

# **SMALL-SCALE BIOMASS GASIFICATION IN REGIONAL COMMUNITIES: POSSIBILITIES, ADVANTAGES, PROBLEMS AND IMPACT**

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## **ABSTRACT**

Based on our current understanding of the mechanisms of global warming and climate change, it is likely that activities involving the emission of greenhouse gases will soon become regulated in one form or another. Ultimately this, (and the decreasing availability of crude oil) will drive up the price of energy for the consumers who depend upon it in its most convenient high-grade forms: liquid hydrocarbon fuels and grid electricity.

Many regional communities and their micro-economies are at present heavily exposed to changes in both cost and availability of their high-grade energy supplies. This level of exposure to energy prices directly reflects the fact that even now Australia still enjoys some of the lowest energy prices in the world. Transport vehicles rely solely on the national petrol and diesel supply chain; distributed electricity generation (mostly in the form of cogeneration at industrial sites) has had a relatively poor uptake in Australia principally due to the availability of low-cost brown- or black-coal based electricity.

This paper explores the possibilities for disengaging small regional community local economies from high-grade energy consumption via the sustainable use of biomass resources to generate either electricity or motive power via gasification. Unlike wind or solar photovoltaic renewable energy systems, biomass gasification has the advantage of being an “on demand” electricity provider and gasification systems typically have an attractively low installed cost. However, for biomass gasification to qualify as renewable, responsible resource management is required and unlike the other renewables, biomass gasification plant are not “set-and-forget”; they require regular operator attention for fuelling and cleaning out.

The background, advantages, disadvantages and possibilities for a small-scale biomass gasification system for electricity generation are discussed both generally, and via a specific study of its potential in a small Central Goldfields community with a sustainable forestry program.

## INTRODUCTION AND CONTEXT

Energy is fundamental to all living processes, and at all scales, whether it be the metabolic functions of a single-celled organism or the exchange of commodities within the global economy. The growth of the latter is largely underpinned by the increasing consumption of ancient biomass; the chemical energy stored for millennia in the form of fossil fuels. But it is now well understood that both the availability of these energy-rich materials and the tolerance of our environment to their use is finite. The interesting challenge ahead therefore, is what to do about our unsustainable energy practices, in other words how to kick the fossil habit without going into economic withdrawal.

In Australia, our economy is fundamentally reliant on fossil fuels as sources of high-grade energy. Around 78% of our electricity is generated from black and brown coals (Australian Government, 2004), which are relatively accessible, abundant and consequently, cheap to extract. As a result, industrial electricity prices are relatively low by world standards, but greenhouse gas emissions are high – approximately one-third of the national emissions result from electricity production (Australian Greenhouse Office, 2002).

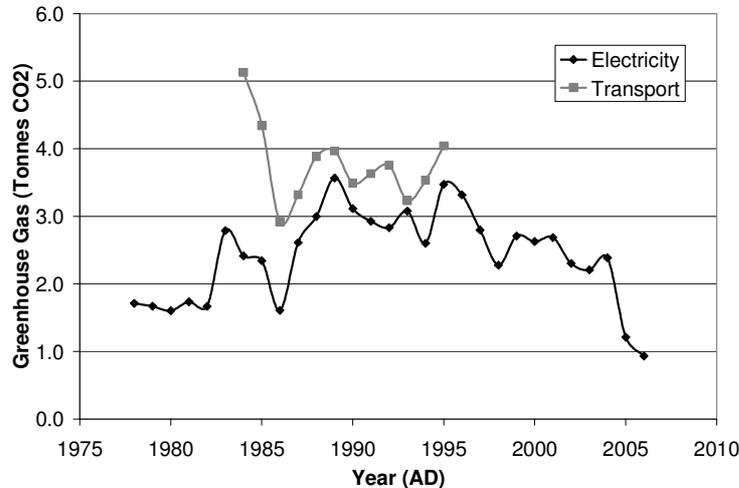
Additionally, our transport systems are almost entirely reliant on petroleum fuels; the prices of which are subject to fluctuations over which the end user has little, if any, control. Australia is a net importer of liquid hydrocarbons (imports totaled approximately 46% of what we used in 2004-05 (ABARE, 2005)), and around 14% of our national greenhouse emissions are derived from the transport sector (Australian Government, 2004).

Thanks to our intrinsic reliance on fossil energy, it is difficult to live in a society like ours and do anything other than generate greenhouse gas emissions! By way of a “home truth” example, Figure 1 shows some historical greenhouse emissions data for one of the authors.

Because public concerns about greenhouse gas emissions have increased significantly in recent years, governments have begun attempts to reduce the greenhouse impact of electricity generation including, amongst other things, legislating for increased use of renewable electricity generation. Laws which promote renewable electricity generation such as Germany’s Erneuerbare-Energien-Gesetz (EEG) have had an interesting side effect; they start to shift the emphasis away from large centralized generating facilities and towards small-scale distributed schemes which are typically run at a community or individual level. This is because renewable energy resources and recovery methods are typically of a small-scale and distributed nature.

Distributed generation (DG) schemes, renewable or otherwise, are finding favour for other reasons too. Small modular generating systems with short construction timeframes are adaptable to changes in the market or regulatory conditions and

those small enough to be physically relocated can achieve a higher expected value than a non-portable generating resource by being moved around to follow market demand changes.



**Figure 1** Greenhouse gas emission data for Sanderson household: Electricity emissions from 1978 to 2006; Transport emissions (2 cars) from 1984 to 1995.

Portable generation also offers a higher residual value as an asset that can be re-sold as compared to a large fixed system which merely has an end-of-life demolition cost. Distributed generation is typically deployed close to the electricity end-user, minimizing transmission losses and helping to directly improve the “worst” parts of the electricity supply grid (*viz* lowest load factors, highest marginal grid capital costs, etc). Multiple distributed generators offers significantly better energy security than the equivalent centralised plant; and DG units have enhanced value when installed as “backup” for customers for whom continuity of supply is critical. Finally, small distributed generation systems operate at a scale that puts them within financial reach of small groups of individuals, thus allowing local communities the option to be responsible for their own electricity generation. (For additional benefits of DG the reader is referred to Lovins *et al*, 2002)

As energy becomes more expensive, the average consumer is starting to realize the extent to which the rising prices of different fossil fuels are correlated with each other and to other important commodities - like food. As a result, some communities have begun to re-evaluate their usage of energy (and other resources) and their level of exposure to global economic forces. Proactive groups within some regional centres are already developing long-term “energy descent” plans (*eg* Hopkins, 2005). These are designs for gradually reducing a community’s use of and reliance upon externally sourced high-grade energy and switching to local renewable energy resources as part of local economies. In this context, bio-energy is seen as an important part of a future renewable energy mix, as unlike wind or solar energy, biomass-based power generation can be operated on demand.

## BIOMASS FOR ELECTRICITY PRODUCTION

Of the present renewable electricity generation in Australia (other than hydroelectricity), biomass constitutes the largest source, principally derived from bagasse cogeneration (at sugar mills), landfill gas and black liquor (paper mills). The penetration of these sources into the Australian electricity market has been possible principally because the biomass resource is in these cases a waste stream or by-product of another process, making for favourable economics.

Although biomass does have the potential to be a significant player in future renewable electricity generation scenarios, it should not be thought of as a simple means to replace fossil fuels and continue “business as usual”. Large-scale energy cropping, whether it be for biomass to feed a power station or the production of biodiesel to replace fossil diesel, can have a substantial environmental impact of its own. Intensive biomass production schemes take arable land away from natural ecosystems or food production, and may in fact require greater primary energy input (for irrigation) than can actually be gained from the resulting biomass crop (Moriarty and Honnery, 2005). A responsible biomass energy system must therefore be managed in a sustainable way, taking advantage of the function of natural systems but minimizing impact on them. In the authors’ opinion, this necessitates the use of small-scale, re-locatable biomass-fuelled electricity generation equipment that can become part of the “toolkit” for sustainable forestry operations. Gasification is arguably the simplest and most cost-effective technology in such a scheme.

## A BRIEF HISTORY OF GASIFICATION

Gasification is the conversion of combustible solids (*eg* wood, coal, charcoal) into a gaseous fuel mixture containing hydrogen ( $H_2$ ) and carbon monoxide (CO). Depending on the production context, the gas may be known as “wood gas”, “synthesis gas”, “producer gas” or “coal gas” to name a few. Gasification is not a new process. Thomas Shirley conducted experiments using “carburetted hydrogen” in 1669; the first patent in which mention is made of producer gas driving an internal combustion engine was issued to John Barber in 1791; and the first recorded attempts to gasify wood were made by Lebon in 1798 (Kaupp and Goss, 1984).

By the early 1900’s, vehicles were driving on producer gas, many large gas engines had been built in Europe and the U.S, and the Humphrey Pump (Towne, 2003) was using producer gas directly to pump large volumes of water for irrigation purposes<sup>†</sup>. Possible disruption to gasoline supplies in World War I inspired further development of automotive gas producers, especially in France where the use of wood and charcoal as fuel was encouraged by government

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<sup>†</sup> The only Humphrey Pump in the world to be still operational is at Cobdogla in the South Australian Riverland. [http://www.cobdoglacaravanpark.com.au/irrigation\\_museum.htm](http://www.cobdoglacaravanpark.com.au/irrigation_museum.htm)

policies. The Frenchman Imbert filed for a patent on automotive gas producers in 1923.

In the 1930's, gasifier development was driven by the economics of the depression era and actual or perceived shortages of that more convenient fuel, gasoline. Subsequent fuel shortages in Europe during World War II thus brought small automotive gas producers to their peak of utilisation, with over a million vehicles converted to run on producer gas worldwide (Egloff and van Arsdell, 1943). In Australia, wartime petrol rationing resulted in as many as 72,000 vehicles being retrofitted with gas producers, and charcoal production to supply them reached an estimated 20,000 tons per month (Anon, 1946).

Abundant and cheap supplies of petroleum fuels available shortly after the war quickly put an end to the use of gasifiers on vehicles, and interest in the technology diminished in the subsequent years (as demonstrated by the number of publications listed in major engineering indexes dropping from several hundred per year to less than ten per year during the period 1950 to 1970 (Kaupp and Goss, 1984)).

During the 1970's there was a renewed interest in gasifiers (driven in part by the 1973 Oil Crisis), and in contrast to the efforts of the wartime era, much more attention was given to the direct gasification of wood and biomass, with the energy and resource losses associated with charcoal production for gasifiers considered unacceptable.

Apart from some consideration given to the risk of petroleum supply disruption (La Fontaine and Zimmermann, 1989), most of the recent work on wood, biomass and coal gasification has been driven by environmental issues, principally greenhouse gas emissions. But now, an economic factor has been added. In 1995 the World Bank reported that "World market oil prices must rise by a factor of one-and-a-half to two for biomass gasification to become attractive again." (Stassen, 1995). At the time, crude oil was at \$18 USD/barrel. With the current price at over \$70 USD/barrel (a four-fold increase since 1995), many companies and individuals (especially those reliant upon petroleum for power generation in remote areas) are considering alternatives.

## **PRESENT GASIFIER TECHNOLOGY**

The gasifier technology that is the subject of the present study is the small-scale downdraft "Tasman Class" wood gasifier which commenced preliminary production earlier this year in Melbourne, under license from Fluidyne Gasification (New Zealand) and the supervision of the authors. The gasifier is designed to operate on small wood blocks and will produce sufficient gas to power a 3-litre spark-ignition engine (petrol car engine) driving a 15 kVA single-phase 240 volt alternator; sufficient power at full load to provide for the complete electrical needs of around 3 to 6 average homes. Depending on site and

connection requirements, the installed cost of the gasifier and generator system is expected to be around AUD \$20,000. The gasifier is robustly designed with a minimum of instrumentation and control, requiring only simple manual procedures for its operation. Whilst intended for stationary applications, the same gasifier unit could potentially be coupled to an automobile's engine for emergency transport in a fuel crisis.

The gasifier operates in batch mode, running continuously for 2 to 3 hours, after which time it requires re-fuelling. Maximum wood consumption is approximately 20 kg per hour. As different wood types have different burn characteristics, changes to the type of feedstock will in some cases affect the gasifier output and/or the fuel consumption rate. Cleaning out is normally required after every second run, a task taking one person approximately half an hour to complete. As a rule of thumb, complete fuel preparation (harvesting, cutting and sizing) takes one person approximately half the amount of time as the same amount of fuel is expected to burn for. Pre-drying of the fuel is carried out using waste heat from the engine exhaust-gas stream, and wood shavings (*ie* from chainsaw cuts) are not wasted, but are utilized in the gasifier filter system. Waste products from the gasifier are ash, carbon residue, condensate water and the wood shavings from the filter containing additional ash and fine carbon. All of these products can be combined and should be returned to the soil as a soil conditioner. Exhaust emissions (*ie* sulfur and nitrogen oxides) from an internal combustion engine running on wood gas are typically lower than for hydrocarbon fuels (Reed and Das, 1998).

In general, gasifiers such as the above example find successful niche applications in areas with the following characteristics:

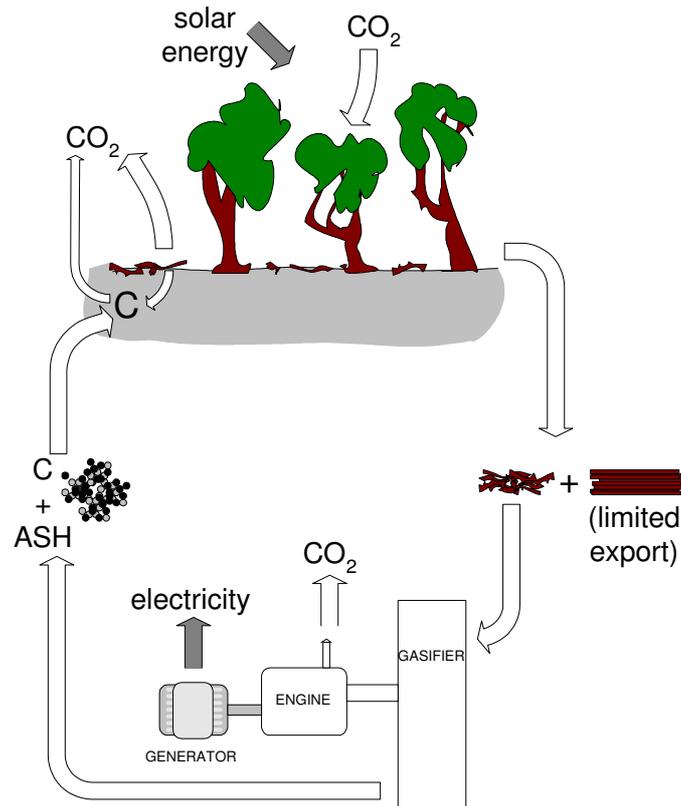
- No grid electricity
- Limited availability and/or high price of diesel or gasoline
- Plentiful wood supply
- Low labour costs

Thus the uptake for this technology has been historically in areas of the developing world that satisfy the above criteria.

## **FORESTRY CONTEXT**

It needs to be stressed that biomass gasification is not a sustainable or environmentally acceptable energy alternative unless the biomass resource utilised in the process is responsibly and sustainably managed. From a social perspective, this is most easily achieved at a small scale where individuals and groups can feel a sense of ownership and responsibility for their resource. Sustainable resource management relates not only to the carbon cycle (*ie* ensuring that the overall process is greenhouse neutral), but also to the impact of forestry operations on habitat. Ideally, regional native, rather than imported plantation species are utilized as these are adapted to the local conditions and require no additional energy inputs to maintain them.

Figure 2 shows the context for gasification as integrated into a sustainable forestry process. The net energy outputs of the process (electricity and system energy losses) are balanced by the solar energy absorbed in the production of the biomass. Carbon emissions from the gasification process are balanced by the carbon uptake in the biomass. Solid residues (ash and carbon) retained after gasification are returned to the soil. If the forestry practices involve the harvesting and exporting of a timber product, this should be undertaken in a limited and environmentally responsible way.



**Figure 2** Biomass gasification of small-sized wood should be a net greenhouse-neutral process integrated with sustainable forestry practices. Carbon dioxide emissions from the gas engine (as well as natural decay of dead wood) should be balanced by the take-up in the biomass resource. Minerals (ash) and solid carbon matter collected in the gasifier should be returned to the soil. The export of high-grade timber should be limited to minimize ecological impact.

More specifically, let us now consider the type of forest resources and possible management practices in the Central Goldfields region of Victoria. The Mount Alexander Shire consists of approximately 7000 households and covers an area of roughly 145,000 hectares. Approximately 30% of the land area is covered by native forests (mostly Box Ironbark). Within the Shire there are also around 700 hectares of privately established plantations for firewood and sawlog production. Assuming a realistic (*ie* imperfect) forestry management strategy, an average

sustainable yield of 1.5 to 2 T/Ha/Yr (tonnes per hectare per annum) is possible from such plantation operations if they are sustainably managed<sup>†</sup>. In addition, a substantial proportion of the Shire's State Forests (well over 8000 Ha) could potentially embark upon an ecological thinning program in which smaller trunks are removed in order to support the growth of larger ones. This sort of ecological thinning leads to a healthier forest ecosystem. In such a scenario, a large amount of small-diameter wood could be made available as feedstock for small gasifier units. Additionally, as the yields from ecological forestry thinning are non-linear (declining in the longer term), multiple small-scale distributed modules are better suited to the changing resource availability and location. Mobile systems also have the potential to respond to sudden changes in resource distribution resulting from bushfires.

## CASE STUDY

Fryers Forest is a small intentional community in the Mount Alexander Shire incorporating a forest (approximately 100 hectares) of native eucalypt box species that is undergoing thinning through sustainable forestry practices. The community will ultimately consist of 11 households (currently there are 8) and one larger central community building. All house sites are grid connected.

One of the longer-term goals of the community is the sustainable production of timber from the forest both for site use and local export. The wood resource is predominantly Grey, Yellow and Red box species and some areas of up to 20% Red Stringybark. Maximum yield estimates for sustainable forestry (Holmgren and Dennett, 1997) are around 48 m<sup>3</sup>/yr of post, pole and sawlog with around 112 m<sup>3</sup>/yr of firewood (down to 75 mm diameter). Community use of firewood is estimated at 50 m<sup>3</sup>/yr, leaving an annual firewood surplus of approximately 60 m<sup>3</sup>. An additional yield of 5 to 15 m<sup>3</sup>/yr of smaller waste-wood (25 to 75 mm diameter) may also be possible, albeit at a somewhat higher labour cost<sup>[15]</sup>. Both the surplus firewood and waste-wood materials are potential feedstock for gasifier operations to generate electricity in the community. It should be noted, however, that future wood yields may be substantially lower if the current 8 year drought is more typical of prevailing future conditions under global warming.

The cost of the sustainable forestry operations is predominantly labour, with some additional machinery rental costs. Labour involves marking, felling and docking the trees, clearing and stacking wood and heads, debarking, applying paint and borax, and cutting, splitting and stacking firewood for air-drying. It is estimated that the majority of the rental and labour costs, (up to \$25- per hour for the latter depending on task) can be recovered in the sale of harvested posts and poles. Thus the net cost of firewood as part of an integrated thinning operation is around \$50- per m<sup>3</sup> (Holmgren, 2004).

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<sup>†</sup> Note that sustainable practices require that a minimum of 300 linear metres per hectare of dead wood (minimum 100 mm diameter) is retained on the ground as habitat in addition to bushy understorey.

Good solar passive house design within the community has resulted in relatively low electrical energy needs (an average of approximately 5kWh/day per household) with the potential for further reductions in the future. Most households purchase 100% “Greenpower”. Considering aggregate electricity usage only, the annual average for the community (assuming 5kWh/day and all 11 house sites occupied) is 20.1 MWh/yr.

Table 1 shows the electrical energy estimates assuming that 60m<sup>3</sup>/yr of harvested wood from Fryers Forest is used as input to a grid-connected Tasman Class gasifier. An average solid density of 1000 kg/m<sup>3</sup> and moisture content of 30% (wet basis) has been assumed for the air-dried wood fed to the pre-drying stage of the gasifier system. It is further assumed that the gasifier pre-drying stage reduces moisture content to 15% (wb), and that wood consumption is 20 kg/hr. It is uncertain how future electricity tariffs will be applied to small generation schemes such as this example, or indeed whether electricity generated in this fashion will be regarded by the authorities as 100% Greenpower. We have therefore chosen 3 rates to consider; the Greenpower Premium rate (as currently applied to some households with solar photovoltaic generation); a typical retail rate (also applied to some PV generators); and a typical large-scale generation rate which may be applied to some small generators in the future.

**Table 1** Estimated electrical energy outputs and income from Tasman Class gasifier at Fryers Forest.

Annual feedstock volume (m <sup>3</sup> )	60
Annual feedstock mass (Tonnes)	60
Mass after drying to 15%wb moisture (Tonnes)	51
Daily mass feed to gasifier (kg/day)	140
Daily operation time (hrs)	7
Electrical power output (kWe)	15
Electrical energy export (kWh/day)	105
Annual electrical energy export (MWh)	38.2
Annual electrical energy import (MWh)	20.1
Annual income from net export electricity (at Greenpower Premium rates, ~\$300-/MWh)	\$5,475
Annual income from net export electricity (at retail rates, ~\$150-/MWh)	\$2,737
Annual income from electricity (at generator rates, ~\$40-/MWh)	\$730

The example shows that the estimated surplus firewood available in the community could generate substantially more electrical energy than is likely to be consumed. In addition to eliminating electricity purchase from the grid for all households (saving over \$3,000), the sale of community electricity into the grid at Greenpower Premium rates would cover the firewood’s residual cost (\$50- per

m<sup>3</sup>) and net \$2,475. However, this is insufficient income to pay for the additional labour required to operate the gasifier (approximately 4 hours per day). The other lower electricity rates will not cover the residual cost of the firewood alone. It must therefore be questioned whether a better alternative would be to simply sell the firewood *as firewood*, as this may net more income than the export of electricity for similar or less labour, without the embedded energy and capital costs of the gasification equipment.

So although the proposed system is technically feasible and increases the self-reliance and demonstration value of using renewable power in the community, there is no clear economic advantage in using a grid-connected gasifier system in the above scenario. This may change in the longer term if costs of energy were to rise due to the consequences of “peak oil” or carbon taxes.

The economics are somewhat different for an off-grid system replacing or competing with intermittently-operated fossil diesel-powered generator sets. In this instance, the off-grid installed capital cost of either form of generation will be about the same at the 15 kVA scale. Thus in simple terms, fuel harvesting at \$50- per m<sup>3</sup> is now competing with diesel at a retail price of around \$1.40 per litre, (around \$1.00 per litre after tax credit for household electricity or off-road business use). The key parameter here is therefore the equivalent diesel use for the same electrical energy output. As a basis we have used the effective energy content of each fuel in each system<sup>†</sup>. From Williams (2001), a litre of diesel has an energy content equivalent to 3.16 kg of wood. Table 2 shows a brief comparison.

**Table 2** Simple fuel cost comparison of a gasifier generator set with a diesel generator set, off-grid application.

Residual labour cost for 60 m <sup>3</sup> of firewood	\$3,000
Mass of 60 m <sup>3</sup> of wood (Tonnes)	51
Daily operation time (hrs)	7
Daily operator hours for gasifier	4
Equivalent litres of diesel required	16,140
Cost of diesel (retail at \$1.40 per litre)	\$22,596
Cost of diesel (after tax credit, \$1.00 per litre)	\$16,140

From the table it can be seen that in terms of fuel cost, biomass gasification integrated with sustainable forestry has a significant competitive advantage (an annual saving of \$13,000 to \$19,500) over diesel generation at this scale in an off-grid setting even with a rural diesel tax credit. For the diesel prices and consumption used in this example, a local operator could be paid \$9 to \$13.40 per hour to operate the gasifier, rather than spend the same money on importing diesel fuel.

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<sup>†</sup> Data are for normally-aspirated diesel engines. Some turbo-diesel generator manufacturers claim up to 20% lower fuel consumption than yielded from our calculation.

## **DISCUSSION**

In the scenarios explored in the preceding section, we have focused principally on the net energy supply-demand balance and simple economics of small-scale gasification for electricity production. We have shown that the biomass resource available at Fryers Forest is more than sufficient to provide for the electrical needs of the community in a sustainable way, but the economic drivers are insufficient to warrant such a scheme at present. We show that the economics for an off-grid application are more favourable when compared with a similar-sized diesel generator as they offer the opportunity to direct cashflow to a local operator rather than to fuel imports.

In addition to offering the potential for regional employment, the generation of renewable power from biomass increases the perceived “value” of sustainably-managed forest resources; allows a community to become responsible for its energy production and more mindful of its use, and has the potential for complete energy independence (of considerable value in the event of either an electrical or petroleum supply crisis).

If integrated into an extensive sustainable forestry management and/or ecological thinning program within the Mount Alexander Shire, biomass gasification has the potential to be a significant contributor to the local electricity supply/demand balance (*ie* at Gigawatt-hour per annum levels). As an on-demand source, it may provide a valuable means to balance out the variable nature of other future renewables in the region such as wind and solar photovoltaic generation.

Finally, as demonstrated in the Fryers Forest case study, a reasonably large area of sustainably-managed forest can only provide sufficient energy for a relatively small number of households. This is a sobering reminder that a sustainable energy future is only possible with responsible and reduced energy use.

## **IN CONCLUSION**

Biomass gasification is (quite literally), the growing alternative to fossil fuel. Our vision is for a world where sustainable energy production meets responsible energy use, and where biomass is valued for its energy contribution in a diversified energy market.

At the small scale, biomass gasification can be integrated into sustainable forestry practices and provide relocatable greenhouse-neutral distributed generation resources for regional groups and communities. The capital costs of the equipment are relatively low, however ongoing labour is required to operate the system.

Whilst providing a realistic opportunity to shift costs from fuel imports to local employment in an off-grid application, we find that for our grid-connected case study, at the present time biomass gasification cannot be justified simply on economic grounds alone.

However, in a future where rising fuel costs and the impact of carbon emissions from fossil electricity production are a major concern, biomass gasification will be valued as one means to provide regional communities with environmentally responsible energy independence.

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