%	3,375,0 95% 00	30%	70%	0%	95%	4,725,0 95% 00	0%	75%	25%	95%
2008	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%	5,250,0 95% 00	0%	75%	25%	95%
2009	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%	5,250,0 95% 00	0%	75%	25%	95%
2010	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%	5,250,0 95% 00	0%	75%	25%	95%
2011	5,075,0 95% 00	30%	70%	0%	95%	3,625,0 95% 00	30%	70%	0%	95%	5,075,0 95% 00	0%	75%	25%	95%
2012	4,900,0 95% 00	30%	70%	0%	95%	3,500,0 95% 00	30%	70%	0%	95%	4,900,0 95% 00	0%	75%	25%	95%
2013	4,725,0 95% 00	30%	70%	0%	95%	3,375,0 95% 00	30%	70%	0%	95%	4,725,0 95% 00	0%	75%	25%	95%
2014	4,550,0 95% 00	30%	70%	0%	95%	3,250,0 95% 00	30%	70%	0%	95%	4,550,0 95% 00	0%	75%	25%	95%

Table B.2 Expected Relates Scenario 3 assumes 8 million per year for 2001-03 and uses growth, survival and proportion of sites that are harvestable. 2003

Increased planting in the UGS region to 6 million per year in 2001, 2002, and 2003

Expected growth, to survival and proportion of sites that are harvestable. 2,5,6, and 7

Relates to Scenarios 2,5,6, and 7

Scenario 3 assumes 8 million per year for 2001-03 and uses growth, survival and proportion of sites that are harvestable from this table.

Region	Upper Great Southern region						Southern region					
Planting year	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival
1992							40,000	70%	0%	80%	20%	70%
1993	23,000	70%	0%	80%	20%	70%	18,000	70%	0%	80%	20%	70%
1994	67,000	70%	0%	80%	20%	80%	79,000	70%	0%	80%	20%	80%
1995	325,000	70%	10%	80%	10%	80%	144,000	70%	10%	80%	10%	80%
1996	450,000	70%	10%	80%	10%	80%	170,000	70%	10%	80%	10%	80%
1997	300,000	80%	20%	80%	0%	80%	139,000	80%	20%	80%	0%	80%
1998	350,000	90%	20%	80%	0%	90%	160,000	90%	20%	80%	0%	90%
1999	640,000	90%	20%	80%	0%	90%	236,000	90%	20%	80%	0%	90%
2000	1,200,000	95%	25%	75%	0%	95%	500,000	95%	25%	75%	0%	95%
2001	6,000,000	95%	25%	75%	0%	95%	1,200,000	95%	25%	75%	0%	95%
2002	6,000,000	95%	30%	70%	0%	95%	1,750,000	95%	30%	70%	0%	95%

2003	6,000,0 95% 00	30%	70%	0%	95%	2,000,0 95% 00	30%	70%	0%	95%
2004	3,150,0 95% 00	30%	70%	0%	95%	2,250,0 95% 00	30%	70%	0%	95%
2005	3,675,0 95% 00	30%	70%	0%	95%	2,625,0 95% 00	30%	70%	0%	95%
2006	4,200,0 95% 00	30%	70%	0%	95%	3,000,0 95% 00	30%	70%	0%	95%
2007	4,725,0 95% 00	30%	70%	0%	95%	3,375,0 95% 00	30%	70%	0%	95%
2008	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%
2009	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%
2010	5,250,0 95% 00	30%	70%	0%	95%	3,750,0 95% 00	30%	70%	0%	95%
2011	5,075,0 95% 00	30%	70%	0%	95%	3,625,0 95% 00	30%	70%	0%	95%
2012	4,900,0 95% 00	30%	70%	0%	95%	3,500,0 95% 00	30%	70%	0%	95%
2013	4,725,0 95% 00	30%	70%	0%	95%	3,375,0 95% 00	30%	70%	0%	95%
2014	4,550,0 95% 00	30%	70%	0%	95%	3,250,0 95% 00	30%	70%	0%	95%

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Table B.2 (continued)
Increased planting in the UGS region to 6 million per year in 2001, 2002, and 2003
Expected growth, to survival and proportion of sites that are harvestable.
Relates to Scenarios 2,5,6, and 7
Scenario 3 assumes 8 million per year for 2001-03 and uses growth, survival and proportion of sites that are harvestable from this table.

Region	Eastern Wheatbelt region						Central region					
Planting year	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival
1992												
1993												
1994	95,000	70%	0%	55%	45%	70%	387,000	70%	0%	55%	45%	70%
1995	269,000	70%	0%	55%	45%	70%	605,000	70%	0%	55%	45%	70%
1996	599,000	70%	0%	55%	45%	80%	732,000	70%	0%	55%	45%	80%
1997	291,000	80%	0%	60%	40%	80%	324,000	80%	0%	60%	40%	80%
1998	341,000	90%	0%	65%	35%	90%	454,000	90%	0%	65%	35%	90%
1999	644,000	90%	0%	65%	35%	90%	780,000	90%	0%	65%	35%	90%
2000	1,200,000	95%	0%	70%	30%	95%	2,000,000	95%	0%	70%	30%	95%
2001	2,100,000	95%	0%	70%	30%	95%	3,000,000	95%	0%	70%	30%	95%

2002	2,450,0 95% 00	0%	75%	25%	95%	3,000,0 95% 00	0%	75%	25%	95%
2003	2,800,0 95% 00	0%	75%	25%	95%	3,000,0 95% 00	0%	75%	25%	95%
2004	3,150,0 95% 00	0%	75%	25%	95%	3,500,0 95% 00	0%	75%	25%	95%
2005	3,675,0 95% 00	0%	75%	25%	95%	4,000,0 95% 00	0%	75%	25%	95%
2006	4,200,0 95% 00	0%	75%	25%	95%	4,500,0 95% 00	0%	75%	25%	95%
2007	4,725,0 95% 00	0%	75%	25%	95%	5,250,0 95% 00	0%	75%	25%	95%
2008	5,250,0 95% 00	0%	75%	25%	95%	6,000,0 95% 00	0%	75%	25%	95%
2009	5,250,0 95% 00	0%	75%	25%	95%	6,750,0 95% 00	0%	75%	25%	95%
2010	5,250,0 95% 00	0%	75%	25%	95%	7,500,0 95% 00	0%	75%	25%	95%
2011	5,075,0 95% 00	0%	75%	25%	95%	7,500,0 95% 00	0%	75%	25%	95%
2012	4,900,0 95% 00	0%	75%	25%	95%	7,500,0 95% 00	0%	75%	25%	95%
2013	4,725,0 95% 00	0%	75%	25%	95%	7,250,0 95% 00	0%	75%	25%	95%
2014	4,550,0 95% 00	0%	75%	25%	95%	7,000,0 95% 00	0%	75%	25%	95%

Table B.3 Scenario 4 – optimistic values for proportion of sites that are harvestable, growth rates and survival

	Region	Upper Great Southern region						Southern region						Eastern Wheatbelt region					
	Planting year	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival	Planted	Harvestable	High growth	Medium growth	Low growth	Survival
08	1992							40,000	80%	10%	90%	0%	80%						
	1993	23,000	80%	10%	90%	0%	80%	18,000	80%	10%	90%	0%	80%						
	1994	67,000	80%	10%	90%	0%	80%	79,000	80%	10%	90%	0%	80%	95,000	80%	0%	60%	40%	80%
	1995	325,000	80%	20%	80%	0%	90%	144,000	80%	20%	80%	0%	80%	269,000	80%	0%	60%	40%	80%
	1996	450,000	90%	20%	80%	0%	90%	170,000	90%	20%	80%	0%	90%	599,000	90%	0%	65%	35%	90%
	1997	300,000	90%	20%	80%	0%	90%	139,000	90%	20%	80%	0%	90%	291,000	90%	0%	65%	35%	90%
	1998	350,000	90%	25%	75%	0%	95%	160,000	90%	25%	75%	0%	90%	341,000	90%	0%	75%	25%	90%
	1999	640,000	90%	25%	75%	0%	95%	236,000	90%	25%	75%	0%	90%	644,000	90%	0%	75%	25%	90%
	2000	1,200,000	95%	30%	70%	0%	95%	500,000	95%	30%	70%	0%	95%	1,200,000	95%	0%	85%	15%	95%
	2001	6,000,000	95%	30%	70%	0%	95%	1,200,000	95%	30%	70%	0%	95%	2,100,000	95%	0%	85%	15%	95%
	2002	6,000,000	95%	40%	60%	0%	95%	1,750,000	95%	40%	60%	0%	95%	2,450,000	95%	0%	85%	15%	95%
	2003	6,000,000	95%	40%	60%	0%	95%	2,000,000	95%	40%	60%	0%	95%	2,800,000	95%	0%	85%	15%	95%

2004	3,150,000	95%	40%	60%	0%	95%	2,250,000	95%	40%	60%	0%	95%	3,150,000	95%	0%	85%	15%	95%
2005	3,675,000	95%	40%	60%	0%	95%	2,625,000	95%	40%	60%	0%	95%	3,675,000	95%	0%	85%	15%	95%
2006	4,200,000	95%	40%	60%	0%	95%	3,000,000	95%	40%	60%	0%	95%	4,200,000	95%	0%	85%	15%	95%
2007	4,725,000	95%	40%	60%	0%	95%	3,375,000	95%	40%	60%	0%	95%	4,725,000	95%	0%	85%	15%	95%
2008	5,250,000	95%	40%	60%	0%	95%	3,750,000	95%	40%	60%	0%	95%	5,250,000	95%	0%	85%	15%	95%
2009	5,250,000	95%	40%	60%	0%	95%	3,750,000	95%	40%	60%	0%	95%	5,250,000	95%	0%	85%	15%	95%
2010	5,250,000	95%	40%	60%	0%	95%	3,750,000	95%	40%	60%	0%	95%	5,250,000	95%	0%	85%	15%	95%
2011	5,075,000	95%	40%	60%	0%	95%	3,625,000	95%	40%	60%	0%	95%	5,075,000	95%	0%	85%	15%	95%
2012	4,900,000	95%	40%	60%	0%	95%	3,500,000	95%	40%	60%	0%	95%	4,900,000	95%	0%	85%	15%	95%
2013	4,725,000	95%	40%	60%	0%	95%	3,375,000	95%	40%	60%	0%	95%	4,725,000	95%	0%	85%	15%	95%
2014	4,550,000	95%	40%	60%	0%	95%	3,250,000	95%	40%	60%	0%	95%	4,550,000	95%	0%	85%	15%	95%

