Prepared for

The Energy Efficiency and Conservation Authority

FIDA Engineering Solutions: Remote Bio energy

Report

Bio-oil Option

Submitted by

Alternative Energy Solutions

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Contents

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Alternative Energy Solutions (AES) take pleasure in submitting this report prepared for the Energy and Efficiency and conservation Authority (EECA). The Report is submitted as a supplement to the FIDA Engineering Solutions program: Remote Bio-energy Proposal and is titled: Bio-oil Option.

The FIDA Engineering Solutions Bio-oil option study and report will be delivered in two phases. This is the *phase one* report and contains a review of Bio-oil technologies and an evaluation of the position of technology systems and suppliers to manufacture the product in New Zealand.

The intended readers of this report include investors; forest and mill owners who have access to quantities of remote forest and mill residue and may consider Bio-oil production as a technically and economically viable business option.

How should an investor or a forest and mill owner evaluate the investment option? This approach by AES is to introduce some benchmark considerations for plant evaluation - a guide can be read in the appendices of this report.
The report offers a précis's of Bio-oil technologies and economic considerations for forest residues, and directs the reader to further information if required. Conclusions are made and from these AES make recommendations that offer a progress path to achieving bio oil production from remote forest residues.

What is Bio-Oil?

Bio-oil is produced in a pyrolysis process whereby residue (Forest Residue) is rapidly heated to high temperatures in the absence of oxygen. (*More BioOil information*[1A]) The Residue vaporizes and is then condensed into a liquid fuel all in a matter of 2 seconds.
Bio-oil can be stored, pumped and transported like petroleum products and can be combusted directly in boilers, gas turbines (proven) or in slow to medium speed diesel engines (experimental).
The simplicity associated with handling Bio-oil at the plant site should be kept in mind as an additional advantage. [B]

Bio-oil as raw liquid contains many chemicals. It can also be upgraded with proven technologies to more valuable fuels such as methanol or bio-diesel – or special chemicals can be extracted before the final product is combusted or upgraded.

Bio-oil, by definition, is a renewable greenhouse gas (GHG) neutral fuel, as long as the residue that is converted is being replanted.

Reducing Feedstock Costs.

The challenge with traditional use, as an energy source is that the residue is diffuse and thus difficult to transport economically from resource to customers. Handling and transportation of the material are the main issues that make the Residue as combustion fuel expensive. Handling is expensive due to labour and primary handling costs, and transporting is expensive due to its voluminous nature and high water content. The handling cost is dependent on quality requirement of the Residue and the Bio-oil plant will have stricter quality requirement than standard boilers.
Beyond 100km of trucking distance, transportation costs begin to outweigh the value of the raw Residue itself.

Mobile pyrolysis plants addresses some of those problems, using Bio-oil for combustion for power or heat generation is more convenient than using raw Residue as this requires extensive handling systems at the mill site. Bio-oil plants can be modular and transportable, allowing them to be located close to the source of forest residue and therefore reducing the subsequent transportation cost of the high density Bio-oil to a central plant.

The study shows that Bio-oil can have six to seven times the energy density of raw residue, it can be pumped and burned in replacement of other liquid fuels in heat and power applications and is more

[1] See Appendices

economic to transport or handle. We should emphasize at this point the transporting cost in NZ will be related to allowable truck weights GVW (gross vehicle weight) and the true transport cost advantage analysis needs to be done on this basis, it is likely to be between 2 and 3 times. Comparison of energy densities of various types of biomass can be found in the Appendices[C 2]

References to all report data are given and further technical detail is available from these. This critique highlights the key points as related to the reports core subject Bio-oil manufacture from forest residues, allowing a reread of the section and then further study of referenced sources.

This report specifically addresses the studies prime objective, identifying plants that are suitable for the remote recovery of forest residues. Some of the prerequisites will be portability, plant cost, ease of operation and the systems maturity.

The report concentrates on using the Bio-oil as a combustion fuel – a fossil or gas replacement, the reader should be aware of the potential of secondary use as feedstock for Biorefinery use and the emerging Bio Char opportunities –a relatively easy step and the potential conversion selected plant in this study.

Generalities of relevant Bio-oil related interest points are given. Please note all points can be further studied from the considerable number of reports available, referenced in the excellent Pyrolysis Biomass handbook by professor Tony Bridgwater of Aston University – essential reading for further development into Bio-oil.

Further information on Biomass Pyrolysis is available on the IEA Bioenergy website www.ieabioenergy.com.

2 ELSEVIER –Use of mobile fast pyrolysis plants to density Residue and reduce Residue handling costs (Jan 2006)

Conclusions

Fast pyrolysis is a relatively new technology that can realize the economic potential of remote forest residues, producing high yields of liquid that can directly be used for fuel applications, as a base for high value chemical extraction and potentially a carbon sink material for CO2 reduction.

This report is part of a continuing effort to determine the feasibility of utilizing forest residues (low-grade wood) and wood sources to a technically acceptable and commercially sustainable industry. One objective of this report is to establish a Bio-oil (pyrolysis liquid) industry and market in New Zealand. *-See recommendation 1.*

The report introduces Bio-oil and its current manufacturing fundamentals, general parameters relating to manufacture and a cross section of current manufacturers with both development and commercial plant. The report emphasis is to identify manufacturing plants that are technically and economically suitable for remote processing of forest residues.
Please note while some items are generic, the specific objective is directed at addressing utilization of feedstock sources that are considered remote for usual processing and would normally be lost as a revenue. *-See recommendation 2.*

Identification of this financial opportunity - this is -where feedstocks are better utilized as a remote rather that a “conventional” process feedstock, and will be part of the reports’ phase two study -economic and sensitivity analysis. However, a preview of plant and operating cost against expected return on investment (ROI) is given.
We applied this methodology in the section -Develop Conceptual Plant Design and have developed budget cost on this specific plant, however, - there may be others. *-See recommendation 3.*

In summary - a plant of NZ$4.5 - 5 million investment has an ROI of approximately 5 years and also could save 20% of petroleum fuel costs.

In the section headed 100 Tonne per Day (dry residue) Plant Analysis (Page 23) the data is a projected cash flow for a 10-year period. To summarize:

- The internal rate of return (before taxes) calculated on a NZ$4.2 million investment is 21%.
- The data used in the analysis is considered conservative and since fuel prices continue to increase, the risk of a lower rate of return is minimal.
- Potential revenue from the sale of chemicals has not been taken into account.
- Bio-oil competes very well in the heavy fuel market and can therefore be priced relative to current heavy fuel oil prices.
- The key to cost control is to keep the biomass feedstock cost at or below NZ$20 per tonne.
- This is a realistic target in the short term. The advantage of the mobile system is it can capture forest residues that are currently unavailable and are uneconomic to the current bio-fuels market. The company will therefore not be competing with other users for the raw materials and costs can be controlled.

We can expect continuing increase of oil prices, political incentives to reduce CO2 emission, and possible new markets for high value chemical extracts, all NOT included in the plant cost evaluation, and are surely worth further evaluation. *-See recommendation 4.*

Recommendations

1

Further analysis of remote forest residue is required, i.e.:
* Review of harvesting information
* Research of Bio-oil equipment, fuel drying and conditioning

Complete stage two of this report.

2

Ideal remote residue utilization is likely to be from skid site harvesting activities and some small but necessary operational changes in current methodologies are required as suggested in this report.

Develop specific skid site requirements for residue handling, storage and recovery.

3

The economic and social implications of new ventures of this nature need to be assessed from the diverse points of view of resource owners, operators and local communities.
Ownership structure of a Bio-oil venture may not be traditional. A possible option is a joint venture between the residue owner and the plant operators with the product profits being shared. This eliminates individual profit centers so as not to impact on the total project viability, and encourages efficiencies in residue handling and skid site operation, and allows the joint venture to benefit from these gains.

Develop a joint venture concept to include forest residue through to product sale.

4

Initial capital cost steps using new technologies at a commercial scale (100TPD) are generally difficult to progress; an operational trial plant, market testing and overall familiarization would overcome this.

Operate a small plant (1 ton Bio-oil per day) to cover these aspects and use the resulting product to develop a market to promote the business and progress to a commercially scaled plant.

This Study - Resources and Information

Resources and information required for a study of this nature is generally available from three sources:

Web information:
This resource was used extensively for this study. However, web information generally is dated, sales and promotionally oriented and often inaccurate. For instance, plants are generally promoted as fully commissioned and functional. Communication with these companies with direct questions will generally resolve performance and plant status queries.

Scientific literature, books, reports, and case study documents.
These predominately present scientific study accurately, but are often slanted towards funded, lab scale investigations with ideal feedstock etc and generally don't consider commercial sized plants and real world issues such as plant costs, scale up issues, building and operational complexities, feedstock availability, product handling and market.

Privately funded research Investigation:
AES recognized the limited information available of the above sources and that the report must address FIDA Engineering Solutions fundamental question: "is Bio-oil production, technically and commercially sustainable for remote residue feedstock?"

To complete this report AES carried out a privately funded research investigation and visited many recognized residue sites with our personnel, who have significant thermal engineering and production experience, operational skills, commercial business and scientific skills in order to accurately assess Bio-oil plant performance and production issues to answer the above. AES submits this report from this basis.

Phase 1	**Corresponding Sections**	**Phase 2 - Economic Analysis**
This study	This Study - Resources and Information ……8	Subsequent study containing
Review project plan – structure	Review Method……………………………..........9	Research equipment Spec & pricing
Review available Bio-oil information	Review Available Bio-oil Information…………9	
		Review harvesting information
Review at least 3 Technology Suppliers	Review of Technology Suppliers…………….12	Investigate plant operating costs
Study draft report on forest and skid site handling systems	Study and review of report on forest and skid site handling systems………………………...15	Investigate fuel drying and conditioning systems
Study operation of Selected Plants	Study Operation of Selected Plant - Advanced Bio Refinery Inc……………………………….20	Investigate site alteration costs
Develop Conceptual plant design	Conceptual Plant Design……………………21	Perform economic analysis
With Tech Suppliers assemble plant costing	With Tech Suppliers Assemble Plant Costings……………………………………….24	Perform sensitivity analysis
Complete plant design	Complete Plant Design……………………….24	
Phase One Report	100 Tonne per Day (dry residue) Plant Analysis (Preliminary)…………………………………..25	**Phase Two Final report**
	Note* below	

*Note** -

This report follows EECA requirements for the FIDA Engineering Solutions submission grant these section headings being highlighted in the report.

Review Method

The methodology used to evaluate is based on the evaluation characteristics table [D]. This table identifies the fundamental issues for developers evaluating systems and equipment.

Review Available Bio-oil Information

Readers intending to evaluate plants for commercial use should have an understanding of plant configurations and operational concepts. This section summarizes the standard reactor configurations, and references further material for additional information.

Bio-oil

Bio-oil is a dark-brown, free flowing liquid fuel that is derived from plant material. (*See Appendix 1 for more Bio-oil detail)*
Essential Features are:
Fast Pyrolysis (see Section below) is a process in which very high heat and heat transfer rates are needed, generally requiring the wood feedstock to be finely ground. This requirement varies in the various processes and systems later discussed in this report, but the degree of processing reflects in processing difficulty and cost.

The feedstock moisture content impacts on the moisture content of the Bio-oil. Typically, Bio-oil moisture content is approximately 15% by weight - this being from feedstock of less than 20% moisture content (wet basis). Higher moisture content will result in increased Bio-oil moisture and considerable reduction in the Fuel's energy value.

Careful control of the pyrolysis reaction temperature and heat transfer is necessary. Variances contribute to the Bio-oil under storage conditions "phasing" i.e. separating into a low "water based component" and a more "organic rich" heavy liquid. While awareness is necessary with the technologies available and the shorter storage time for domestic use, "phasing" is unlikely to be an issue.

Health and Safety

All aspects of health and safety must be addressed separately by specialized and qualified personnel and this report provides generalities only, which must be separately checked.

The oils can be handled safely with personnel protective gear i.e. rubber gloves, goggles and protective clothing. Bio-oil safety information needs to be read in full context of reference material such as Fast Pyrolysis of Biomass: a Handbook, edited by Dr Tony Bridgewater (CPL Scientific Publishing Services Limited, Newbury, 1999) and independently checked.

Bio-oil as a "Green" Fuel

The first commercial use of Bio-oil in New Zealand is likely to be as a combustion fuel, in the generation of power and heat.

With modest equipment modifications, Bio-oil can be substituted for fuel oil or diesel in a number of static applications including stationary diesel engines, gas turbines, boilers and furnaces.

Bio-oil has been successfully test co-fired with coal, providing 5% of the BTU value to a 20MW boiler.[3] Bio-oil has a successful record of utilization in commercial boilers to provide industrial process heat and drying, and is approved for use in district heating utility boilers in Sweden. ORENDA Aerospace Corporation has successfully tested Bio-oil in its 2.5 MW combustion turbine-powered generator.[4]

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[3] Sturzl, Ray. The Commercial Co-Firing of RTP™ Bio-oil at the Manitowoc Public Utilities Power Generating Station. June 1997.
[4] Dynamotive Energy Systems Corporation and R. Thamburaj of Orenda Space Corporation. Fast Pyrolysis of Biomass for Green Power Generation. First World Conference and Exhibition on Biomass for Energy and Industry. 2000.

Physical Properties		Typical Value
Moisture Content		15-30%
pH		2.5-3.0
Specific Gravity		1.20
Elemental Analysis, dry basis	C	5.64%
	H	6.2%
	O	37.3%
	N	0.1%
	Ash	0.1%
HHV as produced (depends on moisture)		16-19 MJ/kg
Viscosity (at 40C and 25% water)		40-100 cp
Solids (char)		0.5%
Distillation		Max. 50% as liquid degrades
Characteristics • Liquid fuel. • Substitution for conventional fuels in many static applications – boilers, engines, turbines. • Heating value is about 40% of that of fuel oil or diesel on a weight basis and 60% on a volume basis. • Does not mix with hydrocarbon fuels. • Less stable than fossil fuels.		

Table 1. Typical properties and characteristics of wood derived Bio-oil

Fast Pyrolysis

Fast Pyrolysis is a thermo chemical process where biomass is heated in the absence of oxygen to temperatures between 350°C and 600°C.

The fast pyrolysis and the resulting Bio-oil, is dependent on:

- Biomass heating rates in the order of 1000^{o}C/sec (500^{o}C) and rapid heat transfer to the biomass particles.
- Close control of the pyrolysis reaction temperature (350 – 600°C) and residence time (< 2 sec).
- Rapid cooling of the hot Pyrolysis vapor to the resulting liquid Bio-oil.

Moisture content of the feedstock needs to be at 10-20% on wet basis. Higher moisture content means higher moisture content in the Bio-oil and lower CV.
Lower moisture content produces a heavy viscous Bio-oil that tends to separate into two phases.
The moisture acts as a bridge between the aqueous phase and the tar phase. When the moisture is out of range, the Bio-oil will separate into two phases. Note: when considering chemical extraction, the separation is an advantage.

Particle size is also critical to obtaining a rapid heat transfer because wood biomass in itself is very poor in transferring heat. Most systems are therefore based on using small biomass particles, 2-3 mm, although some technologies accept larger pieces.

A number of the common technologies are further explained in Fast Pyrolysis of Biomass: a Handbook[5]: These are summarized as follows:

Fluid Bed

Fluid Bed variants are the most common configurations used - the proponents claiming ease of operation and scalability. Biomass feedstock is generally required to be ground to a fine consistency with a MC of less than 10%. Each of these technologies relies on hot sand as a heat carrier. Sand is either fluidized or transported in a hot gas stream and the biomass is mixed with the hot sand.

The three fluid bed configurations are:

- Bubbling Fluid bed
- Circulating Fluid bed
- Transported Fluid bed.

Ablative Pyrolysis

The process refers to the presentation of wood feedstock to a hot surface by mechanical means.

The feedstock is pressed onto a hot surface (usually rotating), rather like butter on a hot pan surface, and the resulting liquid formed is rapidly evaporated to be condensed and collected later in the process.

The immediate advantage is feedstock particle size can be larger than that for other systems, the limitation being heat surface and heat transfer to the biomass.

Parasitic power use, capital and scale up costs at present render ablative systems unsuitable for the recovery of forest residue.

Rotating Cone

This process is proprietary to BTG and the University of Twente and operates as a transported bed

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5 Fast Pyrolysis of Biomass: a Handbook, edited by Dr Tony Bridgewater, (CPL Scientific Publishing Services Limited, Newbury, 1999)

reactor.

Auger Pyrolysis

Advanced Biorefinery and FZK (Germany) have developed auger pyrolysis systems whereby hot steel shots or balls are mixed with the biomass to produce the high heating rates and short residence requirements for fast pyrolysis.

Review of Technology Suppliers

Genting Bio-oil and BTG

Malaysian-based Genting Sanyen Bhd have installed and operated a 2 tonne/hr (feedstock) plant producing approximately 1.2 Tonne per hour of Bio-oil. This plant is based on BTG Biomass Technology Group BV design and original supply. Considerable modifications have been made mainly in the feedstock handling area by Gentings' own engineering group.

Feedstock for this plant is palm oil residue; the empty fruit bunches after palm oil extraction.
Genting have extensively modified the feedstock handling systems for this plant and are near to completion of testing before considering a plant capacity upgrade.

Characteristics	
Technology Characteristic -	Ease of use implications as applied to this technology.
Maturity -	BTG is an R&D and consultancy firm with approximately 20 years of relevant Lab Scale Bio-oil development.
Complexity -	Technology is a transported bed reactor.
Scalability -	Scalability is by upsizing and then by “stacking” reactor cones. Large plants have not been built/operated at this stage.
Adaptability -	Not suitable for mobile configuration.
Packaging -	BTG is a technology consultant and offers license to manufacture. Construction is by others. Plants are large and only suitable for fixed site location.
Fragility -	One pilot scale plant in operation is in Malaysia. A considerable time period has passed since this trial plant was installed and there has been considerable difficulty with the feedstock (palm oil husks), which is reported as having been worked through.
Trial ability -	From size and cost considerations, not suitable for re-locatable plant for forest residue.

ENSYN Group Inc

ENSYN's claim that Rapid Thermal Processing (RTP™) is the only process operating commercially today is generally correct.

All other processes researched, while some have produced significant quantities of Bio-oil, generally are in stages of rebuild, development or commissioning.

We include RTP™ technology because of its installed base and quantities of Bio-oil reliably produced over 25 years of development. The RTP™ technology best suits permanently sited locations, but the technology may suit smaller plants.

ENSYN Corp (EC), the parent of several ENSYN companies, has two primary business objectives: to develop industrial applications for its core technology, Rapid Thermal Processing (RTP™), and to exploit these applications commercially in the biomass sector.

RTP™ is a patented, state-of-the-art process that transforms carbon-based feedstocks, either wood "biomass" or petroleum hydrocarbons, to more valuable chemical and fuel products.

Characteristics	
Technology Characteristic -	Ease of use implications as applied to fluid bed technology
Maturity –	ENSYN Technology has a 20 year history, and is based on circulating Fluid bed Technology. Five or six operating plants produce 5 M Gal (US) per year.
Complexity –	Technology is a fluid bed reactor.
Scalability –	Technology has been scaled in subsequent plants to 150 green tonnes per day.
Adaptability	Plant is suitable for fixed site location.
Packaging –	Requires permanent fixed site location and established team of specially trained staff.
Fragility –	Technology is well proven.
Trial ability –	From size and cost considerations, not suitable for portable plants.

Aston University

Ablative technologies for Bio-oil production are an interesting R&D technology being carried out at Aston University and NREL in the US.

Ablative technology relies on the biomass in larger sizes being held against a heated surface. This can be done hydraulically, the feedstock or surface being rotated to clear the reaction zone.

At this stage pilot sized and trials of larger plants are being carried out. Capital costs and high parasitic electrical loads rule these out of this study.

Characteristics	
Technology Characteristic -	Ease of use implications as applied to this technology.
Maturity –	Evolving.
Complexity –	Low.
Scalability –	Plants are scalable .5 TPD upwards. 50 TPD plant is built and is currently being commissioned.
Adaptability -	To get a best balance situation a dual 50 or 100 TPD plant will be a standard offering. This is as costed out in the example.
Packaging –	Plants are purpose designed for portability with transport modules being fitted with quick connect couplings and skids / wheels etc.
Fragility –	Plant is constructed to be portable. The system is designed using standard components for serviceability.
Trial ability –	The .5 TPD plant is built as a customer trial and evaluation plant. Basic functionality is similar to the large plants a difference is the fuel drying is propane heated. The section – Operation of Selected Plants is modelled on an ABRI 100TPD plant.

In relation to this Bio-oil option the report clearly identifies the significant volume of residues potentially available as revenue in the form of bio fuels *(Report –Forest Residue Harvesting for Bio Energy Fuels – Scion 2007).*

The concepts presented in this report concentrate on the current uses of residue and is based on familiar conversion technologies currently used in New Zealand. That is, the forest residue will be collected/harvested and hogged for transport to the end user.

Harvesting and handling equipment in all cases are sized to process significant quantities in the form of hogged material sold at minimal cost and transported, usually with considerable moisture content.

With specifically remote residue utilization in mind, the table in the case studies' section (page 15) is important data when considering options such as Bio-oil.

This report provides a possible alternative to the long hauling of a wet, low-density fuel and the realization that trucking costs, as in the table above, make transportation distances of more than 100 KM expensive. The reader can quickly summarize the real issue of transporting residue by a quick look at Table 4 (page 28) and consider this in conjunction with the moisture content /calorific value table, Figure 1 (page 11). The data clearly illustrates the adverse factors of high moisture fuel transportation on the viability of transporting residue fuels.

Bio-oil and other remote processing options (i.e. distributed generation, bio-char) offer alternative solutions and are very dependent on these points:

1. The remoteness of the residues. In NZ this is generally more than 100 Km.

2. The opportunities of the Bio-oil processing which are at present:

   - A combustion fuel for both heat and electricity production by using steam turbines, gas turbines or organic rankine cycle (ORC).

   - Bio-oil has great potential for chemical extraction, which is currently done at a commercial level in Europe and Canada.

Harvesting and Operational Costs.

Plant capital costs and available technology.

This Study specifically addresses economics in Stage 2 however the fundamentals of remote processing need to be appreciated at this stage.

Consider:

Bio-oil Transport	Hogged Fuel
	
TANKER TRAILER 1300 GJ @ US$6.00 PER GJ = US$7800	**HOG FUEL TRANSPORT 300 GJ @ US$3.00 PER GJ = US$900**

These Canadian based figures are clearly endorsed in the transport section of the draft report.

Remote manufacturing of Bio-oil feedstock processing steps are:

FEEDSTOCK

The optimum source of residue is likely to be *a companion operation of skid site harvesting*. This avoids the additional cost of "cut over" residue collection, particularly on steep country.

Skid site management could include placing Waratah off cuts into stacked windrows, where it would remain until hogged.

Applying natural (wind, sun and time) drying and achieving moisture content of less than 35% considerably increases Bio-oil production and may avoid the need for primary drying.
Note however 10% moisture content is required for the Bio-oil reaction so the integral dryer on the Bio-oil plant is still required.

FEEDSTOCK -Continued

CHIP or GRIND

The importance of minimizing operational steps can not be over emphasized.

Loading directly into a transportable container, minimizing truck standing time, and keeping the fuel clean and dry will maximize Bio-oil quantities and quality.

Typically, portable Bio-oil plants will require between one hundred and three hundred tonnes per day, making multiple utilization of auxiliary plant such as tractors important.

This photo shows the tractor performs a dual role of hogger power and hogged fuel haulage. The short distances for which the extra hogger weight is carried is minor against reconnection time and the inconvenience.

RAW RESIDUE HANDLING

The single operator required to efficiently transfer residue to the hogger uses a hydraulic manipulator. This example is set up to convey the processed residue to a bin or trailer.

The manipulator could be incorporated with the first examples of equipment (above) or be as shown. This set up is perhaps more applicable where multiple skid sites are being processed.

The bin or trailer method of transporting residue is a decision related to transport distance and roading. The truck method being more efficient with better road conditions, distance, and where transport speed is a factor.

LOADING AND HAULING

Again the importance of minimizing operational steps cannot be over emphasized. This also applies to equipment and the necessary operational staffing.

If the operation is on one skid site only, the need to haul is minimized to the on site movement of processed residue.

It is possible for short hauls (between skid sites) that a tractor and trailer combination is a better economic solution.

Equipment minimization is important: i.e. loading directly into a transportable container, and then moving this to become a storage bin for the Bio-oil plant will keep the fuel clean and dry.

BIO-OIL PRODUCTION

The plant shown is a 50 TPD (dry biomass).

The photo shows the four main plant modules; the primary loader and conveyor module is wheel equipped to skid load by a winch truck for easy transport between sites. Similarly the reactor tower lies down and is similarly transported. Foundations are not required, inter-connection is via quick release couplings, and services are self-contained.

Our later economics throughput study indicates two reaction modules and fuel conditioners achieving 100 TPD is preferable. (More detail of this plant will appear in - The develop conceptual plant design section.)

This plant with modification to the reactor module and operating parameters will produce mainly bio-char – used as a fertilizer for agricultural use and potentially a more lucrative product for forest residues.

The plant is self contained – requiring no external energy for operation.

BIO-OIL SHIPPING

The suggested plant size produces 65 tonne of Bio-oil per day. (100 TPD feedstock)

On site storage and transport optimization economics will be addressed in Phase 2. Suitable Bio-oil containment will be stainless steel (milk tankers) or plastic. It is likely tank trailers would provide better economics with the on-site production storage being handled using this method.

Bio-oil does not pose the level of risk petroleum does - it is not explosive and has a minimal environmental risk.

Study Operation of Selected Plant - Advanced Bio Refinery Inc

Preview

Advanced Bio Refinery Inc (ABRI) is a continuation of Encon Enterprises Inc., a technology company founded in 1988.

During this period four Pyrolysis development models have been trialed; a 1 TPD trial plant has operated for a year thus demonstrating the technology is functional. Three 1 TPD plants are currently being manufactured for customers.

This experience with the 1 tonne per day plant has been applied to a new 50 TPD plant currently being commissioned with a commercial release date of January 2008.

Technology Advantages

The plant is attractive because of its simplicity and subsequent lower capital investment.

The method of heat transfer using “steel shot” offers compact high heat transfer and full recovery of the transfer medium. Feedstock sizing is considerably larger than other technologies, significantly reducing conditioning costs.

The combination fuel conditioning dryer is simple, compact and efficient and is expected to require very low maintenance. Plant is designed to be portable and to compact and load onto standard trucks. Assembly and disassembly is expected to take 8 to 10 hrs.

Disadvantages

Limited testing of the 50 TPD ABRI technologies has been conducted.

Bio-oil specifications are not available at this time.

Company History

ABRI is a privately held corporation that was founded in 2005 by Dr. Peter Fransham and is based in Ottawa, Canada.

ABRI's business strategy is to develop and commercialize affordable, transportable pyrolysis plants that can be used to generate high value heating fuel and chemicals at minimal cost. ABRI's technologies include 1 TPD systems designed for small businesses such as farms, evaluation, market introductions and 50/100 TPD systems for conversion of wood waste to Bio-oil.

ABRI's technology will have the lowest capital costs of any of its major competitors. ABRI's heated auger reactor is very compact and also has very low parasitic loads.

The plant design is compact and cost effective, which reduces the minimum economic size of pyrolysis plants from 200 TPD to 100 TPD. At this size the plant is fully mobile. This mobility allows strategic access to biomass resources that are uneconomic using competitors' technology.
No permanent site structure, foundations, electrical connection etc are required to support ABRI's skid-mounted technology.

Conceptual Plant Design

Skid Sites

The ideal operating scenario is to process residues that are easily available such as those already found on hauler skid sites.

Currently with hauler harvesting operations, whole trees are lifted to the skid site and Waratah trimmed and cut to log length. The resulting residue is then pushed clear and abandoned.

The EECA report Forest Residue Harvesting of Bio energy Fuels reports that in 2005 forest residue on landing sites was estimated at 1.04 million tonnes with 100,000 tonnes per annum being utilized. This is the most available and lowest cost residue.

Feedstock for the Bio-oil plant should be "clean" as dirt and other contaminants will affect plant operation. The residue should be left as produced in a "windrow". Any collection, unless picked up from a clean surface or conveyed, is likely to contain dirt.

The residue left in "deep windrows" for a period (i.e. more than three months) will drop in moisture content considerably, natural drying therefore saving the energy needed to reach the 20% required by the plant. This is critical and is likely to be a key issue for economic operation.

Ideally the plant being brought in 6-12 months after harvesting and operated at 50-100 tonne per day is an optimum operational target. A 100 tonne plant has dual fifty tonne reactors only, the improved economics being common components such as the loading and fuel conditioning modules and the full unitization of staff.

Certainly for Bio-oil production, a skid site size increase and a small increased harvesting operational cost will occur. However, considering the current and projected positive value of Bio-oil, additional revenue is available from currently lost residues. No other remote residue system is even close to becoming a reality.

The modular packaging of the system allows relocation by standard trucking between sites. Sections can typically be lifted or skid loaded in approximately five tonne sections and quickly re-assembled. Target beak-down or rebuild is less than one day.

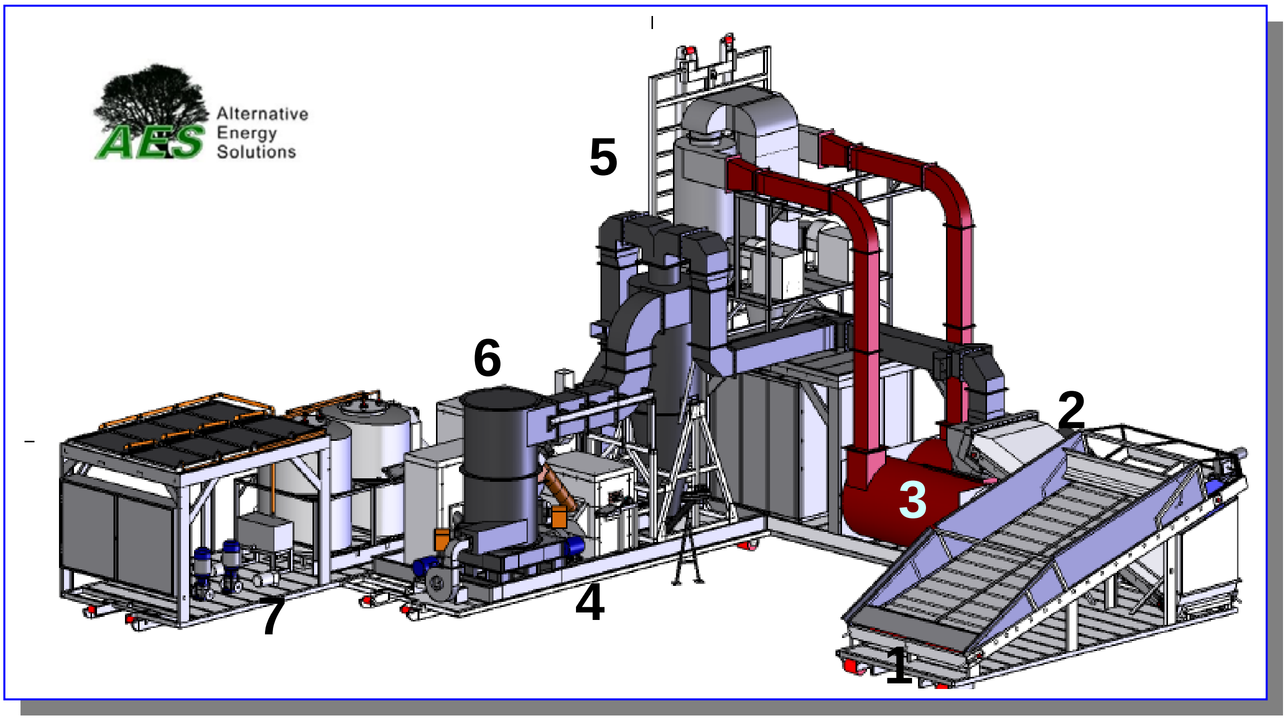
The plant could be operated 24 hours per day for 47 weeks per year, which allows for five relocations, maintenance shutdowns, and holidays. For the remainder of the year, an 85% utilization rate has been assumed (typical for mining or other bulk materials handling operations).

Design process performance is 63% conversion of dry input biomass material into Bio-oil. The non-condensable gas produced provides electric power to the plant's generator set and the char produced provides heat for the reaction and to dry the incoming biomass.

Operations

Consider the skid site management aspects are as the section above, the hogged and bin contained feedstock is loaded onto the plants inclined conveyor.

Ideally the bin system would form the feedstock storage (clean and dry) and the transfer would be direct from this.



1. Trucks or the storage bin conveyor drops the hogged forest residue into an inclined hopper. The hopper chains drag the biomass up the incline.

2. The second conveyor moves the biomass into the dryer/pulveriser.

3. The pulveriser breaks the biomass into smaller pieces. A constant flow of hot air dries the biomass.

4. The hot air and biomass particles are separated using cyclones. Centrifugal forces and friction cause the biomass to drop to the bottom of the cyclones where the dry material is removed with a conveyor and dropped into the reactor.

5. The reactor is a hot, air free chamber where the biomass is rapidly heated and the vapors are quickly driven off. At this point there are two products - hot vapors and char.

6. The char is burned in a furnace and the resulting hot air is used to dry the biomass as well as providing heat for the process.

7. The hot vapors are cooled and most form liquid called Bio-oil. The small amount of remaining non-condensable gases are cleaned and used to generate electricity for the plant.
   The Bio-oil produced would require tankage but these may be able to be the trailer units circulating between the manufacturing and usage site (i.e. customers' storage tanks).

Personnel

A fully operational 100 TPD Bio-oil plant operating full-time will require 4 full-time operating personnel with one operator working per shift. Harvesting personnel have been included in the cost of the feedstock.

Automated process controls mean the plant generally will operate itself allowing the operator to load fuel, carry out routine maintenance, etc. Operators' skill levels will be technically inclined, trained to do routine plant maintenance, have computer skills and the ability to drive heavy loading equipment. Where cell phone coverage is available it is possible to monitor the status of the plant via the internet. Therefore any plant issues can often be solved remotely with the operator rather than out-sourcing maintenance staff.

With Tech Suppliers Assemble Plant Costings

Residue Collection

As this is waste, cost of the Residue itself is free (see phase 2 – A Shareholder Stake?) but the collection will have some cost. Residue will be collected from slash piles on skid sites or by logging roads etc in the forest. This would be chipped by the road using a tub grinder and delivered as chips to the pyrolysis plant in container dump trucks. Residue collection cost has been estimated at $30 per tonne, which clearly is why skid site residue is optimal. See stage 2 for summary of calculated Residue collection costs.

Bio-oil Trucking

One 100 TPD Bio-oil plant will produce approximately 2 or more truckloads of Bio-oil per day; a fully operational plant will likely require a dedicated truck. The cost of transport has been estimated at 16¢ per tonne per km which is close to the $100-$130 per hour transport companies would charge.

Engineering and Maintenance

The technology and first plant has been fully designed and built in Canada by ABRI and is currently being commissioned. Subsequent plants will be made under license in NZ or Australia, resulting in improved costs, local spares, maintenance and support.
The advantage of the modular design is that once several systems are operational, a spare module can be kept in inventory and moved to the site when major maintenance is required on the original. The replaced module can be removed quickly and the new module installed. The replaced module can then be transported to a workshop for refurbishing.
The automation and control system has remote communication capabilities allowing remote monitoring and control. The ability to remotely locate and possibly correct malfunctions will result in less downtime and reduced technical capability being required on site.

Permitting

Permitting may be an issue on a number of fronts:

Bio-oil plants may need environmental permits under the Resource Management Act (RMA).

Transportation for Bio-oil will require specific permits as per fuels and other toxic materials. Bio-oil will need to be approved as a chemical substance for transport.

Complete Plant Design

The second stage of this study qualifies and completes economic evaluation with appropriate sensitivity analysis of the reports objective.

However to provide an interim conclusion with the objective of a potential final finding, we apply the previous sections 'Conceptual Plant Design' and 'Assemble Plant Costings' to produce the following spread sheet.

100 Tonne per Day (dry residue) Plant Analysis (Preliminary)

We demonstrate below with estimated plant and handling equipment costs that Bio-oil production is financially viable.

Stage 2 of this study will compile this information into a five-year pro forma income statement, balance sheet and cash flow projection for an investor to apply to the New Zealand forest residue situation.

A sensitivity analysis of a number of key factors with respect to the plant value will be presented. These key factors could be energy price differential, Bio-oil, oil, transport distance, biomass collection costs and Bio-oil yield. These would be graphically illustrated for presentation.

Operating Assumptions:	New Plant Use of Available Time:	50%	Est.
	Exist. Plant Use of Available Time:	85%	Typical Mining Operation
	Available Hours/yr:	7896	47 Weeks
	BioOil Yield:	63%	Specs
	Management SG&A:	$100,000	1 foreman/owner
	Avg. Bio-Oil transport Distance (km):	200	Est.
	Transportation Costs ($/tonne-km):	0.09	Trans calc
	Plant Relocation Costs:	$40,000	Trans, lab, Site prep
	Plant Relocation Frequency (/yr):	2	Est.
	Power Requirements (kW hr/tonne):	48	200Kwe for 100TPD
	Insurance $/plant:	$24,000	Est.
	Sales Cycle (Months):	6	Est.
	CCA Depreciation	50%	Est.
Evaluation Criteria	**Plant Value**	3.5	$M
	Discount Rate	15%	
	Tax Rate	37%	
	Plant Size	100	TPD
Price and Cost Assumptions	Direct Labour $/hour (w. benefits):	$28	Std +30%
	Residue Collection Costs $/tonne	$20	Est.
	Plant Site Equipment Costs $/tonne:	$4	Plant equipment Calc
	Maintenance (% of Capex):	4%	Typical Mining
	Electricity costs $/kWh	$.065	Est. on Grid Connect
	CO2 Offset Value $/tonneCO2:	$15.00	Projected?
	ABRI Bio-Oil Price $/GJ*:	$9.00	*17.5GJ/T $157.5/T

Notes

1. We have used $US in the above calculation.

2. Oil prices have increased since this calculation, further improving the result.

3. We have included an estimated value for CO2 as it is not available for trade at this time in NZ.

4. The staffing is high if the project is run in conjunction to other forest operations.

Appendix A

Bio-oil

Bio-oil is a dark-brown, free flowing liquid fuel that is derived from plant material. Bio-oil is produced in a pyrolysis process whereby small particles of biomass waste are rapidly heated to high temperatures in the absence of oxygen, vaporized, and then condensed into liquid fuel. The process happens very quickly with residence times of less than 2 seconds and products of the process are typically 65% liquid bio-oil, 15% solid char and 20% non-condensable gases.

Some pyrolysis plants use the char and condensable gasses to provide heat and power for the process.

Also known as pyrolysis oil, bio-oil is unlike conventional oils because it contains about 25% water and is not soluble with conventional hydrocarbon-based fuels. Bio-oil can be stored, pumped and transported like petroleum products and can be combusted directly in boilers, gas turbines or in slow to medium speed diesel engines for heat and power. With a density of 1.2 kg/litre, and heating value of approximately 17.5 MJ/kg, bio-oil has approximately 61% of the heating value of diesel on a volumetric basis. Bio-oil is CO2 neutral, contains no sulfur and therefore does not produce SO2 (sulfur dioxide) emissions during combustion; usually produces approximately half the NOx (nitrogen oxide) emissions compared to fossil fuels, and has an ash content of approximately a quarter that of heavy fuel oil.

Bio-oil is non-toxic but it is acidic and has a pH that is 2-3 compared to diesel with a pH of 5. The acidic nature of bio-oil means that storage tanks, transportation vehicles and piping should be composed of stainless steel (304) or polymers, not mild steel. Bio-oil is not a homogeneous fluid and will separate into phases if left standing for prolonged periods, therefore slow speed agitation is required when held in stationary tanks. No agitation is required on transport vessels. Bio-oil is viscous at normal temperatures and pumping may require product heating.

Bio-oil transportation has some advantages over fossil fuels. In the case of oil spills, petroleum oil spreads over water in a thin layer causing major environmental harm. Bio-oil is not hydrophobic and does not spread, but separates into a heavy organic fraction that sinks and an aqueous fraction that dilutes and easily bio-degrades - making the environmental impact much less damaging. Bio-oil is combustible but not flammable. It ignites and burns readily when properly atomized, and once ignited, burns with a stable, self-sustaining flame.

Chemicals

A wide range of “green” chemicals can be extracted from bio-oil, and are an attractive possibility to producers of bio-oil because they generally offer much higher value added products as compared to fuels and energy products.

Chemicals can be isolated and extracted and the remaining bio-oil will still retain its value as a fuel. For wood-based bio-oil, such chemicals include hydroxyacetaldehyde, acetic acid, formic acid, levoglucosan and levoglucosenone.[15]

These chemical compounds have the potential to serve as the basis for a wide variety of chemicals.

Food flavorings are extracted from bio-oil in a number of countries, including the United States.

Researchers are also working on developing natural resins and polymers for use in engineered wood products; these have already undergone mill trials[16]. Additional tested uses of bio-oil include: as a base for organic wood preservatives; as an ingredient in slow-release fertilizer used in commercial agriculture.

[15] Radlein, Desmond, of resource Transforms International Ltd., The Production of Chemicals and Materials from Bio-oil. In Fast Pyrolysis of Biomass: a Handbook, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp. 164-188.

[16] Boulard, David C. Bio-oil: The New Crude. Presentation by Ensyn Technologies, Inc. Concord, NH. August 16, 2002.

Table 2. Comparative Heating Value of Fuels

	MJ/l	BTU/U.S. gallon
Bio-oil (wood)	21.0	75,500
Bio-oil (bark)	22.7	81,500
Fuel Oil #6	38.9	153,200
Fuel Oil #2	35.2	138,500
Methanol	17.5	62,500
Ethanol	23.5	84,000

Combustion Properties

Extensive combustion studies have been performed with bio-oil generated from wood feedstock. Results of these tests are summarized as follows.

Burner Considerations

To maintain an energy release rate equivalent to that for petroleum-based fuels requires a flow rate approximately 1.6 times that required for # 2 fuel oil.

Typical combustion parameters for burning bio-oil include an air atomizing burner and fuel handling system similar to that used for emulsified bitumen.

Bio-oil is stored in a tank with the temperature maintained at approximately 36^{o} C and a blade impeller mixer to keep the fuel homogenized.

Fuel is transported to the burner using a positive displacement pump and an in-line steam heat exchanger is used to obtain increased uniform fuel temperatures at the burner.

Nominally preheated atomizing air (114C to 132C) is used and flue gas oxygen is maintained at about 5 to 5.5% (15-20% excess air).

Although the bio-oil flow rate is increased, the airflow required to maintain effective combustion is reported as similar to that for the petroleum-based fuels.

Exhaust Considerations

The exhaust gases from bio-oil have a higher content of water vapor resulting in a slightly higher dew point for the stack gases, but values are well below normal exhaust temperatures.

Composition of the flue gas shows higher CO_2 levels from the bio-oil and CO and NO_x levels close to those for #2 fuel oil but lower than those for burning #6 fuel oil.

SO_2 emissions from the combustion of bio-oil are dramatically lower than those for petroleum-based fuels.

At lower bio-oil flow rates, i.e. lower heat transfer rates, and lower flame temperatures, NO_x emissions are substantially reduced.

For bio-oil flow rates comparable to #2 fuel oil, NO_x emission is reduced by approximately 50%. This is because of the low fuel nitrogen content with most of the NO_x coming from air nitrogen.

Particulate emissions tend to be higher than those for #2 oil and about the same as for #6 oil; roughly correlating with the ash content of the bio-oil.

Emissions

Emissions are influenced by the quality of the bio-oil, in particular the char/ash content, and by the bio-oil contaminants which are dictated by the composition of the biomass feedstock from which the bio-oil was produced. A significant destruction of dioxins/furans (up to 99%) occurs during combustion. From the reported combustion studies, it is reasonable to expect that combustion systems for fuel oils can be converted to use a reasonable quality of bio-oil without producing emission levels that would prevent permitting in normal situations.

Char

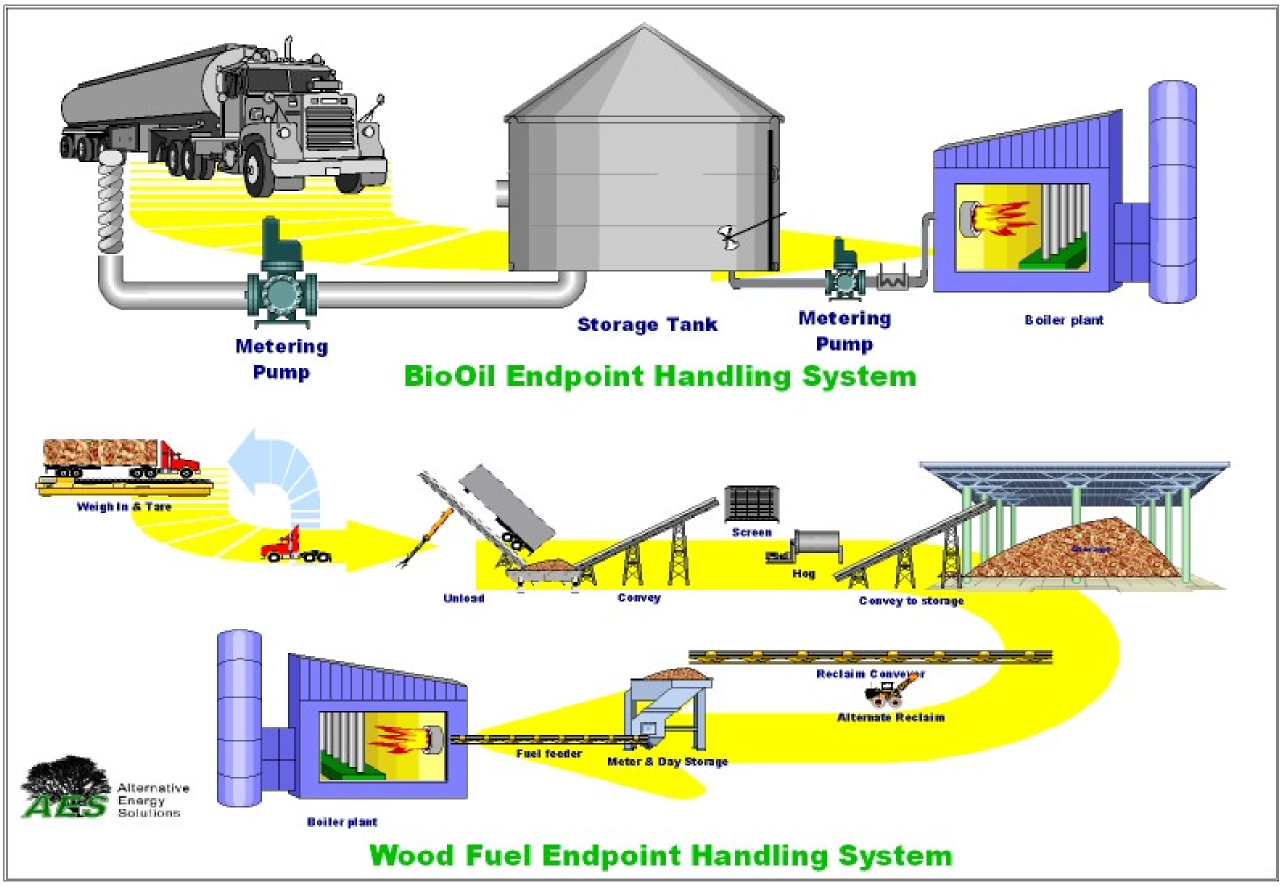
Char is the other major pyrolysis product. The quality of char produced is dependent on the feedstock. Whole tree chips of hard wood, soft wood, or a mixture results in a high quality char product. The char is typically used in the process as a fuel for drying the feedstock. If dry feedstock is available and/or alternative fuels are available to operate the pyrolysis process, the char can be sold as a high quality fuel (i.e. charcoal briquettes) and/or converted into activated carbon.

The LHV of chars is approximately 27mJ/KG. The ash content of char is about 6 to 8 times greater than that of the feedstock. Because the ash is concentrated in the char, the alkali content of the char is quite high. The high ash content in the char causes fouling and corrosion problems during combustion similar to those found in other high ash fuels such as coal. The low temperature of ash slagging and alkali vapor deposition leads to the higher fouling and corrosion.

Gas produced by pyrolysis is used in the process as a fuel and as a carrier gas. The LHV for the gas is approximately 13mJ/m3 the use of pyrolysis gases as a synthesis gas to produce higher value products would require extensive reforming. Due to the unfavorable economy of scale, it probably will not be feasible to use pyrolysis gas as a synthesis gas.

Appendix B

End User handling systems –Bio-oil and Bio mass



The above diagram is offers a diagrammatic comparison of Bio-oil / Biomass handling systems necessary for thermal operation.

Other important factors are moisture content retained and the resulting performance of the combustion system. For Bio-oil the energy density is higher and retained when considering thermal performance. I.e. the boiler co fueled/fueled on Bio-oil is likely to perform better. (The original moisture content of the Bio-oil feedstock being already reduced for the Bio-oil manufacture.)

Ash handling and stack discharges will be considerably less using bio-oil resulting in simpler flue particulate systems.

The diagram indicates less staff required for bio-oil fuel system, less maintenance and generally lower cost storage facilities.

Appendix C

Ratio of Bio-oil energy density to other forms of biomass.

Comparison of energy densities for various types of biomass					
	Density kg M-3	MC % wb (a)	Energy density MJ kg- '" (b)	Energy density GJ m_'	Energy density ratio' ©
Loose, uncompacted straw or hay	95	20	15.51	1.489	1/15
Baled grasses	190	20	15.51	2.979	1/8
whole tree chips	350	56	8.53	3.003	1/7
whole tree chips	350	45	10.66	3.754	1/6
Solid wood, low density (DF)	400	12	17.06	6.826	1/3
Cubes (e.g., grasses)	450	8	17.83	7.993	1/3
Pellets	640	10	17.45	11.170	1/2
Solid wood, high density (oak)	865	12	17.06	14.744	2/3
BioOil	1200		18.00	21.610	1

a Moisture contents are on wet basis and are assumed values based on authors' experience.
b. Assumed biomass bone dry higher heating value = 19.36 MJ kg-'
Ref (Dr Peter Framsham ABRI)

Appendix D

Characteristics	
Technology Characteristic	***Ease of Use Implications as Applied to This Technology***
Maturity – measures how close the technology is to commercial introduction.	End-users require a technology that is proven and in production mode.
Complexity – measures the number of "layers" of technology that must be integrated into this technology.	The complexity of the main activity of the end-user (i.e. timber harvesting / mill operation) is such that additional support technology, such as this pyrolysis system, needs to be easy to use.
Scalability – measures how easy it is to duplicate the technology to meet market demand. Highly scalable technologies are easily replicated (i.e., software or plastic cups).	End-users have a broad scale of needs with respect to throughput of waste and bio-oil production. A large electricity utility has a much higher demand for bio-oil than a mid-sized pulp and paper mill. Therefore, the pyrolysis technology needs to be highly scalable.
Adaptability – measures how easily the end-user can tweak the technology to meet their unique needs.	End-users expect to use only waste wood supplies (forest residues) available and therefore require minimal adaptability to feedstock composition.
Packaging – measures how much special infrastructure must be provided with the technology in order for the end-user to capture its utility.	End-users expect the process to arrive on-site ready to be installed in a short period with minimal Labour. However, they also expect maintenance and technical support to sustain the regular production of bio-oil.
Fragility – measures the technology's robustness outside the lab.	End-users expect the pyrolysis system to be very robust.
Trial ability – measures how easily the end-user can test a technology to determine whether to acquire it.	End-users place a high value on either being able to view an operational demonstration plant, view pilot plant data, and talk to the company that participated in the pilot program