RENEWABLE ENERGY OPTIONS FOR AUSTRALIAN INDUSTRIAL GAS USERS

Prepared by IT Power for the
Australian Renewable Energy Agency

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ARENA

Australian Government
Australian Renewable Energy Agency

RENEWABLE ENERGY OPTIONS FOR AUSTRALIAN INDUSTRIAL GAS USERS

Australia has a range of renewable energy options that can reduce natural gas use by industrial consumers.

Domestically produced gas is a significant part of Australia's primary energy mix. Industrial users have benefited from gas prices significantly lower than international benchmarks, which trend with the oil price.

It is forecast that Australian gas prices will increase due to the growth in demand from Liquid Natural Gas exporters. Price and security of supply are of increasing concern to industry.

The Australian Renewable Energy Agency (ARENA) has commissioned research into the options for reducing industrial gas use with renewable energy. The analysis focused on renewable energy options that could be installed at the sites of existing industrial gas users.

ABOUT ARENA

ARENA was established by the Australian Government to make renewable energy technologies more affordable and increase the amount of renewable energy used in Australia. ARENA invests in renewable energy projects, supports research and development activities, boosts job creation and industry development, and increases knowledge about renewable energy. ARENA is currently supporting more than 200 projects and is actively seeking new projects to support.

RENEWABLE ENERGY OPTIONS FOR AUSTRALIAN INDUSTRIAL GAS USERS

This document is the summary of the analysis undertaken by IT Power in conjunction with Pitt&Sherry and the Institute for Sustainable Futures. For further details of the research undertaken, there is a background Technical Report. A financial analysis tool is also available for screening of options.

IT Power (Australia) Pty Ltd is part of the IT Power Group, a specialist engineering consultancy focusing on renewable energy, energy efficiency and climate change policies.

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THE OPPORTUNITY

Industrial gas users consume gas for process heat ranging from below 100°C to over 1000°C and also as chemical feedstock. Industrial users account for nearly half of domestic demand for gas. A relatively small number of large users account for a large fraction of that. In this category, the metals and alumina sector figures prominently. Of the smaller 'mass market' industrial users, food and beverage related sectors are the largest in usage and have the greatest demand for heat below 150°C.

As LNG exports grow, overall demand for Australian gas is expected to triple. Domestic prices are predicted to increase to levels determined by international prices. However there is great uncertainty around supply and demand and linkages to uncertain future oil prices. Industrial gas users are concerned about the uncertainty of future gas prices.

The gas prices paid by users depends on; their size, location, if they are distribution or transmission connected and when their contract was negotiated. Renewable energy options could offer potentially lower energy costs, but also greater certainty once the required investment has been made. However, gas users have an imperative to protect their core business and limit risk, expect high Internal Rates of Return for their investments and many have limited access to capital.

Globally, uptake of renewable energy technology continues to grow, motivated in part by the imperative to reduce greenhouse gas emissions. There are renewable energy solutions that are established and technically feasible for substitution for most gas applications. Solutions include bioenergy and solar thermal, hot sedimentary aquifer geothermal and heat pumps. An 'off the shelf' renewable alternative can heat water/steam for process heat while operational risk is minimised by maintaining a gas-fired capability as back-up.

Rigorous economic evaluation is very site and process specific, however an approach that can provide indicative assessment of the value proposition as a precursor to a site specific detailed investigation has been developed.

All technologies have a strong size dependence on capital cost that makes larger systems more cost-effective. Balancing this is the fact that small users tend to pay more for gas.

Investing in renewable energy options minimises exposure to the uncertainties of future gas prices.

BIOENERGY

Biomass can be converted in combustion boilers, gasifiers or digesters. All approaches are proven and applicable.

Bioenergy solutions that appear close to being economically viable in suitable circumstances are:

- Heating of water or steam on any scale and at any temperature using biomass fired boilers where a sufficiently low cost (less than $5/GJ) combustible biomass resource is available and convenient to the location.
- Combustion of digester biogas in boilers, kilns, furnaces or engines where the composition of the gas is suitable and where a low cost digestible biomass resource is available.
- Combustion of biomass gasifier gas in boilers, kilns furnaces or engines where the composition of combustion products does not affect the process and where a low cost biomass resource is available.

SOLAR THERMAL

Solar thermal systems are technically proven for all temperatures of industrial use. Lower temperatures are available from simple flat plate and evacuated tube collectors. More complex and costly concentrator systems are needed for higher temperatures. To a good approximation, capital costs increase linearly with temperature.

Performance is strongly linked to the average level of solar radiation at a site. Some level of storage is usually needed to allow for daily cycles. Performance will be lower in Winter than Summer.

At a site with a reasonable solar resource, solar thermal is likely to be economically viable for temperatures up to 150°C and possibly viable up to around 250°C. Higher temperature systems are not currently economically viable although may become so in future.

OTHER OPTIONS

For temperatures up to 100°C, hot sedimentary aquifer geothermal systems and electrically driven heat pumps are alternatives that should also be considered. Geothermal solutions rely on the presence of a suitable aquifer, and so will only be relevant at sites near such a resource.

Only a minority of gas users are likely to be able to access a useful sedimentary aquifer resource. Where it is possible it can be quite cost-effective. Demand needs to be sufficient to justify the minimum investment in an extraction well plus reinjection well pair and the associated infrastructure.

Grid connected heat pumps will be economic if they are operated at high utilisation factors and if the cost of electricity divided by the Coefficient of Performance is significantly less than the cost of gas. This is likely to be the case for temperatures below 100°C. Using contracted renewable electricity supply from the grid or partial supply from on-site Photovoltaics to operate them can be considered.

Switching to coal combustion is an alternative fossil fuel choice that can be lower cost. A similar investment cost to a biomass boiler is needed and delivered coal prices between $2 and $4/GJ makes it competitive with gas if externalities are not considered. While these costs are more than waste biomass, they are less than most other sources.

CONCLUSION

There appear to be potential opportunities for reducing gas usage with renewable energy that are economic, or close to economic, across all mass markets and some large user industry sectors, and these will grow as gas prices rise. There is no single favoured sector or application, each case must be considered separately. There is also no clear link between industry sector and most appropriate renewable technology. The closest observation that can be made in this regard is that agriculture, food, beverage and wood-and-paper related gas users are more likely to have low to zero cost biomass available and if so should definitely consider exploiting this. Those users that have no low cost biomass available but are obviously in high solar resource areas are more likely to favour solar thermal solutions. Some of the alumina refineries may fall in this category.

A full system-based feasibility study of all renewable energy technology options, as well as fossil fired approaches, together with energy efficiency, energy storage, electricity supply and process optimisation issues, is needed for an individual user to choose an optimal overall solution.

While there are many examples of the renewable energy technologies in operation around the world, the supply chain in Australia is still somewhat immature. This situation will improve as demand increases. There is scope for third party organisations to establish systems on a sale of energy basis to reduce business risk for gas users. There is a range of information sources and support programs already in place that would be of direct benefit to gas users if they wish to pursue renewable energy options.

THE OPPORTUNITY

Summary

- Industrial gas prices vary over a wide range and have limited transparency.
- Gas users are concerned by uncertainty in gas availability and pricing, and the trend to higher gas bills.
- Mature, low risk renewable energy solutions could offer a hedge against uncertainty in both gas price and availability.
- Biomass, Solar and Geothermal resources can potentially be used within the boundaries of an existing industrial facility.
- The gas price is a key parameter in assessing the economic viability of renewable energy options, however it varies by location and volume of demand over a wide range.

BACKGROUND

Natural gas use is a major part of Australia's energy mix and provides a very large fraction of the energy used by industry.

In 2012-13, total Australian gas use was reported to be 1,387PJ[1]. Of this amount, 587PJ per year are attributed to the industry sectors which are within the scope of this study[2]. At an indicative wholesale gas price of $6/GJ[3] this gas had a cost of approximately $2.4 billion.

End use energy 2012-13

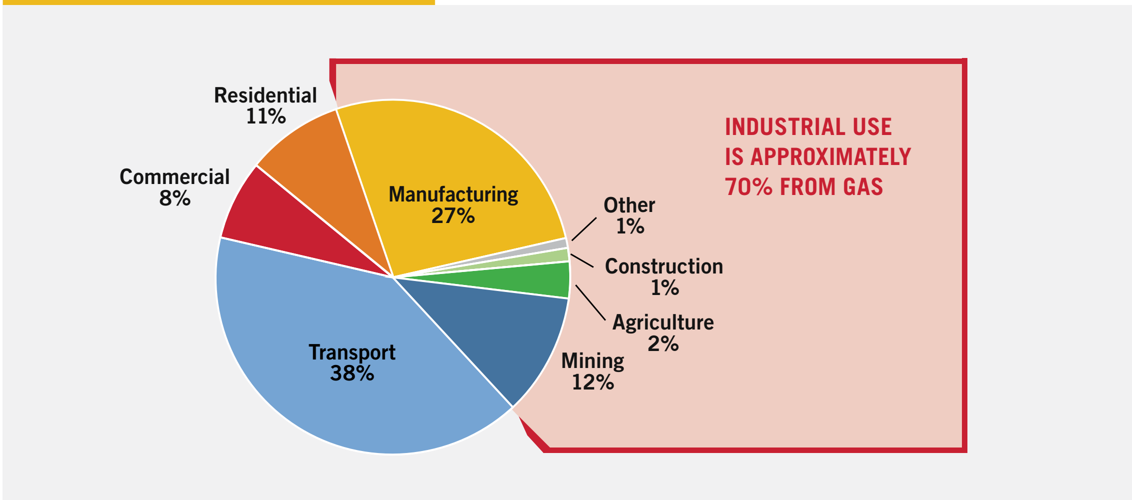


Figure 1. Australian 2012-13 end use energy consumption by sector

Industrial use for this study means the combination of manufacturing, mining and agriculture which, as shown in Figure 1, account for more than a third of end-use energy. In turn, industrial end-use energy is around 70% gas. Within the overall industry category it is the manufacturing sector which dominates in gas use.

Export vs. Domestic

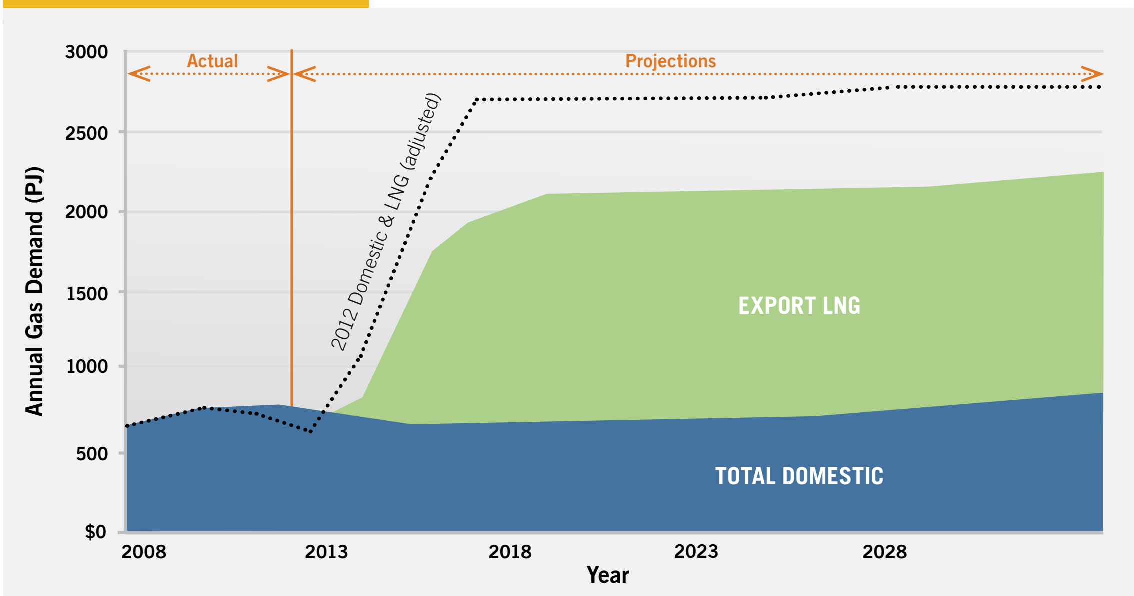


Figure 2. Projected domestic and LNG demand for East Coast[4]

1 Energy in Australia 2014, Australian Government Bureau of Resources and Energy. www.industry.gov.au/industry/Office-of-the-Chief-Economist/Publications/

2 The bulk of the remainder is power generation, domestic use and commercial building heating, which have not been considered in this study.

3 1PJ = 1 million GJ

4 Gas Statement of Opportunities for Eastern and South Eastern Australia, 2013, Australian Energy Market Operator. www.aemo.com.au

Uncertainty around continuing availability and likely cost of natural gas for local industrial use is of increasing concern in Australia. Exports of Liquefied Natural Gas (LNG) are a growing source of income for the Australian economy, worth $10.3 billion in 2012-13[5]. In addition to the existing LNG export plants in Western Australia, new plants are coming online in Queensland and the Northern Territory. As illustrated in Figure 2, this is predicted to treble the overall demand for the gas that is produced in Australia.

A trend of increasing gas prices in Australia is already in evidence. This is widely expected to continue as increasing demand for gas for LNG exports pulls the domestic price close to a cost that is determined by the international market.

2014 wholesale prices are in the range of $6/GJ to $8/GJ and it is forecast that they will continue to rise and prices between $9 and $12/GJ may be experienced before the end of the decade. Large gas users are also reporting difficulty in securing long term supply contracts.

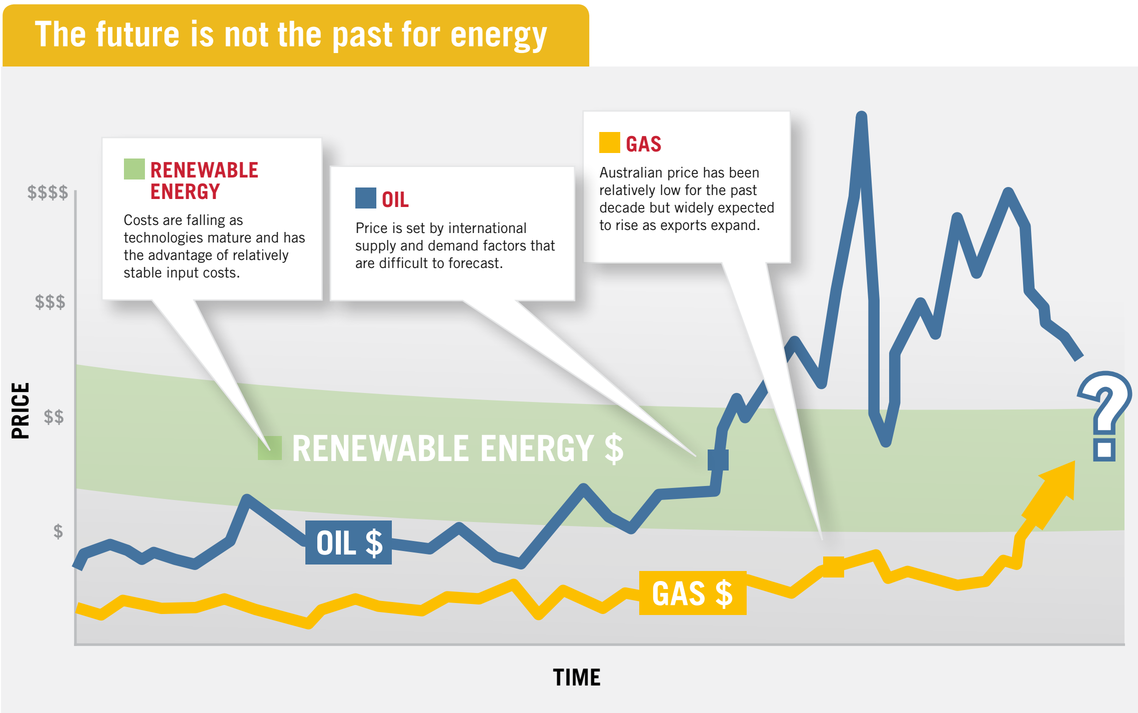


Figure 3. The only certainty is uncertainty with future gas prices.

There is a large degree of uncertainty and volatility in these projections, exacerbated by delayed linkages to the variable international price for oil and impacts of other sources of LNG supply on the international market (as illustrated in Figure 3). There are also strong suggestions that high prices will contribute to the closure of some large manufacturing operations, which would reduce demand and possibly limit the price rise seen by other users. Industrial gas users are concerned by the trend to higher gas prices and increased uncertainty[6].

CURRENT INDUSTRIAL GAS USAGE

Direct industrial use of gas can be divided into four broad categories:

- use at lower output temperatures for steam raising and hot water, and also for various types of drying processes,
- use in high temperature thermal processes, in kilns, furnaces etc,

5 Energy in Australia 2014, Australian Government Bureau of Resources and Energy. www.industry.gov.au/industry/Office-of-the-Chief-Economist/Publications/

6 See for example Deloitte, 2014. Gas market transformations – Economic consequences for the manufacturing sector.

- as fuel for power generation, and
- use as chemical feedstock, principally for the production of ammonia.

Renewable energy alternatives exist for all these applications. This study examined renewable energy technology options, associated costs and industrial end-use applications. It excluded consideration of power generation and domestic and commercial building HVAC uses.

Industrial gas users are a combination of:

- large users who are connected to the gas transmission system and, typically, pay close to the wholesale gas price,
- smaller, mass market customers who are connected to the gas distribution system and, typically, pay significantly more than the wholesale gas price depending on their size - in 2014 this ranged between around \$9/GJ and \$25/GJ, and
- LPG users, who are too far from the natural gas distribution systems and so instead rely on trucked in LPG at prices of more than \$20/GJ.

The gas consumption of the key specific industry sectors within the scope of this study (in PJ/year) have been categorised against temperature of conversion as shown in Figure 4.

Breakdown of gas use

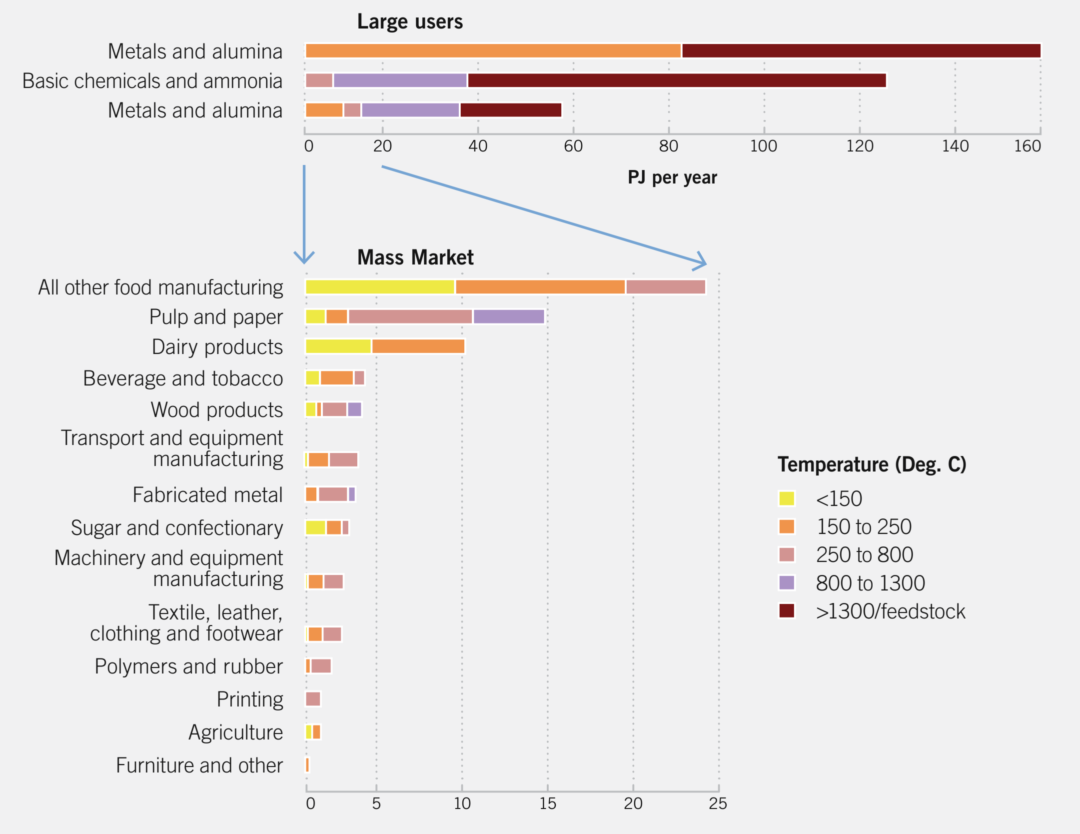


Figure 4. Sector breakdowns for the various industrial gas uses for the year 2012-13. The total is 412PJ per year[7].

7 The gas use reported as 'mining' in energy statistics is excluded from this figure. It is use of gas by oil and gas producers themselves for upstream processing. Such gas has low marginal cost to them and is not judged prospective for renewable energy substitution.

The large users are relatively few in number. The basic chemicals and ammonia segment is dominated by 6 ammonia plants and 2 polyethylene plants and most of the metals and alumina sector use can be attributed to 5 large alumina plants. These individual users are using gas at average rates of several hundred MWs each[8].

The mass market users are much greater in number with around 2000 separate users consuming energy at an average rate of 0.3MW or more.

It is important to note that the categorisation by temperature is based on the current estimated temperature provided by gas combustion. In many cases the actual end use temperature can be considerably lower. There is also the potential for providing some of the higher temperature heat as lower temperature pre-heating in a hybrid system. The lower the temperature of energy required, the more renewable energy options there are available and the more cost effective they will be.

Examining the large users, it is notable that a very large amount of gas that is consumed in making alumina. Much of this is for production of steam by the Bayer process in the temperature range of 150°C – 250°C. This is the lowest temperature opportunity in the large user category.

Within the mass market users, it is notable that the various food related sectors are very significant. Their requirements span the temperature spectrum but also have the largest fraction at the lower temperature end.

The actual price a gas user is, or will be, paying can vary over a wide range. The only real certainty is the presence of future fuel price uncertainty.

The food sector is a growth area for Australia and an increasing source of exports. Recent projections[9] have forecast a 77% increase in the value of Australian agri-food exports (meat, dairy, fruit) by 2050. These increases are due to increasing demand from developing markets, primarily in Asia. Such growth is already being witnessed in the dairy products manufacturing industry, where milk production in Australia to the decade ending 2011 increased by around 41%[10]. Such increases in production will increase the demand for energy.

Quality and environmental credentials are seen as important considerations for the food sector in particular, above and beyond the price of energy.

Within the food sector, many specific operations such as abattoirs have issues of disposal of wet biomass waste. This can cost money to deal with, but also lead to methane emissions (a very strong greenhouse gas) from decomposition if not flared or utilised for energy.

In contrast to the food sector, many other aspects of manufacturing have been declining in Australia and an increasing cost of gas would clearly add pressure in this regard. A recent study commissioned by a group of larger users[11] claims that ammonia and alumina operations would be at risk of closure if faced with gas prices in the $8 - $10/GJ range.

8 An annual consumption of 20PJ would correspond to a continuous 24 hour per day thermal power level of 634 MW.

9 Linehan V, Thorpe S, Andrews N, Kim Y and Beaini F, 2012, 'Food demand to 2050: Opportunities for Australian agriculture', paper presented at ABARES Outlook Conference, Canberra, 5–6 March 2013, p. 1.

10 Food Processing Industry Strategy Group – Final Report of the Non-Government Members, September 2012

11 Deloitte, 2014. Gas market transformations – Economic consequences for the manufacturing sector.

Sugar, paper and wood products operations are notable for already having a large use of renewable energy via use of their own biomass waste materials in bioenergy systems.

Most of the mass market users are scattered around the Eastern seaboard within 200 km of the south east and east coasts. There are also some in the south west of Western Australia and Tasmania. The large users are also close to the coast, with notable concentrations in the region of Gladstone, Newcastle, Perth/ Kwinana, Geelong and the Pilbara[12].

OTHER CONSIDERATIONS

The actual price an individual gas user is or will be paying can vary over a very wide range compared to another user, according to circumstances. Factors include,

- the amount of gas consumption
- the consumer's bargaining power,
- the timing of contract negotiation (in relation to market futures)
- the state the user is located in; and
- how far toward the extremities of the distribution system the site is located.

Whilst it is convenient to consider the average cost of gas to users, gas supply contracts are complex and feature aspects such as; connection charges, tariffs that reduce as daily consumptions is increased, take or pay clauses, and tariffs linked to the level of firmness of demand. This makes measures which reduce but do not eliminate gas use economically challenging.

For an industrial gas user, there are a range of other factors that weigh heavily on an investment decision such as substitution of gas by renewable technologies. These can be categorised as:

- **Business continuity** – maintaining operational continuity, cash flow and presence in the market place is paramount. Thus continuity of process energy supply is also critical.
- **Market risk** – the risk of losing market share to a competitor due to a disruption.
- **Contractual (supply) risk** – the risk of being let down by a technology supplier.
- **Investment Return** – expectations of internal rates of return can typically range from 10% to 30% per year, with many smaller companies having limited access to capital and rates of return expectations at the high end of this range.
- **Future fuel prices** – uncertainty around future gas prices drives interest in alternatives, however future biomass prices are also uncertain due to unknown supply and demand pressures.
- **Technology risk** – risk of poor reliability from unproven alternatives, lack of performance and impact on product quality. For many industrial users, reliable operation 24 hours per day is required.

A lack of familiarity with the technologies typically amplifies the perception and reality of these factors and adds an additional barrier to adoption.

12 Beath, A.C., 2012. Industrial Energy Usage in Australia and the Potential for Implementation of Solar Thermal Heat and Power. Energy, 43(1), pp.261–272.

ENERGY ALTERNATIVES

The renewable energy sources that could be utilised within the premises of an industrial gas user depending on the particular circumstances are; bioenergy (Figure 5), solar (Figure 6) and geothermal. Electrically driven heat pumps are another possibility. Switching to coal fired systems is the key non-renewable approach that can offer cost savings.

Figure 5. Biomass boiler – full case study see page 39. Photo: Australian Tartaric Products

Figure 6. Solar flat-plate collector field – full case study see page 45. Photo: Erik Christensen

Technically, a renewable energy solution can be engineered for every single current use of gas by industry. However, there is a subset of solutions that are lower in technical risk and cost, and are both proven and commercially available. Those that are still in the pilot or even R&D phase (for example solutions for very high temperatures or for chemical feedstocks) bring higher risk and cost.

Given the low technical risk appetite of industrial gas users, technologies at pilot or R&D phase are not likely to be attractive unless the organisation has a parallel technology development business agenda.

These considerations, plus the economic analysis, lead to the conclusion that it is process heat in the form of steam or hot water and renewable gas for non-quality sensitive combustion[13] that are the most suitable applications at present.

ECONOMICS

Economic performance can be assessed by comparing the annual running cost of different energy supply options. Annual running costs must consider the input fuel costs, amortisation of capital, as well as operation and maintenance costs.

Various metrics can be used to compare alternatives. Some businesses may assess the merits of a change to energy supply via a simple payback time. Another common approach is to forecast the Internal Rate of Return on the investment.

For a gas user, inputs such as fuel cost, interest and depreciation are tax deductible so it is the annual cost of output energy after tax deductions that should be compared. However, as every business has different tax arrangements, a generic comparison before tax is easier to understand.

Capital costs for all technologies have a strong dependence on system size, with larger systems being more cost effective per unit of process energy delivered.

For natural gas systems, the fuel cost dominates the annual operating cost. Reducing technical risk to users suggests that existing gas fired systems should frequently be retained as back up if a renewable energy system is adopted[14]. In this case the full annual operating cost of a renewable solution needs to be compared to a cost of output energy for a gas system based on fuel cost alone.

The analysis suggests that bioenergy and lower temperature solar thermal options are the most relevant, depending on resource availability. These two options are discussed in most detail in the following sections.

Technically, a renewable energy solution can be engineered for every single industrial use of gas.

13 Quality sensitive combustion refers to applications where the altered nature of the gases in combustion will affect the product. This will occur in applications where the process or product is in direct contact with the gases from the combustion stream, such as high temperature direct firing for example. Not all products will be affected by the substitution of one gas source for another.

14 For some (many) users there is a real and quite high cost to maintaining the ability to use large natural gas volumes. Contracts may be based on peak usage capacity to a large extent rather than actual energy used. This can hamper this conservative approach.

BIOENERGY

Summary

- The cost of biomass is highly site specific and transport costs make local sources the most viable.
- Capital costs of bioenergy systems vary with size, location and any energy storage requirements. Integration costs with existing plant are also highly site specific.
- Biomass fired boilers, biomass gasifiers and wet biomass digestors are all commercially available.
- Biomass material ranges from zero cost waste material to woodchips from energy plantations.Bionenergy can be economically feasible if a biomass resource can be accessed at less than around $5/GJ.

BIOENERGY TECHNOLOGY

Biomass feedstocks are varied, and the specific feedstock will affect efficiency as well as the type of technology used. Feedstocks can be solid or liquid, and include wood, bark, bagasse, agricultural crops (e.g. straw and rice husk), energy crops (e.g. mallee), and waste products (e.g. wood or paper waste, black liquor, sewage sludge). Biomass can be combusted, gasified, pyrolised or digested.

Combustion systems can be configured in various ways and are primarily used for steam and hot water production (Figure 7). The biomass must be progressively fed to a grate where combustion takes place or in smaller particles to a fluidised bed for combustion. In either case, fan systems introduce air and automated feed systems are incorporated. Heat is extracted usually via water/steam passing through boiler tubes that surround the combustion region.

Figure 7. Biomass grape marc – full case study page 39. Photo: Australian Tartaric Products

Gasification or pyrolysis involves heating biomass via partial oxidation to high temperatures so that the bulk of it is converted to combustible gases or oils. These in turn can be combusted for process heat or used in engines or, with extra investment in gas purification, can be converted to chemical feedstocks.

Digesters involve wet biomass in a suitable tank or covered pond with air excluded and conditions suitably controlled (Figure 8). Anaerobic bacteria cause it to decompose and give off methane and carbon dioxide. This biogas can also be combusted for process heat or used in engines or, with extra investment, purified and in principle used for chemical feedstock or sensitive combustion applications.

Figure 8. biomethane – full case study see page 43. Photo: Nordmethan

Biomass resources are expensive to transport (relative to their cost). Thus the lowest cost biomass resources are those local to the user.

Bioenergy system capital costs and performance are influenced by operating temperatures and pressures to only a minor degree. However, as shown in Figure 10, bioenergy capital costs are strongly dependant on system size, with large systems being progressively more cost effective.

Depending on the biomass feedstock, the plant capacity, and the conversion technology, cycle efficiencies for current biomass plants generating process heat range from around 80% to up to 90%.

Figure 9. Truck being loaded with biomass material.

Effect of size on bioenergy system cost effectiveness

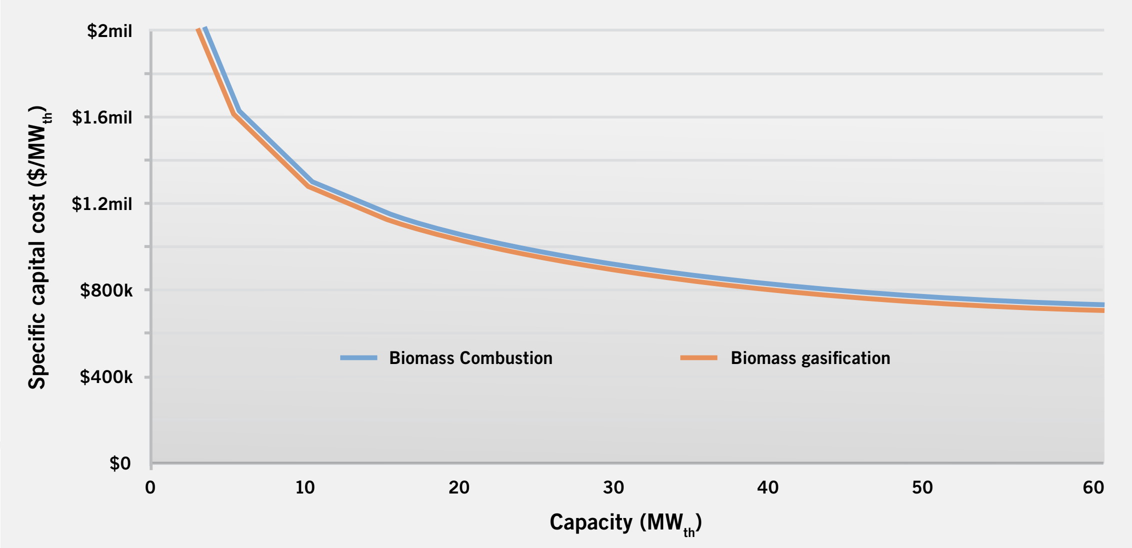


Figure 10. Specific cost of a bioenergy system as a function of thermal capacity

Locally available low cost biomass is a key component of a cost effective bioenergy solution.

The greatest influence on overall cost of process energy is the cost of the biomass, which is extremely site dependant. As shown in Table 1, typical cost can range from less than zero for waste products to around $12/GJ for wood pellets.

Table 1. The range of costs of typical biomass sources[15].

Resource	Indicative cost per GJ
Animal wastes, sewage sludge, landfill gas	Generally zero, and may be negative if disposal costs are avoided
Wood process residues, bagasse etc. used on site	$0 - 0.20/GJ
Short cycle crops (such as oil mallee)	$5-7/GJ near term, $3/GJ mature industry
Wood pellets	$12/GJ ex plant, add $0.3/GJ up to 15km, $0.8/ GJ up to 70km

Australia does not yet have an established supply chain for biomass material such as wood pellets (Figure 9). This is a possibility for the future and the potential locations, volumes and costs have been assessed in other studies[15].

Overall, bioenergy solutions are technically mature. Most of the risk with a bioenergy solution lies with the biomass supply. The costs of fuels can be expected to fluctuate with supply and demand. Apparently zero cost waste streams will have an inherent value when they are more widely used. Climatic variations will affect the availability of many biomass types. As interest increases, progress with more efficient and larger scale production from short cycle energy crops can be expected, however these new initiatives will carry enhanced risk in their early stages of commercial operation. There can be social licence issues to contemplate if biomass use competes with food production or creates an incentive for native forest harvesting.

15 Stucley, C. et al., 2012. Bioenergy in Australia, Bioenergy Australia, Sydney.

COMPARISON WITH GAS

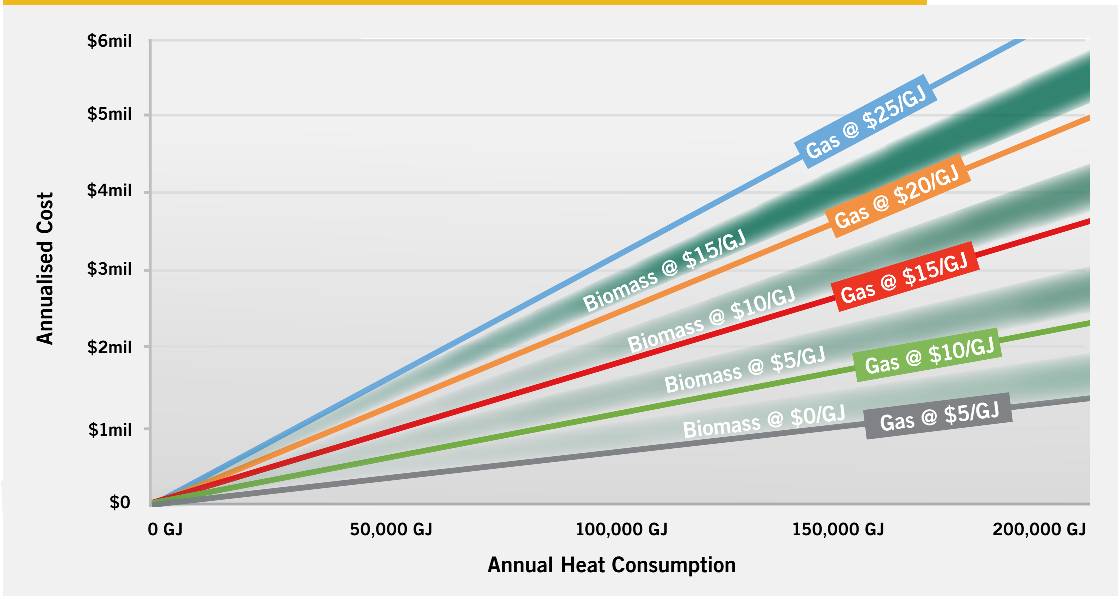
Comparing the annualised cost of providing process heat from an existing gas boiler with a range of possible gas prices, to the alternative of a new biomass fired boiler with a range of possible biomass costs, gives the results shown in the *Annualised Cost* graph at the top of Figure 11. It can be seen that the annualised cost increases largely in proportion to the size of system.

For a given biomass input energy cost, the annualised cost is higher than for the same gas input energy cost. This is because the capital cost of the new biomass boiler system must also be amortised. The biomass curves are seen to flatten and cross the gas curves at higher sizes, this reflects the increased cost effectiveness of the investment in large biomass systems.

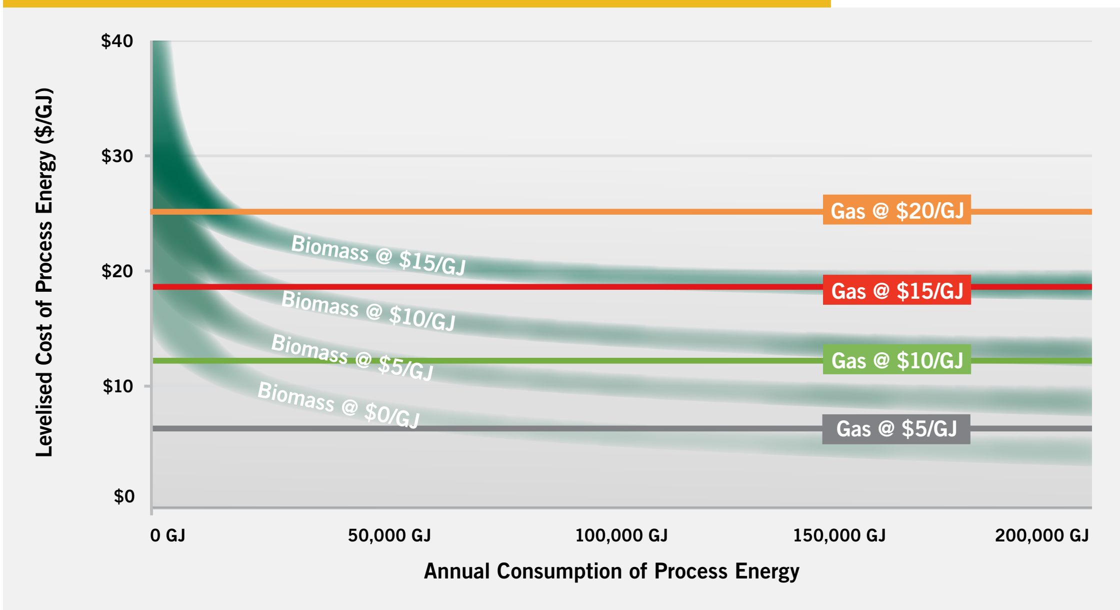
To examine the relative cost effectiveness versus size more directly, the *Levelised cost of process heat* graph in the middle of Figure 11 shows the annualised cost divided by the annual energy production to give a levelised cost of the process heat. The gas driven options with an existing boiler now become a series of horizontal lines. The increase in cost effectiveness of the biomass options with system size is clearly seen in a rapid reduction to lower levelised cost of process heat with size. However, as smaller gas users are likely to be paying higher prices for gas, the biomass options are still worth considering at the small end.

The Internal Rate of Return (IRR) can be forecast for a particular combination of gas cost and bioenergy assumptions. As an example, the *Internal Rate of Return* graph at the bottom of Figure 11 shows the IRR that applies for a situation where biomass is available for the relatively low cost of $5/GJ for a range of possible gas costs. In this situation it can be observed that positive IRRs are achievable if gas prices are above around $10/GJ. For zero cost biomass, the breakeven cost of gas is around $5/GJ.

Comparing the annualised cost of a new biomass system with an existing gas boiler



Dividing annualised cost by annual energy consumption to compare the levelised cost of process energy from new biomass and existing gas



The Internal Rate of return of a new biomass system for the example of a $5/GJ biomass source compared to gas at various gas price levels

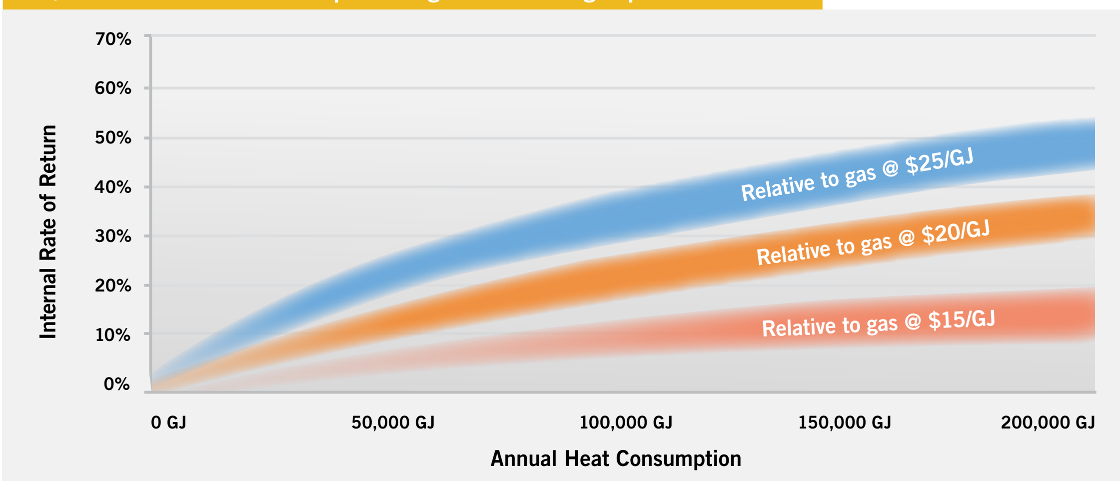


Figure 11. Economic comparison of bioenergy solutions to existing gas fired operations. (Financial parameters include 60% debt at 7.5%/a interest, 10%/a discount rate for equity, 15 year depreciation plus 20 year system lifetime, tax set to zero, boiler operating at average 70% of full capacity.)

SOLAR THERMAL

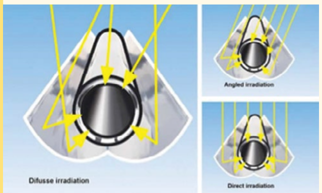
Summary

- The average solar resource varies across Australia. The design of solar thermal solutions needs to factor in the seasonal nature of the resource and the loads it would be supplying.
- Capital costs also vary strongly with size and operating temperature. Location, energy storage requirements and integration costs with existing plant are highly site specific.
- Solar thermal approaches for temperatures below 150°C can be economically feasible for most regions of Australia. Higher temperatures up to 250°C are also feasible in regions with above average solar resources.

SOLAR THERMAL TECHNOLOGY

Solar thermal systems are available for any desired temperature range as shown in Table 2. Lower temperatures are available from simple flat plate and evacuated tube collectors. More complex concentrator systems are needed for higher temperatures and these come at a higher capital cost.

Table 2. The different categories of solar thermal technology.

Technology	Example	Description
Unglazed flat plate 20–40°C		Unglazed collectors are suitable for temperatures of around 40°C and are often used for swimming pool heating. For this application, they are typically fabricated from rubber or PVC tubing. A relevant case study can be found on page 44.
Glazed flat plate 30–85°C		Flat plate glazed collectors are the dominant technology in the Australian domestic solar hot water market. They consist of a metal sheet with passages for fluid flow, mounted in an insulated case with a glass cover sheet. They can be connected in large arrays for industrial processes. A relevant case study can be found on page 45.
Evacuated tube 50–150°C		Evacuated tube collectors are the competing solar technology for domestic and commercial solar hot water. An evacuated space between two concentric tubes minimises heat loss and allows the inner surface to reach higher temperatures and exchange heat to a fluid. A series of individual tubes are mounted together in panels. A relevant case study can be found on page 46.
Evacuated tube plus non tracking mirror 50–200°C		Addition of an approximately curved mirror behind an evacuated tube collector can boost the energy absorbed allowing higher temperatures and more efficient operation.
Parabolic trough 100–450°C		The focal properties of the parabola are utilised in trough concentrator systems. The tubular receiver is fixed to the focal line of the array of mirrors, which track the sun along one axis throughout the day. Trough systems can heat a heat transfer fluid such as synthetic oil, or generate steam for process heat or power generation. Relevant case studies can be found on page 47 and 48.
Linear Fresnel 100–450°C		A Linear Fresnel system is an analogue of a trough concentrator and provides heat over the same temperature range. Long semi flat mirror strips laid out in parallel rows are each tracked independently so as to focus direct beam radiation on a linear focus that is fixed on a non-moving tower. A relevant case study can be found on page 49.
Heliostats and tower 300–2000°C		For higher temperatures still, the heliostat field plus tower arrangement is available. Many Individual mirrors on double-axis tracking devices are all simultaneously moved to reflect sunlight to a single receiver on a tower, which can reach temperatures of typically around 600°C but in principle several thousand degrees can be obtained.
Dish 300–2000°C		A mirrored paraboloidal dish system can also offer these high temperatures and with higher efficiency, but they are not as commercially mature.

As with the other technologies, solar thermal systems also have a size dependant capital cost that makes large systems progressively more cost effective. This is particularly relevant to solar thermal as the amortisation of initial capital cost is the main determinant of annual operating cost, as there is no fuel cost. Systems for higher temperatures are more complex, this complexity translates to higher capital costs per unit of thermal output.

The study has investigated available cost data for systems that include sufficient energy storage for approximately one day of load. Whilst it is subject to variation and uncertainty, it was found that a linear relationship between specific cost and temperature is a reasonable representation in the region of interest to gas users. This is illustrated in Figure 12 where a linear fit for a range of different thermal capacities is shown.

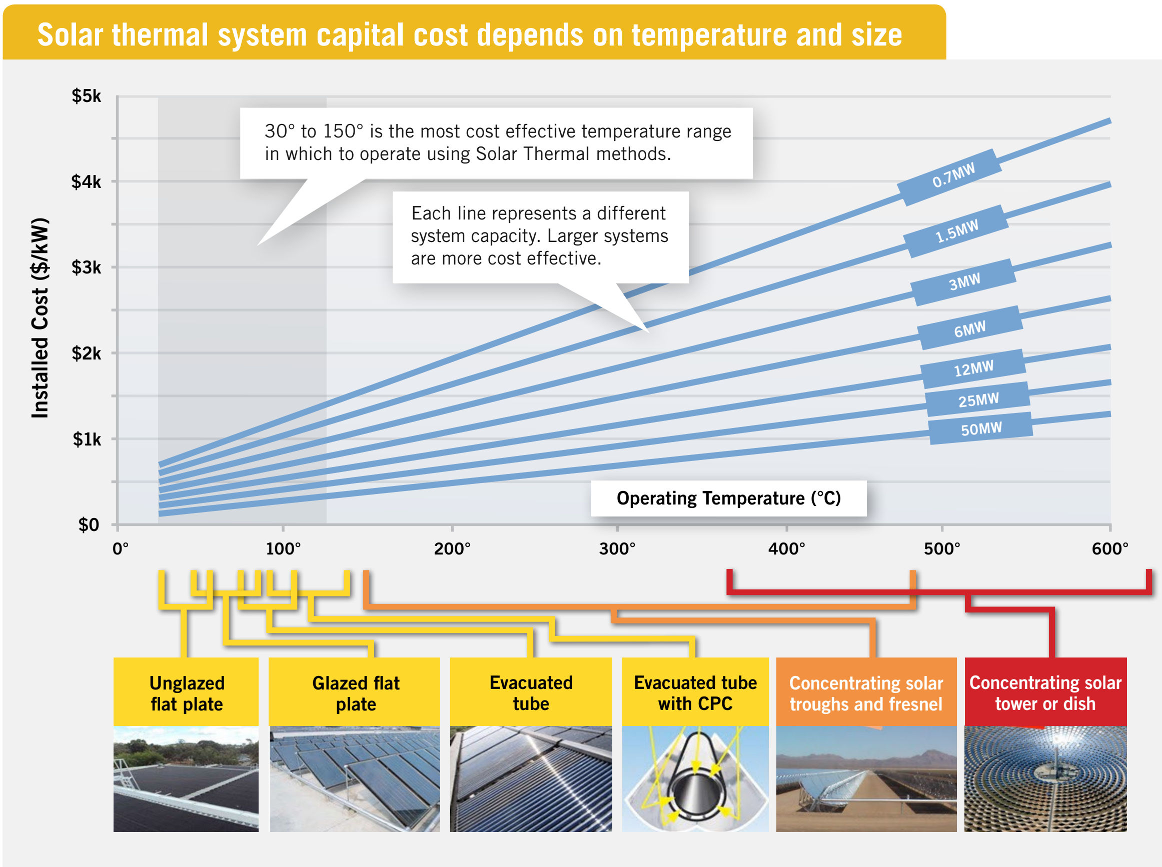


Figure 12. Solar thermal system specific installed cost as a function of temperature and thermal capacity.

Quantifying solar resources is straightforward. For concentrators, direct beam radiation is the key input parameter, for non-tracking systems, global (direct plus diffuse) radiation is the input. There are a range of sources and formats for this data.

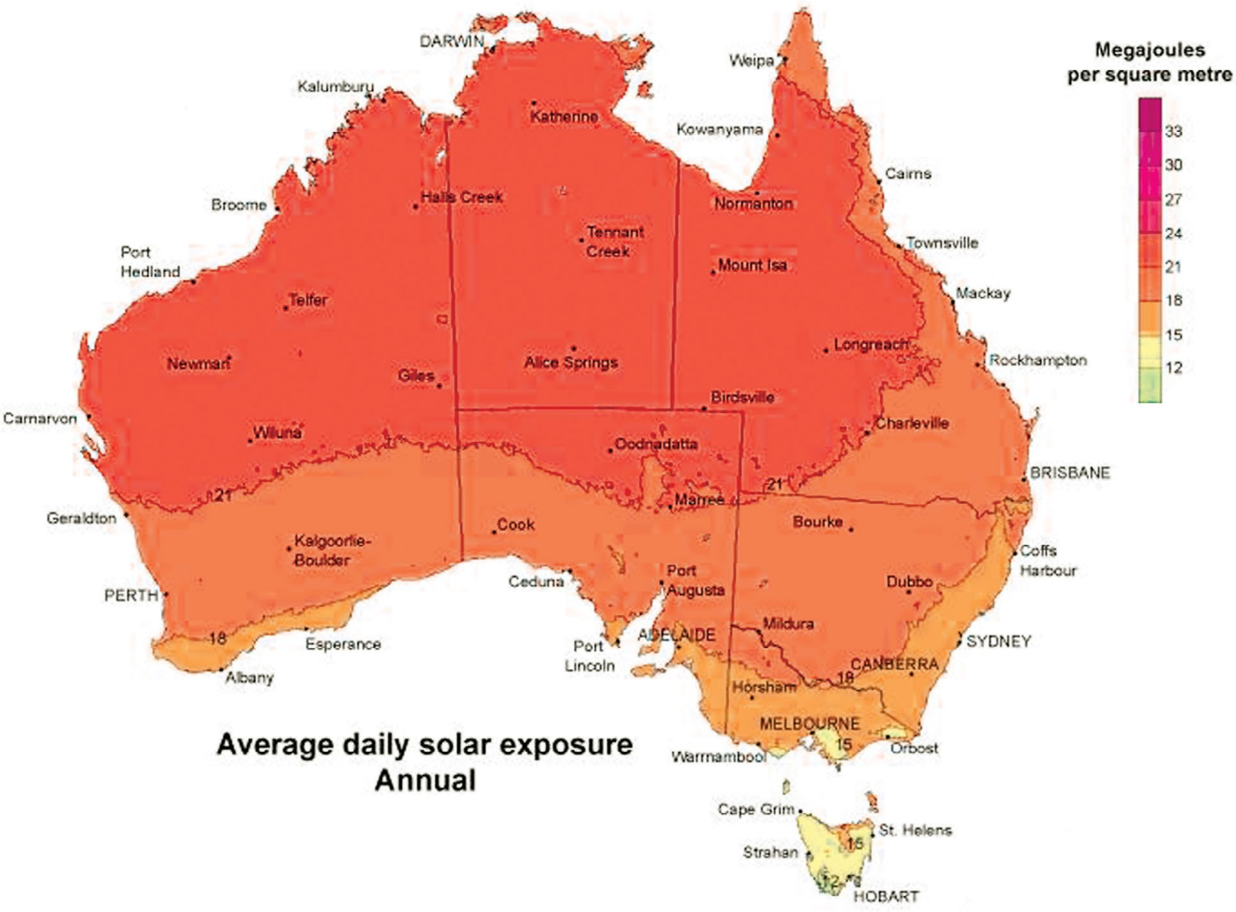


Figure 13. Contour plot of annual average Global Horizontal Irradiation across the Australian continent[16].

Figure 13 illustrates the annual average global horizontal irradiation distribution across the continent. Direct beam radiation has a similar distribution. Overall, higher irradiation levels are found towards the north and centre of the continent. While solar resources increase with distance from the coast, the less favourable resources closer to the coast, where many gas users are located, are still above average by world standards[17] and solar thermal solutions still have significant potential for replacing gas in those areas.

Solar thermal systems are by their nature capital intensive, however the benefit is reduced operational expenditure and no fuel price risks. Whilst there are commercial scale examples around the world of all the various solar thermal technology options, the industry and supply chains for most are still immature, particularly in Australia. Overall, the level of technology and supplier risk is higher for solar thermal systems and suggests the need for back up gas fired systems and the desirability of financial arrangements that move risk to equipment suppliers.

16 Australian Government Bureau of Meteorology, www.bom.gov.au
17 Sydney, for example is as good as many sites in the south of Spain.

COMPARISON TO GAS

For solar thermal systems there is no input fuel cost to consider. However, the capital cost and hence also the annualised cost is very dependent on the temperature of application. Higher capital costs apply for more complex higher temperature systems. There is also a high range of variability due to the uncertainty of initial capital cost estimates and the impact of site specific aspects, such as the amounts of energy storage needed and the level of solar resource available. However despite this, a cost model has been developed that is sufficient to indicate if detailed investigation is warranted or not.

The *Annualised Cost* graph at the top of Figure 14 shows annualised costs of solar thermal solutions at various representative temperatures compared to an existing gas fired system at a site with a reasonable solar resource[18]. Again costs increase with system size but, for solar thermal, are seen to flatten off with size and cross over the lines for the gas fired process heat cases.

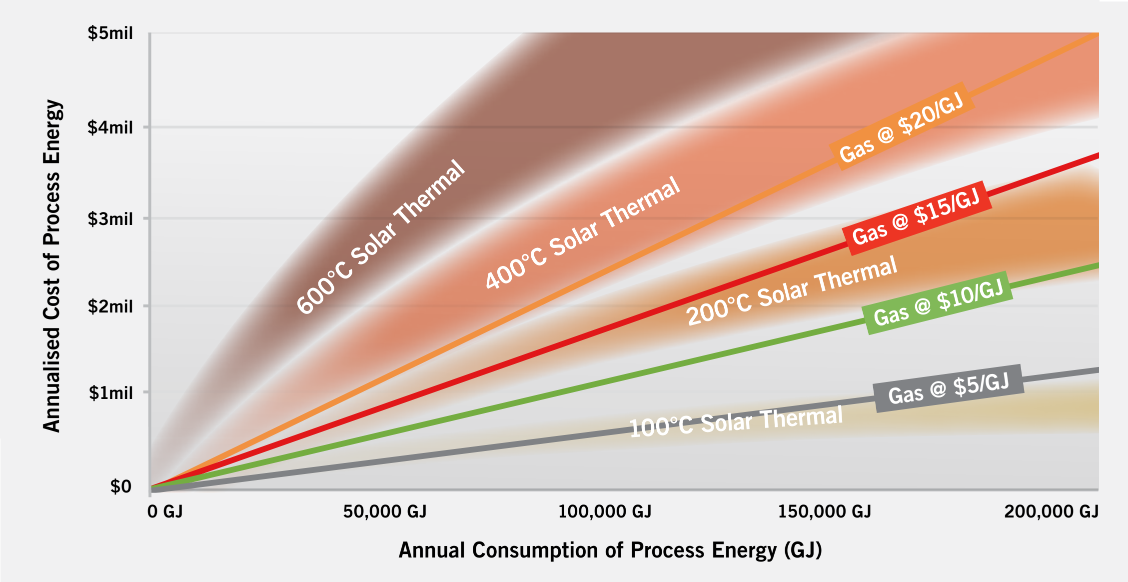
As with the bioenergy analysis, to examine the relative cost effectiveness versus size more directly, the *Levelised cost of process heat* graph in Figure 14 shows the annualised cost divided by the annual energy production to give a levelised cost of the process heat. The increase in cost effectiveness of the solar thermal options with system size, seen as a rapid reduction to lower levelised cost of process heat with size, is even stronger than for the bioenergy technologies. Again it should be noted that smaller gas users are likely to be paying higher prices for gas such that the solar thermal options are still worth considering.

Solar thermal is potentially viable for temperatures up to 150°C and worth consideration up to 250°C. Temperatures above that are economically more challenging depending on gas price assumptions.

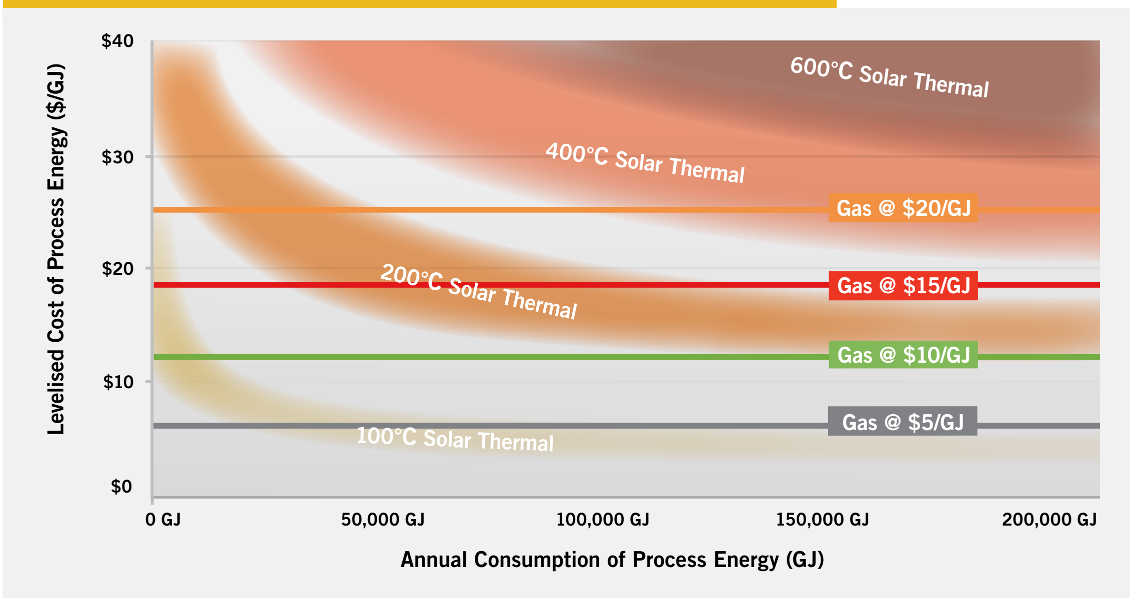
The Internal Rate of Return can be calculated for a particular combination of gas cost and solar assumptions. It can be seen that lower temperature systems are the most prospective at present. As an example, the *Internal Rate of Return* graph in Figure 14 shows the IRR that applies for solar thermal systems producing heat at approximately 100°C, for a range of possible gas costs. In this situation it is seen that reasonable IRRs are achievable for gas prices above $5/GJ.

18 An annual irradiation of 1,850kWh/m^2, corresponding to Brisbane for example.

Comparing the annualised cost of a new solar thermal system with an existing gas boiler



Dividing annualised cost by annual energy consumption to compare the levelised cost of process energy from new solar thermal and existing gas



The Internal Rate of return of a new solar thermal system for the example of 100°C heat compared to gas at various gas price levels

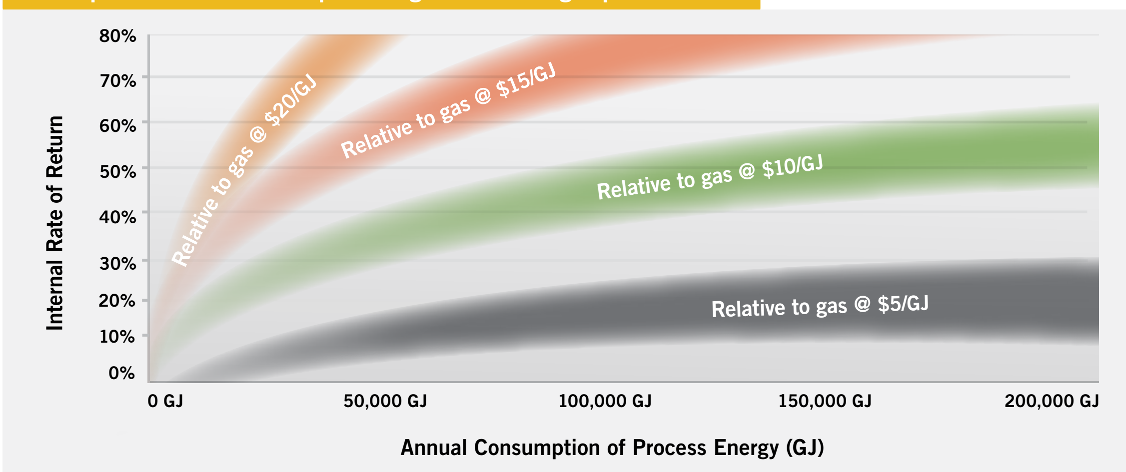


Figure 14. Economic comparison of solar thermal solutions compared to existing gas fired operations. (Evaluated for a reasonable solar location equivalent to Brisbane with 1850kWh/m²/year = 18.3MJ/m²/day. Financial parameters include 60% debt at 7.5%/a interest, 10%/a discount rate for equity, 15 year depreciation plus 20 year system lifetime, tax set to zero.)

OTHER OPTIONS

Summary

- Geothermal opportunities exist in Australia but are highly site specific.
- Gas users may also consider grid electric powered heat pumps, with possible supplement of electricity from on site photovoltaics
- Coal fired boilers are a competing fossil based energy source.
- A system design approach, on a case-by-case basis, is required to optimise the economics of any renewable energy solutions.
- A range of options that include production of chemical feedstocks and future renewable fuels are under development and may play a role in future as the technology matures.

Whilst bioenergy and solar thermal solutions have the widest applicability as options for gas users, geothermal systems can be very cost effective if lower temperatures are needed and a hot sedimentary aquifer resource is available nearby. Heat pumps are also an option for lower temperatures. If grid electricity is used they are not strictly a renewable energy solution, however if renewable electricity is used then they can be. Gas users will also consider other fossil fuel options. In this regard moving to coal use is the only option likely to offer lower costs.

GEOTHERMAL

The potential for geothermal energy has recently been reviewed in detail by ARENA in the context of electricity generation[19]. Engineered geothermal systems have been the focus of much interest for power generation, however for industrial gas users it is the lower temperature and lower cost aquifer based systems that offer the greatest near term potential. In Australia hot sedimentary aquifers are found at depths of 500m to 2000m and temperatures up to around 100°C. Much or the great artesian basin offers aquifers at elevated temperature. The Perth region sits on a basin with temperatures up to around 50°C. The bulk of the industrial gas users on the eastern side of the continent fall outside the great artesian basin, however there is a low but not insignificant probability of being positioned near a resource. Sustainable use of an aquifer involves drilling two wells, one for extraction and one for reinjection. Aquifer water is circulated by a bore pump, up through a heat exchanger and then re-injected at a different level.

Drilling and preparing bores is a well-established industry that mainly focuses on water supply. Wells cost around $1700/m of depth and jump in cost if depth exceeds 1500m, as heavier drilling equipment must be used. Annualised costs are dominated by the amortisation of the investment, however there is a requirement for electricity for pumping that is around 20% of costs.

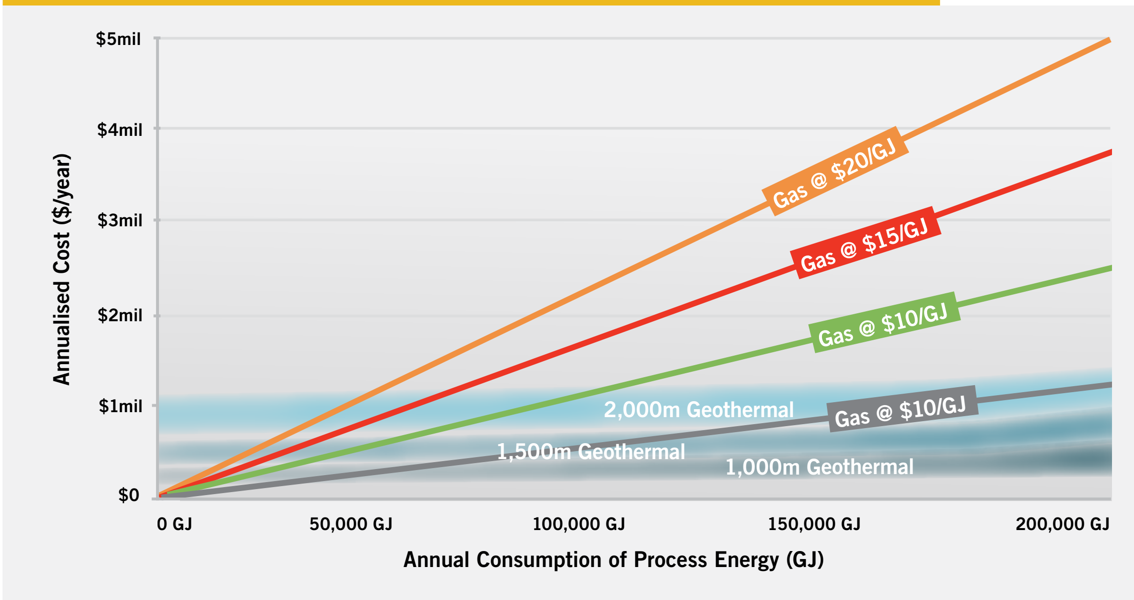
Figure 15 shows the annualised costs, and the levelised cost of process heat relative to gas for a 75°C aquifer at three possible depths together with the internal rates of return possible for the example of a 1500m deep aquifer. Levelised costs of process heat are largely independent of temperature. For larger users geothermal is seen to be potentially cost effective compared to gas at even $5/GJ.

Levelised costs rise rapidly for smaller annual heat requirements as the fixed cost of a single pair of wells must be amortised over progressively lower energy demand. Of all the technologies considered in this study, geothermal is the only one that appears to have a size based cut-off in likely applicability, with users requiring less than around 20,000 GJ p.a (equivalent to a 634 kW_{th} continuous load) unlikely to find the approach attractive in the near to medium term.

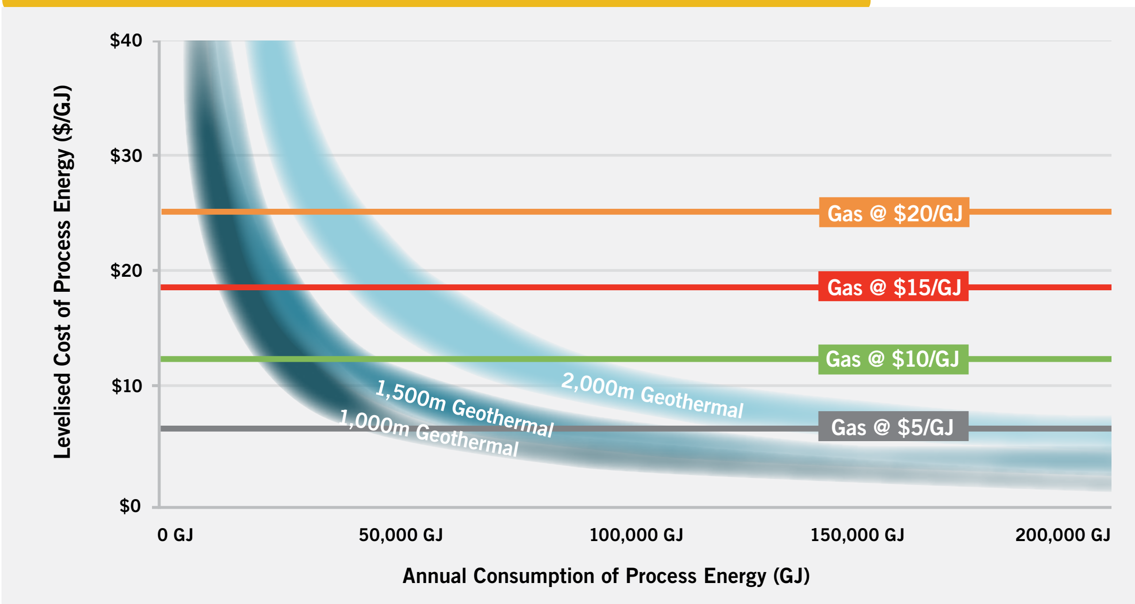
A major issue with geothermal systems is that assessments of potential prior to drilling are probabilistic. There is uncertainty in the depth an aquifer will be found at, the flow rates the strata will allow and what temperature will be found. This represents a major risk issue for a large capital cost investment.

19 ARENA has carried out a comprehensive study of the potential for Geothermal in Australia, including consideration of process heat applications, see www.arena.gov.au/about-renewable-energy/geothermal-energy/expert-group/

Comparing the annualised cost of a new geothermal system with an existing gas boiler



Dividing annualised cost by annual energy consumption to compare the levelised cost of process energy from new geothermal system and existing gas



The Internal Rate of return of a new geothermal system for the example of a $5/GJ biomass source compared to gas at various gas price levels for the example of a 1500m deep aquifer

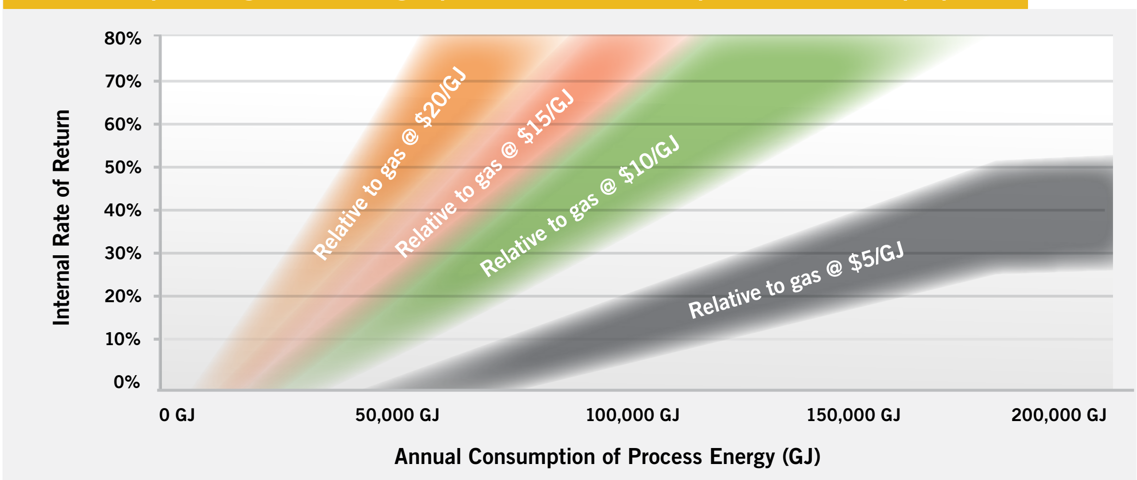


Figure 15. Economic comparison of geothermal energy to existing gas fired operations. (For 75°C resource at various depths, assuming a flow rate of 30L/s and an electricity price of 10c/kWh. Financial parameters include 60% debt at 7.5%/a interest, 10%/a discount rate for equity, 15 year depreciation plus 20 year system lifetime, tax set to zero.)

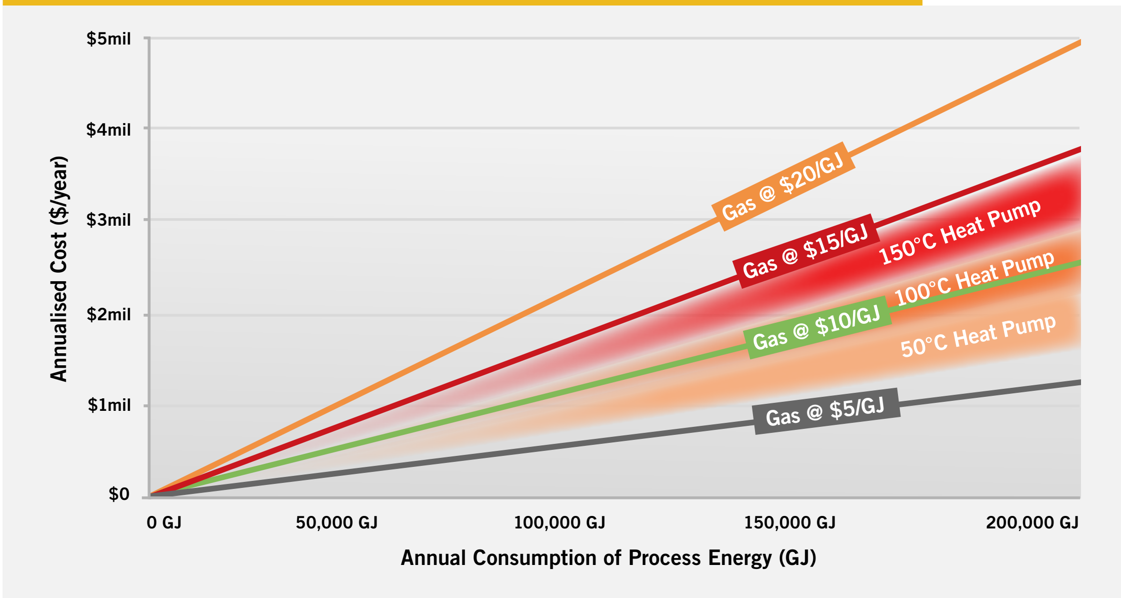
HEAT PUMPS

Vapour compression heat pump systems similar in principle to those used in building heating and cooling systems can be configured to provide process heat up to around 150°C although 100°C represents the upper limit for standard commercially available units. The key performance metric is the Coefficient of Performance (COP) which is the ratio of delivered heat to input electricity. COP is strongly linked to the difference between ambient and required output temperatures and ranges from around 8 for a temperature difference of 20ºC to 2.3 at a temperature difference of 80°C. Capital costs information is difficult to obtain but is in the range of $500,000 for a system of 1MW of electrical consumption. As with other technologies a power law scaling of cost with size is expected. If they are operated with a high capacity utilisation factor, then the main determinant of levelised cost of heat provided is the input cost of electricity combined with the COP.

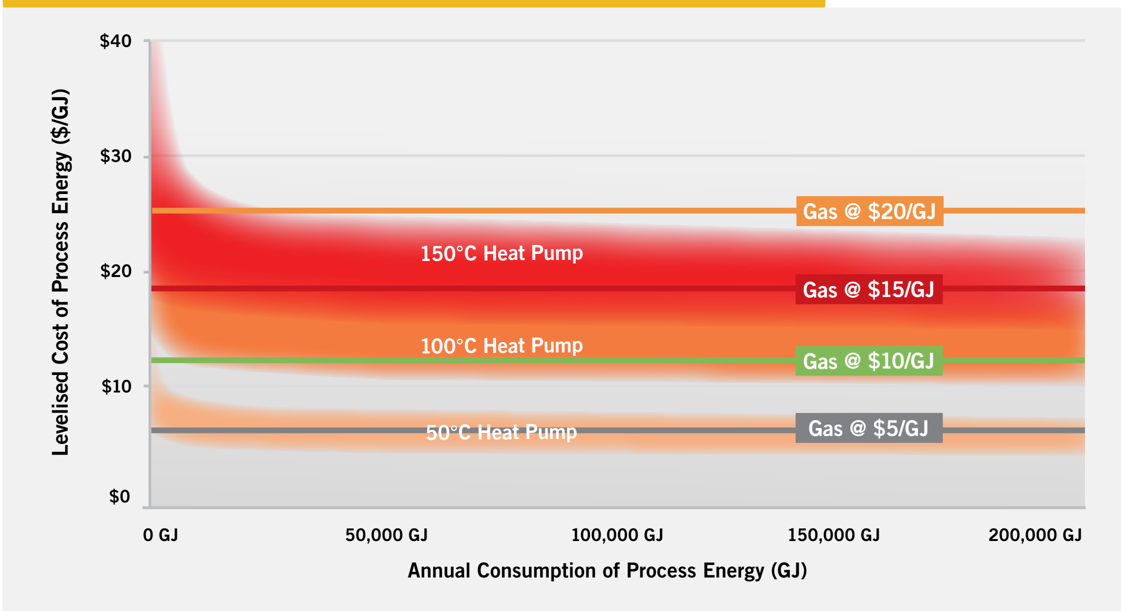
Figure 16 shows the annualised costs and levelised cost of process heat at three temperatures compared to existing gas fired systems if an 80% capacity utilisation of the heat pump and no storage system are assumed for a representative electricity cost of $100/kWh. Also shown is the internal rates of return for the specific case of 100ºC. The wide uncertainty range is a consequence of the uncertainty in COP as well as capital cost. It is seen that the levelised cost has the least dependence on annual energy demand of all the options investigated. Thus for a user the main indicator of the potential for a heat pump solution is the ratio of gas cost to electricity cost. For a COP of 8, if electricity prices (in $/MWh) are less than 30 times the gas price (in $/GJ) then the heat pump option is likely to be favourable. For lower COPs the electricity price hurdle is also progressively lower. At a COP of 2.3 electricity prices (in $/MWh) need to be less than 10 times the gas price (in $/GJ).

Purely Photovoltaic driven heat pumps are an option for a fully renewable energy solution, however for industrial gas users, this option does not appear competitive with solar thermal solutions. This is because in such a circumstance the heat pump is constrained to operate with the much lower capacity factor of the PV array, or else a large extra investment in storage is needed. A combination of grid electricity with behind-the-meter photovoltaic systems, could well be considered, particularly in the context of overall consideration of optimisation of electricity supply, for example to reduce peak demand charges. A user could also choose to obtain 100% renewable electricity via the grid through a contract with a generator or a Green power product from an electricity retailer.

Comparing the annualised cost of a new heat pump system with an existing gas boiler



Dividing annualised cost by annual energy consumption to compare the levelised cost of process energy from new heat pump and existing gas



The Internal Rate of Return of a new heat pump system for the example of a 10c/kwh electricity price compared to gas at various gas price levels

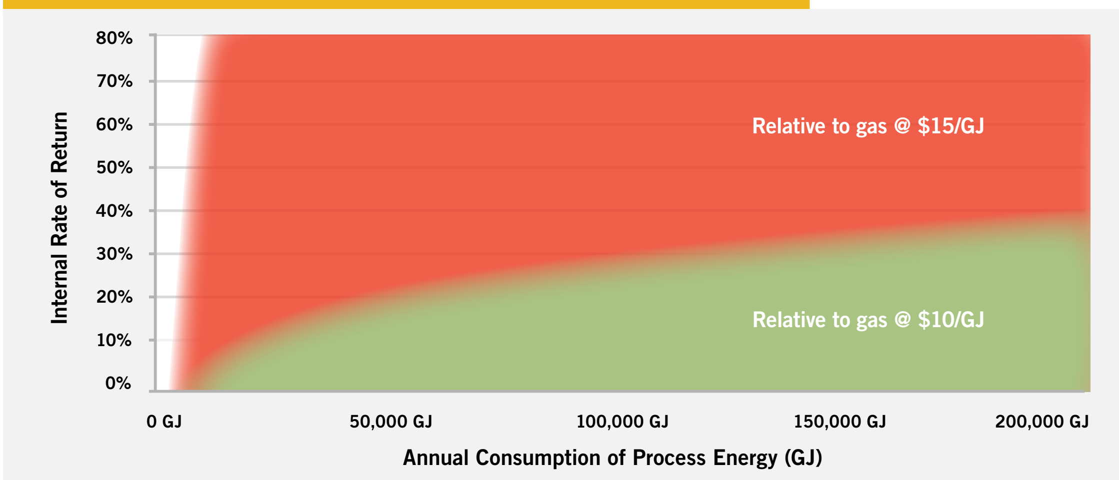


Figure 16. Economic comparison of heat pump systems compared to existing gas fired operations. (Evaluated for 10c/kWh electricity price. Financial parameters include 60% debt at 7.5%/a interest, 10%/a discount rate for equity, 15 year depreciation plus 20 year system lifetime, tax set to zero.)

COAL FIRED SYSTEMS

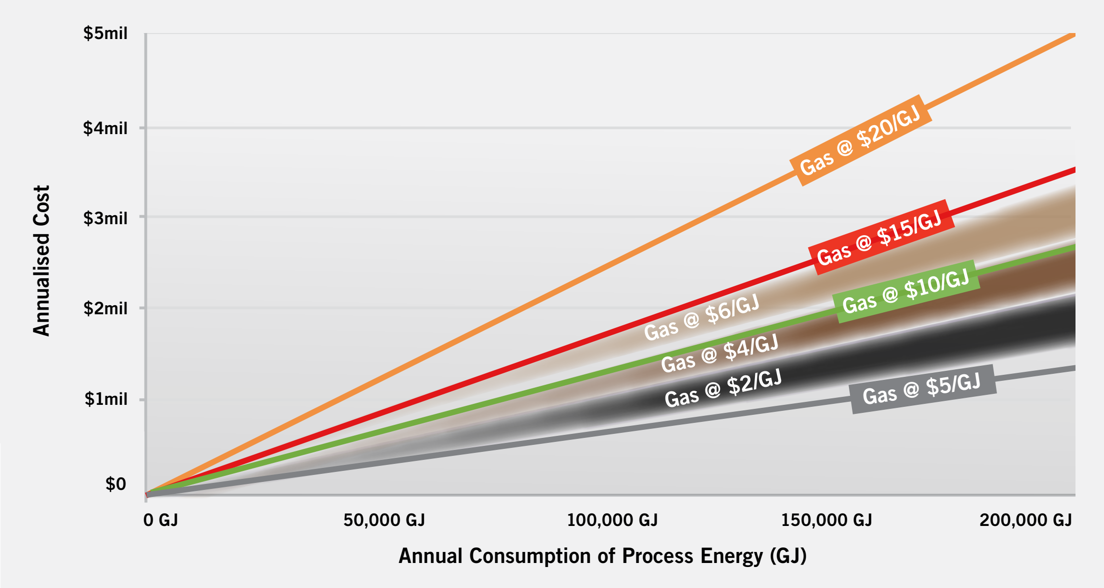
The capital cost of coal-fired boilers is significantly higher than gas-fired boilers due to fuel handling and storage system requirements, but similar or slightly less than that of a biomass boiler. However, coal is significantly cheaper than gas. Obtaining process heat from coal is likely to be highly competitive with gas for many industrial sites. The results in Figure 11 can be read as being applicable to coal fired systems for coal delivered at the same cost as the indicated biomass cost.

Black coal prices after delivery by truck could range from \$2/GJ - \$6/GJ (2014) in the Eastern states, more expensive than waste biomass, but in many cases cheaper than woodchips or other sources.

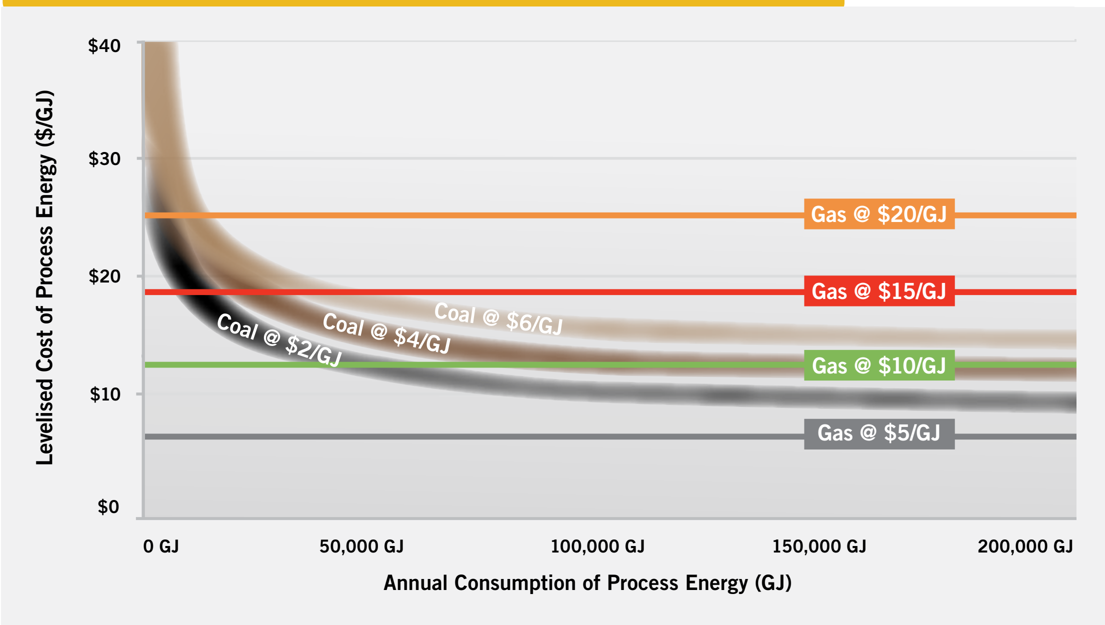
Figure 17 shows the annualised costs and levelised cost of process heat at a range of coal prices compared to existing gas fired systems plus the internal rates of return for the specific case of coal at \$4/GJ. Referring back to figures earlier, it is apparent that on cost of process energy terms, coal is a very strong competitor to renewable energy options. However renewables appear the lower cost option overall for temperatures below 100°C or if waste biomass is available.

The choice between coal and biomass would need to factor in the relative price uncertainty of both. Coal use would be subject to any future policy changes that were to apply a price to greenhouse gas emissions. Users might also consider their social licence and environmental credentials in planning. A biomass/coal hybrid would be technically feasible and may offer a lower risk path to the future.

Comparing the annualised cost of a new coal system with an existing gas boiler



Dividing annualised cost by annual energy consumption to compare the levelised cost of process energy from new coal and existing gas



The Internal Rate of return of a new coal system for the example of a $4/GJ coal price compared to gas at various gas price levels

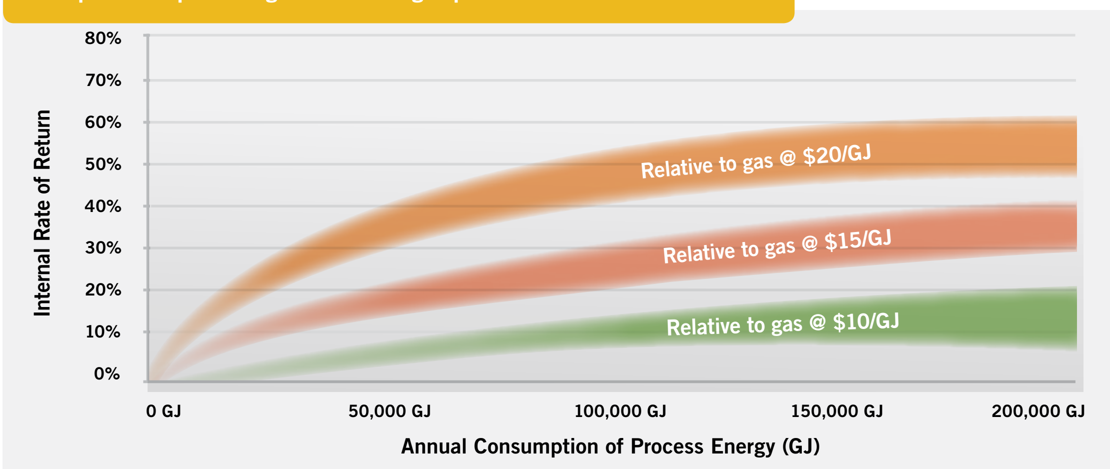


Figure 17. Economic comparison of New-build Coal and existing gas fired operations. (Financial parameters include 60% debt at 7.5%/a interest, 10%/a discount rate for equity, 15 year depreciation plus 20 year system lifetime, tax set to zero.)

SYSTEMS APPROACH

This study has examined the various renewable energy options in a one to one comparison to gas fired solutions, where the output characteristics are assumed to be the same. This was the most practical way to identify the apparent potential of the various renewable approaches.

Ideally all the energy needs of each industrial gas user should be studied from a full system point of view. Energy efficiency measures should be considered along with overall optimisation of energy supply across both electricity and gas. Re-design of production processes to better match the characteristics of optimal energy sources can also be considered where risks to business continuity can be appropriately managed.

Another approach not analysed in this study is renewable energy driven co-generation systems. If substitution of both electricity and gas were targeted, a solar thermal or biomass heated supply of steam at high temperature and pressure can be directed to a turbine for power generation, with lower temperature steam bled from the turbine for process heat. If such an arrangement gave excess electricity it could earn income through electricity exports and any renewable energy certificate value[20].

Hybrid systems are also a possibility, with cheaper lower temperature technologies used for pre-heating, followed by gas boosting to higher temperatures as needed.

FUTURE DEVELOPMENTS

Aside from the future variations in gas prices, all the renewable energy solutions are still in a process of increasing deployment and improving commercial maturity. Costs of technologies in such a process will decrease over time due to a combination of manufacturing and installation efficiencies and technical improvements. Thus many of the specific configurations that have been analysed as being uneconomic at present can be expected to progressively move to being more favourable over time.

Technology options that are still in an earlier stage of development and that may figure prominently in the future include:

- High temperature solar concentrator driven processes to convert biomass, water, gas or other fossil fuels into chemical feedstocks or new solar fuels[21].
- Electrolysis of water to produce hydrogen as a feedstock or fuel.
- High temperature solar thermal approaches to direct driving minerals processing and other thermal processes.
- New advanced biomass gasification systems.
- Innovative systems for purifying gas streams from gasifiers or digestors for use in sensitive direct combustion processes (ovens etc) or for injection to existing gas pipeline infrastructure.
- New advanced biomass production or collection systems.
- Targeted innovations to improve existing renewable energy technologies.

20 Tradeable LGC certificates are produced from eligible renewable electricity generation under the Renewable Energy Target legislation. Industrial process heat is not eligible, although residential solar hot water is.

21 CSIRO is developing a Road Map of solar fuels with support from ARENA, that is due to be finalised at the end of 2015.

CONCLUSION

Summary

- There are opportunities for renewable energy to replace gas for industrial gas users today.
- Although the supply chain for the technologies is typically immature in Australia, it will improve over time.
- There appears to be strong potential for third party energy provider models.
- There is a range of information and government support programs available to assist users with next steps.

CONCLUSION

Through the analysis undertaken in this study it is possible to conclude that there are a range of options for substitution of natural gas use with renewable energy, where the technology is proven and the economic analysis indicates that a positive internal rate of return is possible. Specifically these are:

- Heating of water or steam on any scale and at any temperature using biomass fired boilers where a sufficiently low cost combustible biomass resource is available and convenient to the location.
- Combustion of biogas digester gas in boilers, kilns furnaces or engines where the composition of combustion products does not affect the process and where a low cost digestible biomass resource is available.
- Combustion of biomass gasifier gas in boilers, kilns, furnaces or engines where the composition of combustion products does not affect the process and where a low cost biomass resource is available.
- Heating of water or steam on any scale at temperatures below approximately 150°C using solar thermal flat plate, evacuated tube or linear concentrator technologies in areas of reasonable or better solar resources.
- Hot sedimentary aquifers for low temperature process heat where a resource exists near to the point of use at modest depth
- Heat pumps operated at high capacity factor where the marginal cost of gas is greater than the marginal cost of electricity divided by the coefficient of performance.

The attractiveness of these opportunities will grow as gas prices increase and renewable energy technologies mature. However, there are challenges. The key renewable energy technologies analysed in the study, including indicative technologies, development status, economic viability and attractiveness is summarised in Table 3.

The cost of delivering process energy from renewables falls with increasing scale. This, however, is in almost exact parallel to the higher prices for gas faced by smaller users relative to large. Consequently there is no one size of user for which a renewable solution is inherently more favourable than another. Each user must consider the options in the context of the applicable price for gas.

There is also no clear link between industry sector and most likely renewable technology. The closest observation that can be made in this regard is that agriculture, food, beverage, wood and paper related gas users are more likely to have low to zero cost biomass available and if so should definitely consider exploiting this. Those users that have no low cost biomass available but are obviously in high solar resource areas are more likely to favour solar thermal solutions. Some of the alumina refineries may fall in this category.

Where process heat is needed at temperatures below 100°C, there are clearly more options available.

There are many examples of renewable energy systems in Australia and around the world, providing energy services that could otherwise be provided by gas, with some of these presented as case studies in the final section of this report. However, the supply chain for components and services in Australia is immature and in many cases, equipment needs to be imported, which represents a key risk for technology deployment at this point in time.

Table 3. Summary of the most relevant renewable energy options for gas users.

Renewable energy technology	Indicative temp range °C	Status	Comments	Economic viability	Attractiveness
Biomass fired boiler	**80–800**	Commercially mature with existing support industries	Capex higher than gas boiler	Only if locally sourced material	✓✓
Biomass gasification and combustion	**80–1000+**	Commercially mature with existing support industries	Capex higher than gas boiler, considerable extra cost to produce pure methane	Only if locally sourced material and for non sensitive application	✓
Biomass digestor and combustion	**80–1000+**	Commercially mature with existing support industries	Capex higher than gas boiler, considerable extra cost to produce pure methane	Only if locally sourced material and for non sensitive application	✓✓
Solar thermal unglazed	**30–60**	Commercially mature with existing support industries	Requires unshaded roof space. Significant seasonal output variation	Cost competitive for very low grade heat applications	✓✓
Solar thermal flat plate	**30–85**	Commercially mature with existing support industries	Requires unshaded roof space and a structural assessment. Significant seasonal output variation	Cost competitive for modest temperature heat applications	✓✓
Solar thermal evacuated tube	**50–200**	Commercially mature with existing support industries	Requires unshaded roof space and a structural assessment. Significant seasonal output variation	Cost competitive for modest temperature heat applications	✓✓
Concentrating solar troughs and Fresnel	**60–450**	Commercially mature but support industries are mainly overseas	Design needs to be done by specialists in field	May be cost competitive up to 250°C under good conditions	✓
Concentrating solar heliostats and tower or dish	**300–1000+**	Less commercially available with support industries mainly overseas	High land requirements and not applicable at small scales. Thermal storage easily integrated	Not yet cost competitive	✗
Enhanced geothermal systems	**90–250**	Still at R&D stage	Most identified resources are remote from gas users	Not yet cost competitive	✗
Geothermal hot sedimentary aquifer	**40–100**	Commercially mature but limited supply chain	Highly site specific	Can be low cost if resource is not too deep	✓
Heat pumps with Grid electricity	**40–100**	Commercially available but support industries are mainly overseas	Compare cost of gas to cost of electricity/COP. Some storage may be required	Cost competitive for modest temperate heat applications	✓✓
Heat pumps with photovoltaics	**60–100**	Commercially mature but support industries are mainly overseas	Appropriate storage may be required to ensure heat pumps do not contribute to monthly peak	More costly than solar thermal, but could be favoured in some circumstances	—

In many circumstances, industrial gas users have limited access to capital and expectations of high internal rates of return. Hence, there appears to be potential and industry preference for third party organisations to make investments and offer to sell renewable sourced energy as a business model. Awareness of the growing market opportunity by solution providers will result in third parties being more proactive in promoting renewable energy technologies. However, the level of technical risk perceived by industrial gas users in such solutions remains high.

There is also potential for targeted government initiatives that assist with feasibility studies, demonstration, deployment, information sharing and low interest finance. Such initiatives may need to target energy service providers as well as end users, but could be a valuable way to reduce the perceived risks of renewable energy and improve the supply chain for these technologies in Australia.

CHOOSING A TECHNOLOGY

For an industrial gas user, the information assembled here and in the more detailed background technical report and associated analysis spreadsheet can be used as a starting point to determine whether a detailed study of the user's specific situation and requirements is warranted.

The conceptual decision flowsheet in Figure 18 illustrates the approximate manner in which an individual user might consider options.

A detailed feasibility analysis could be carried out in-house or professional assistance sought from the various specialist consulting organisations in the field.

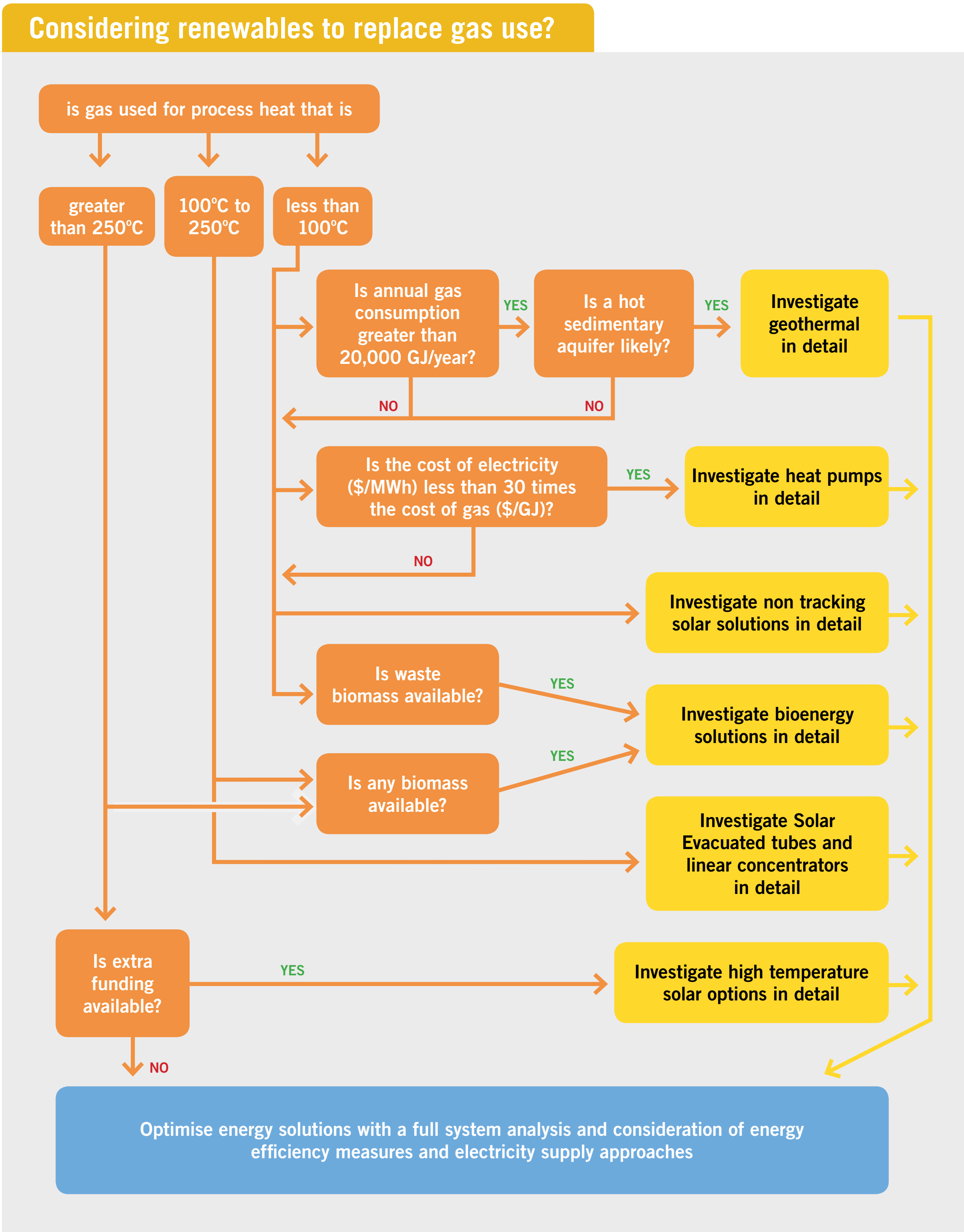


Figure 18. Conceptual flow chart for considering technology options.

FURTHER INFORMATION

In the course of such analysis, there are a range of resources and organisations that can provide valuable input both in understanding the options and potentially in supporting the implementation. These include:

- The Australian Renewable Energy Agency (ARENA) (www.arena.gov.au) has an 'Advancing Renewables Program' which offers funding support. Renewables for Industrial Processes is one of the identified priority areas.
- The Clean Energy Finance Corporation (CEFC) (www.cefc.com.au) has been instrumental in providing preferential financing for renewable energy systems and has supported projects relevant to the present study.
- The International Energy Agency's Solar Heating and Cooling program (www.iea-shc.org) coordinates international collaboration that covers solar thermal applications and maintains a data base of relevant industrial heat projects at www.ship-plants.info
- The Rural Industries Research and Development Corporation Biomass Producer website (www.biomassproducer.com.au) is a useful starting point for gas users that want further information.
- Bioenergy Australia also has useful information and case studies are also available from its website (www.bioenergyaustralia.org).
- The Australian Meat Processor Corporation (AMPC) is the Rural Research and Development Corporation that supports the red meat processing industry throughout Australia. It has published a number of reports addressing bioenergy and energy efficiency options for the sector.
- The Australian Government funded Pork Cooperative Research Centre (www.porkcrc.com.au) has reduction of greenhouse gas emissions in the pork industry as one of its goals. As part of this it has a dedicated bio energy support program, that targets anaerobic digestion in particular (www.porkcrc.com.au/research/program-4/bio-energy-support-program)
- A relevant European program is Resource and Energy Efficient Manufacturing (REEMAIN) (www.reemain.eu). It is working on case studies in the food, textile and metal fabrication industries.

CASE STUDIES

Summary

The case studies presented here are of technology applications that are either in whole or part relevant to natural gas usage replacement:

- Four Australian and one German bioenergy case studies.
- Two Australian and four overseas solar thermal case studies.
- A New Zealand geothermal case study.
- A US heat pump case study.

CASE STUDY B1

Biomass boiler: Australian Tartaric Products, Victoria

Summary

Resource	Biomass 90,000 tonnes per year of grape marc
Investment	\$7.5m for a 8MW$_{th}$ boiler, 600kW$_{e}$ Organic Rankine Cycle generator and associated balance of systems
Construction	Commissioned in November 2013
Designed to deliver	Process steam at 180°C and electricity
Energy saved	2,900MWh per year of electricity, 73,450GJ of fuel oil per year and 40,760GJ of LPG per year
Simple payback	About 5 years
Other aspects	European boiler manufacturer with experience in burning grape marc chosen so that best practice was integrated into design Received \$1.8m grant from the Victorian Government's Regional Infrastructure Development Fund and \$1.7m from the Australian Government's Clean Technology Investment Program

Description

Due to the rising cost of boiler fuels, Australian Tartaric Products (ATP) investigated alternative boiler options for its facility at Colignan, Victoria. In 2013, ATP commissioned an 8MW$_{th}$ biomass boiler using grape marc. The boiler provides steam for process heat and for a 600kW$_{e}$ Organic Rankine Cycle generator. This biomass waste-to-energy project reduces carbon dioxide emissions by about 10,000 tonnes per year. In 2013, this project won the Lever Award for Innovative Processes.

Automatic feed handling and 8MW$_{th}$ boiler using grape marc, photos Australian Tartaric Products

CASE STUDY B2

Fluidised bed boiler: Coffee processing, Nestlé Australia, Queensland

Summary

Resource	Biomass, coffee grounds and sawdust
Investment	About $9m for a 16$MW_{th}$ boiler
Construction	Commissioned in May 2009
Designed to deliver	24 tonnes per hour of process steam
Energy saved	Onsite energy consumption from renewable sources is reported as 70%
Simple payback	Not published, thermal boiler operates at 75% efficiency and saves 4,000 tonnes per year of greenhouse gas emissions
Other aspects	Minimal gas consumption for start-up only Old gas boiler was decommissioned

Description

The Nescafé factory at Gympie is Australia's largest coffee manufacturer producing nearly 10,000 tonnes of instant plus roast and ground coffee per year. In 2009, Nestlé Australia installed a 16MW_{th} bubbling, fluidised bed boiler capable of using coffee grounds, a process waste product, and sawdust. The boiler is optimised for high moisture and finely ground organic materials and supplies all the process steam requirements of the site. Using a renewable fuel lowered greenhouse gas emissions by 4,000 tonnes per year and avoids 5,400 tonnes of waste going to landfill annually.

Installation of the new 45m stack and the Fluidised bed boiler at the Nescafé factory, photos CPM Engineering and Nestlé Australia

Co-firing: Cement manufacture, Adelaide Brighton, SA

Summary

Resource	Biomass, 70,000 tonnes per year of recycled construction and demolition timber, approximately 17 MJ/kg
Investment	Plant upgrade
Construction	2003
Designed to deliver	Process heat above 1,450°C
Energy saved	20% of annual natural gas consumption
Simple payback	Not published
Other aspects	Cement kilns operate with flame temperatures up to 2,000°C

Description

Adelaide Brighton's Birkenhead gas-fired kiln has the capacity to produce 1.3 million tonnes of cement products per year. In 2003, the cement kiln commenced using more than 70,000 tonnes of recycled construction and demolition timber per year as a supplement to natural gas at their Birkenhead cement kiln in South Australia. The receival, storage and feed system was upgraded in 2005.

To provide the recycled timber a designated processing plant was built in the vicinity of the cement plant. The plant was built by SITA-ResourceCo and is capable of converting up to 350,000 tonnes of raw material into 150,000 to 200,000 tonnes of alternative fuel each year.

Construction and demolition timber processing and supply to the Birkenhead cement plant, photos Adelaide Brighton

CASE STUDY B4

Biogas: Berrybank piggery, Victoria

Summary

Resource	Piggery sewage effluent
Investment	$2.3m for a two stage anaerobic digestion plant and biogas cogeneration plant
Construction	1991
Designed to deliver	About 1,700m^3 biogas per day
Energy saved	190MWh of electricity and 440MWhth of heat per year
Simple payback	About 7 years
Other aspects	Biogas is purified to remove corrosive hydrogen sulfide To recover the waste products, the farm modified the existing drainage system

Description

In 1991, Berrybank Farm had about 15,000 pigs and commenced using its sewage effluent to produce biogas. The two-stage, anaerobic digestion plant produces about 1,700m^3 of biogas per day, which is used to fuel biogas engine generators.

Most of the electricity from the biogas generators is used on site with some excess exported to the main-grid. Heat from the engines is recovered and used in the digestion plant and for other purposes. The biogas plant lowers annual electricity, gas, water and fertiliser costs and a seven year payback period was forecast.

Part of the biogas plant and the primary and secondary digestors with the biogas generator shed, photos Berrybank Farm

Biomethane: Arnburg agricultural waste plant, Germany

Summary

Resource	Maize silage, whole-plant grain, sugar beets, chicken manure and other liquid manure
Investment	Four digesters of 4,900m^3 and six digestate storage units of 5,000m^3
Construction	2012
Designed to deliver	1,650m^3 biogas per hour
Energy saved	Biomethane is sold
Simple payback	Not published
Other aspects	Biomethane plants are widespread in Europe Uses amine scrubbing

Description

Biogas can be upgraded to biomethane, through amine or water washing processes. This enables it to be injected into an existing natural gas pipeline or used in processes requiring methane.

The Arnburg plant consists of four digesters of 4,900m^3 and six digestate storage units of 5,000m^3. The plant is capable of producing 1,650m^3 biogas per hour. About 250m^3 of this is used for onsite process heating. The remaining biogas is scrubbed to produce biomethane of sufficient quality to be sold. The plant requires a feedstock supply of about 70,000 tonnes per year, consisting of a mix of maize silage, whole-plant grain, sugar beets, chicken manure and other liquid manure.

Altmark biomethane plant in Germany, photos Nordmethan

CASE STUDY S1

Unglazed collector: Australian Institute of Sport, ACT

Summary

Resource	Canberra averages a global horizontal irradiation of about $18MJ/m^2/day$
Investment	1,500m^2 of PVC strip collector
Construction	2011
Designed to deliver	Hot water to keep three indoor pools at 30°C, pumps are capable of moving 3.4 tonnes of water per minute
Energy saved	About $105,000 in first year of operation
Simple payback	Less than two years
Other aspects	Original 585m^2 system installed in 1983 was removed Site has flat roof areas that are multi-tiered

Description

The Australian Institute of Sport is located in Canberra. Its Swimming Centre has a variety of indoor pools heated to 30°C.

In 2011, Sunbather installed 1,500m^2 of PVC strip collector via HIPEC Commercial. Sunbather worked out the optimal collector area and pumping system for this project using a swimming pool thermal analysis program developed by the University of NSW. The software utilised a climatic data file for Canberra to perform an hour-by-hour thermal simulation of the pools' heat losses and heat inputs from gas and solar.


Aquatic Centre roof areas showing solar collector, photos Sunbather

Glazed flat-plate collector: Marstal district heating, Denmark

Summary

Resource	Marstal averages a global horizontal irradiation of about 10MJ/m^2/day, (Marstal is at latitude 55°N)
Investment	33,000m^2 flat-plate solar collector orientated for optimal winter performance with hot water storage
Construction	In 2012, the existing 18,000m^2 collector field was expanded and the hot water storage was also significantly expanded
Designed to deliver	About half the annual district heating hot water requirements
Energy saved	46,540 to 55,440GJ per year
Simple payback	Not published, the storage system has received grant funding
Other aspects	Integration with existing fossil fuel boilers has recently been supplemented with a new biomass boiler District heating is common in Denmark

Description

Marstal is a town on a Danish island with a population of about 2,300. It has a large flat plate solar collector field that is used to reduce the amount of fossil fuels burnt over the year for domestic heating. The system also has a large hot water storage capacity.

The hot water is stored at 70°to 75°C but can reach 95°C in sunny periods. Next to the storage is a plant room that contains heat exchangers, control systems and the back-up fossil fuel boilers. The boilers are used to supplement the solar field when there is insufficient heat to meet the load.

The back-up system has recently been upgraded with the aim of making it completely renewable. Additional infrastructure installed included a 4MW wood chip boiler with a 750kW$_e$ Organic Rankine Cycle generator operating off the boiler's flue gas and a 1.5MW$_{th}$ heat pump. The wood chips are sourced from locally produced willow crops.

Marstal solar flat-plate collector field, photos Sunstore and Erik Christensen

CASE STUDY S3

Evacuated Tube: De Bortoli Winery, NSW

Summary

Resource	Griffith averages a global horizontal irradiation of about 20MJ/m^2/day
Investment	One hundred 30 tube collectors, about 200kW$_{th}$ with two 6,000 litre storage tanks and two 350kW condensing boilers
Construction	Start May 2013, commissioned August 2013, further control system optimisation Oct 2013
Designed to deliver	About 12,000 litres of 95°C water per day as a pre-heater
Energy saved	More than 80% of annual hot water load, around 1,120GJ per year
Simple payback	About 6 years, before grant funding
Other aspects	Roof needed to be strengthened The solar thermal project was a small part of a larger energy efficiency upgrade project across multiple sites

Description

As part of a bottling line expansion, De Bortoli Winery installed a large solar thermal evacuated tube collector at its Griffith winery in 2013. This system was designed to reduce gas consumption for hot water by more than 80% over the year.

The evacuated tube collectors are mounted at a tilt angle of 37 degrees to optimise performance in high demand periods and two 6,000 litre stainless steel storage tanks are used to store the hot water. Two high-efficiency, 350kW gas-fired boilers were also installed to ensure bottling can be scheduled as required. A programmable smart control system was installed by De Bortoli Wines which maximises daily gas savings.

The winery also installed a 230kW photovoltaic system which was forecast to produce about 349MWh per year, (1,586kWh/kWp/year). The simple payback on the photovoltaic system was estimated to be about three years. De Bortoli Winery received a $4.8m Clean Technology Food and Foundries Investment Program grant to contribute to the plant upgrade and expansion that was forecast to cost $14.5m.

Evacuated tube collectors and storage tanks, photos Apricus

Small solar parabolic trough: Cheese manufacturer, Switzerland

Summary

Solar resource	The site in Saignelégier averages a direct normal irradiation of about 12MJ/m^2/day
Investment	627m^2 trough solar collector field
Construction time	About 2 months
Designed to deliver	Process heat for cheese manufacture
Energy saved	50% of the daily heat demand on sunny days
Simple payback	Not published
Other aspects	Factory had a flat roof

Description

NEP Solar have installed a 627m^2 trough solar collector field on the roof of the Emmis Tete de Moine cheese manufacturing plant in Switzerland. This system produces over 50 per cent of the daily heat demand of the dairy process on sunny days.

In Australia, NEP Solar have installed a 330m^2 trough collector field in Newcastle. This field can reach temperatures of 330°C. The Newcastle Granite Power project received funding from ARENA and generates 30kW$_e$ and produces over 150kW$_{th}$ of heat for the Wallsend swimming complex.

Parabolic trough collector in Switzerland and a ground-mounted system in Newcastle, photos NEP Solar

CASE STUDY S5

Large solar parabolic trough: Minera El Tesoro copper mine, Chile

Summary

Resource	The Atacama Desert averages a direct normal irradiation of more than $30MJ/m^2/day$
Investment	USD $12m for $10MW_{th}$ trough solar collector field
Construction	Commissioned November 2012
Designed to deliver	Reduction in annual diesel use by 55% for the solution heating process
Energy saved	Reduces annual emissions by about 10,000 tonnes
Simple payback	Not published
Other aspects	Installation workforce peaked at 180 people Thermal storage allows for provision of heat outside of daylight hours

Description

Abengoa Solar have installed 1,280 parabolic trough modules on six hectares of land adjacent to a copper mine in the Atacama Desert. The plant cost USD $12m and supplies heat to the copper refining process. The maximum operating temperature is 260°C.

A heat transfer fluid (water with a corrosion inhibitor) is circulated through the solar collectors and a heat exchanger is used to deliver this heat to the storage tanks and the electro extraction process used to produce copper.

The solar thermal system is designed so that it can store energy in the form of pressurised hot water. This allows the system to support operation after sunset and on partially cloudy days. The system controls automatically select the solar field, or the thermal tanks, or both as the sources of heat for the electro-winning process.

Parabolic trough collectors and thermal storage tanks at Minera El Tesoro, photos Abengoa Solar

Linear Fresnel collectors: Football Showcase Stadium, Qatar

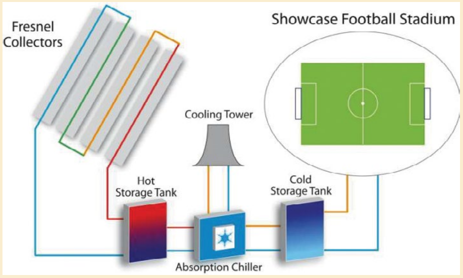
Summary

Resource	Doha averages a direct normal irradiation of about $20MJ/m^2/day$
Investment	$1{,}408m^2$ Fresnel collector, rated at $700kW_{th}$
Construction	2010
Designed to deliver	Water to 200°C to run chiller to cool football stadium
Energy saved	Demonstration project
Simple payback	Not published
Other aspects	Includes a $40m^3$ hot storage tank and a $100m^3$ phase change cold storage

Description

The Doha Showcase Football stadium is typically used for a few hours at a time in the evening and is not used on successive days. To continuously cool the stadium, a large amount of power would be required. However, due to the intermittent nature of its use, an innovative cooling solution was implemented that uses a smaller air-conditioning system, which is predominantly solar powered. It is operated several days ahead of a game and relies on the thermal inertia of the building and eutectic tanks beneath the stadium to maintain conditions during use.

Due to the high ambient temperature and humidity during the daytime, the double-effect lithium bromide absorption chiller is operated in the evenings. The Fresnel collector field heats water to up to 200°C which is stored in the pressurised hot water storage tank. The tank is used to store approximately 2.5MWh of thermal energy. This is used to provide energy to the chiller which has a nominal cooling capacity of 750kW. The evaporator of the chiller is connected via a cold water circuit to a phase change material cold storage with a volume of $100m^3$. The cold storage has a capacity of 5.8MWh thermal and is located beneath the stadium.



Fresnel collector field in Doha and diagram of cooling system, images Industrial Solar

CASE STUDY G1

Geothermal: Kawerau timber processing plant, New Zealand

Summary

Resource	Geothermal fluids at 270°C
Investment	Production wells 950m to 2,100m deep
Construction	Built in 1957
Designed to deliver	5,000,000GJ per year
Energy saved	A range of users benefit from the resource
Simple payback	Not published
Other aspects	Production wells tend to suffer rapid run-down due to mineral deposition and cold water inflow Various measures are used to maintain output

Description

The timber processing plant at Kawerau is one of the largest geothermal heat users in the world. The direct use is more than 5PJ per year spread over three separate owners with supply from a fourth party. The geothermal field has been providing steam since 1957 and is the cheapest energy source at Kawerau.

The production wells range between 950m and 2,100m while the wells for reinjection range from between 300m and 3,000m. The resource temperature is 270°C and about 9 to 12 million tonnes of brine fluid are extracted annually by the timber processing plant. This hot fluid is directed to several uses:

- the Bay of Plenty TG1 power station generating 2.6MW and rejecting fluid at 109°C,
- the TG2 power station generating 3.8MW and rejecting fluid at 85°C,
- to supply 2.7Mt per year of steam for Norske Skog Tasman (NST) for its 8MW geothermal turbo alternator, and
- for use by NST, Carter Holt Harvey and SCA Hygiene in their pre-evaporators, boiler feedwater heating, timber drying kilns and paper drying.


Kawerau timber mill site and 8.3MW binary cycle plant installed in 2008, photos NZ Geothermal Association

Heat Pump: Tree Top Food Processing, USA

Summary

Resource	Ambient air, not a PV with heat pump system
Investment	USD $1.25m industrial heat pump
Construction	2009
Designed to deliver	Heat for apple drying
Energy saved	About 94,300GJ of natural gas per year while electricity consumption increased by 8,580MWh per year
Simple payback	Less than 3 years
Other aspects	Heat pumps can be installed to harvest waste heat from chiller condensers The warm water reclaimed from the heat pump will be used for freezer defrost

Description

Tree Top Food Processing is one of the largest providers of dried apple products to the food manufacturing industry. The Wenatchee facility produces dehydrated apple products with moisture levels below 2.5 per cent. During harvesting periods, the plant can receive up to 900 tonnes of apples per day.

An industrial heat pump was installed in 2009 to provide heat to the conveyor for drying apples. The existing natural gas burners remain as auxiliary heat. It was estimated that the heat pump would save 94,300GJ of natural gas per year while increasing electricity consumption by 8,580MWh per year. The estimated energy bill savings were USD $463,000 per year.

Tree Top apple processing factory, photos Food Manufacturing Magazine

GLOSSARY

ARENA	Australian Renewable Energy Agency
AUD	Australian Dollars
BREE	Bureau of Resources and Energy Economics
CPC	Compound Parabolic Collector
CSP	Concentrated Solar Power
CST	Concentrated Solar Thermal
HTF	Heat Transfer Fluid
IEA	International Energy Agency
IRR	Internal Rate of Return
ISF	Institute of Sustainable Futures
ITP	IT Power (Australia) Pty Ltd
LCOE	Levelised Cost of Energy
LGC	Large-scale Generation Certificate
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
PV	Photovoltaic
RE	Renewable Energy

UNIT CONVERSIONS AND PREFIXES

MW	Megawatt, unit of power equal to 1,000kW
MWh	Megawatt-hour, unit of energy (1MW generated/used for 1 hour)
kW	kilowatt, unit of power equal to 1,000W
kWh	kilowatt-hour, unit of energy (1kW generated/used for 1 hour)
MJ	Megajoule, unit of energy equal to 1,000,000J
GJ	Gigajoule, unit of energy equal to 1,000MJ
TJ	Terajoule, unit of energy equal to 1,000GJ
PJ	Petajoule, unit of energy equal to 1,000TJ

e	As a subscript on any of above indicates electricity
th	As a subscript on any of above indicates thermal

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