Bioenergy and carbon farming opportunities in the Pilbara

Bulletin 4884

Supporting your success
Bioenergy and carbon farming opportunities in the Pilbara

Bulletin 4884

Robert Sudmeyer, Kim Brooksbank and David Rogers
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Copies of this document are available in alternative formats upon request.

3 Baron-Hay Court, South Perth WA 6151
Telephone: +61 (0)8 9368 3333
Email: enquiries@agric.wa.gov.au
Website: agric.wa.gov.au
Bioenergy and carbon farming in the Pilbara

Contents

Acknowledgements .............................................................................................. iv
Summary ................................................................................................................ v
  Bioenergy ........................................................................................................ v
  Carbon farming .............................................................................................. vi
1 Introduction ................................................................................................... 7
2 Growing biomass for energy production .................................................... 8
  2.1 Summary and recommendations ............................................................ 8
  2.2 Introduction ............................................................................................. 8
  2.3 Appropriate technologies ...................................................................... 10
  2.4 Feedstock species options ................................................................... 12
  2.5 Large energy users in the Pilbara ......................................................... 13
  2.6 Subsidies available ............................................................................... 15
3 Carbon farming ........................................................................................... 16
  3.1 Summary .............................................................................................. 16
  3.2 Introduction ........................................................................................... 16
  3.3 Carbon farming project activities .......................................................... 17
  3.4 Methodologies currently applicable in the Pilbara ................................ 18
  3.5 Participating in the Emissions Reduction Fund .................................... 20
  3.6 Risk ...................................................................................................... 24
Appendices .......................................................................................................... 27
Appendix A: Biofuel technologies ..................................................................... 28
Appendix B: Further information ....................................................................... 41
Appendix C: Licensed power stations in the Pilbara ....................................... 43
Appendix D: How Australia accounts for greenhouse gas emissions ........... 45
Appendix E: Carbon farming activities that do not have methodology
determinations applicable to the Pilbara........................................................... 47
Shortened forms .................................................................................................. 49
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Summary

The Pilbara region covers 270,000 square kilometres (km²) of north-west Western Australia (WA). Its main agricultural land use is pastoralism, with beef cattle grazing native pastures. Currently, only 24km² is under irrigation, with irrigated fodder the principal crop, but this could expand to 100km². This expansion has the potential to significantly broaden the economic base of the Pilbara.

Irrigation and the opportunities for changing land use and management may facilitate greater participation in the carbon economy by Pilbara land managers. Bioenergy feedstocks could be sourced from purpose-grown crops or agricultural wastes. Carbon farming activities may be facilitated by the land use and management changes that are possible with the introduction of irrigated agriculture into existing pastoral systems.

This report investigates the potential for land managers in the Pilbara to produce bioenergy from feedstocks sourced from irrigated agriculture, and to undertake carbon farming activities that are facilitated by introducing irrigated agriculture.

Bioenergy

There is a large demand for transport and stationary energy at several Pilbara locations. However, the energy market in the Pilbara is expensive because of the limited interconnected electrical grid and the distance over which fuels must be transported. Combined with the development of irrigation areas, this raises the possibility that locally grown crops dedicated to energy production, crop residues and animal effluent from feedlots might be viable alternatives to current energy supplies, which are dominated by fossil fuels.

Several technologies for converting biomass to energy are now mature and the number of commercial-scale facilities is increasing in Australia and overseas. However, the slow rate of uptake in the market suggests there is still a perception of risk when compared to conventional power generation. To achieve long-term sustainability, bioenergy projects in the Pilbara would need to:

• be technically viable at the medium to large scale
• be suitable for the hot climate and remote location
• be able to use locally available feedstocks
• reduce greenhouse gas emissions and other environmental impacts
• be commercially viable.

With these criteria in mind, using agricultural biomass to produce energy products, such as syngas, biogas or ethanol, is considered not feasible in the Pilbara in the short term. We identified several factors that contributed to this.

The remoteness of the Pilbara adds complexity and therefore risk to any project. For example, there is less expertise for construction and maintenance phases available in remote areas, and the vast distances significantly add to build time and cost.
Further long-term work is required to understand potential sustainable yields of biomass crops grown in the Pilbara. Long-term offtake agreements are often necessary to secure the finances of infrastructure projects.

The viability of most bioenergy projects is underpinned by the ability to use waste heat, which may account for more than 80% of the energy created. In the Pilbara, there is currently no need for this heat, so it is unlikely that bioenergy will be a viable option, at least for the current energy users in this region.

**Carbon farming**

Carbon farming presents an opportunity for agricultural producers and land managers to benefit financially from mitigating greenhouse gas pollution. Carbon farming involves changing agricultural technologies, management or practices to reduce greenhouse gas emissions or to remove carbon dioxide from the atmosphere (sequestration).

Carbon farming methodologies are currently available to land managers in the Pilbara. These methodologies explain how to conduct the project and how to measure (or estimate) and report the abatement. Methods primarily relate to activities that reduce greenhouse gas emissions during beef cattle production. There are limited opportunities for sequestration activities.

While many of the techniques for reducing emissions from livestock are already used in the industry to increase livestock productivity and resilience, their use in the Pilbara could be increased by introducing irrigated fodder production systems. Mosaic irrigation in northern Australia could drive positive change to beef production systems and boost productivity at the enterprise scale. Any income from generating carbon credits would be an additional benefit.

Carbon farming activities are best undertaken where the activity provides a clear productivity improvement or benefit other than just carbon credits; that is, the economic viability of the activity should not be wholly reliant on generating carbon credits.

Those contemplating a carbon farming project should seek independent technical, financial and legal advice about their circumstances. Those considering activities on leased Crown land need to be aware of the lease conditions and must obtain consent from the Minister of Lands.
1 Introduction

The Pilbara region covers 270 000 square kilometres (km²) of north-west WA. Its main agricultural land use is pastoralism, with beef cattle grazing native pastures. Currently, only 24km² is under irrigation, with irrigated fodder the principal crop. The Pilbara Hinterland Agricultural Development Initiative has identified potential water resources that could allow an additional 100km² of land to be irrigated, if the water and soil resources prove suitable. Irrigated agriculture at this scale could significantly broaden the economic base of the Pilbara.

Irrigation and the opportunities for changing land use and management may facilitate greater participation in the carbon economy by Pilbara land managers. Bioenergy feedstocks could be sourced from purpose-grown crops or agricultural wastes. Carbon farming activities may be introduced into existing pastoral systems.

This report investigates the potential for land managers in the Pilbara to:

- produce bioenergy from feedstocks sourced from irrigated agriculture (Chapter 2)
- undertake carbon farming activities that are facilitated by the introduction of irrigated agriculture (Chapter 3).
2 Growing biomass for energy production

2.1 Summary and recommendations

Several technologies for the conversion of biomass to energy are now mature. The number of commercial-scale facilities is increasing in Australia and overseas. However, the slow rate of uptake in the market suggests there is still a perception of risk when compared to conventional power generation.

Undertaking a bioenergy project in the Pilbara adds to the level of risk because:

- further long-term work is required to understand potential sustainable yields of dedicated biomass crops under Pilbara conditions
- there is less availability of expertise for the construction and maintenance phases in remote areas
- remote locations increase build time and cost
- long-term offtake agreements are often necessary to underpin the finances of infrastructure projects; these may be difficult to negotiate when the mines may shut down when commodity prices fall
- the viability of most bioenergy projects is underpinned by the ability to use waste heat, which may account for over 80% of the energy created; in the Pilbara, there is no need for this heat, so it is unlikely that bioenergy will be a viable option, at least for the current energy users in this region.

Given these extra challenges, it is prudent to delay the development of bioenergy projects until precursor industries are well established. We concur with the findings of the GHD report (2015) that this should be re-examined once the first phase of agricultural enterprises have been developed.

2.2 Introduction

‘Bioenergy’ is the term used to describe generation of electricity, heat or liquid fuels from biomass feedstocks. Suitable biomass feedstocks include:

- agricultural products and their waste, including:
  - sugar cane and bagasse
  - grains, waste starch and crop residues
  - oil seed and tallow
  - livestock manure
- algae
- wood and wood waste, including:
  - plantations and plantation residues
  - other forestry residues
  - residual wood from processing activities such as sawmilling
- dedicated energy crops.
Locally produced bioenergy crops, crop residues and feedlot animal effluent might be viable alternatives to the Pilbara’s current energy supplies which are dominated by fossil fuels. This is because of:

- the high energy costs related to the limited interconnected grid and large transport distances for fuels
- the need for large amounts of transport and stationary energy in a number of specific locations
- the large areas of low opportunity cost, arable land
- the availability of low cost water for irrigation, sourced from mine dewatering operations and shallow aquifers.

The number and sophistication of bioenergy installations is increasing in Australia. This has been driven, in part, by improving economics, which has been driven by the improved efficiency of converting biomass to energy, economic drivers relating to reducing Australia’s greenhouse gas emissions and the realisation that there is a range of collateral benefits to producing energy from waste. In many cases, disposing of waste biomass is a cost to industry and local governments. This makes bioenergy an attractive option, even while the cost of fossil fuels is low. As the number of bioenergy projects in Australia increases, there is growing confidence in, and willingness to invest in, these technologies.

The potential for producing bioenergy from feedstocks sourced from irrigated agriculture in the Pilbara is discussed in this chapter.
2.3 Appropriate technologies

For long-term sustainability, bioenergy projects in the Pilbara need to meet several criteria. Projects should:

- be technically viable at the medium to large scale
- be suitable for the hot climate and remote location
- use locally available feedstocks
- reduce greenhouse gas emissions and other environmental impacts
- be commercially viable.

With these criteria in mind, we identified three conversion processes for further investigation: gasification, anaerobic digestion and cellulosic ethanol (Table 2.1).

Each of these processes produces energy products (syngas, biogas or ethanol) and residues, which when applied to soil, return essential elements and enhance carbon levels. When producing cellulosic ethanol, the residue is predominantly lignin, which can be burned to provide heat for the conversion process. Appendix A describes the three processes in more detail.

Table 2.1 Summary of established processes for the conversion of biomass to energy and other products

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Gasification</th>
<th>Cellulose ethanol</th>
<th>Anaerobic digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulosic biomass: cereal straw, grain husks, forestry products and waste from energy crops (grasses, canes)</td>
<td>Syngas, heat, electricity</td>
<td>Cellulosic biomass: cereal straw, grain husks and waste from energy crops (grasses, canes)</td>
<td>Organics (sewage, manure, municipal waste, waste) can mix with cellulosic wastes and abattoir waste</td>
</tr>
<tr>
<td>Energy products</td>
<td>Ethanol, heat, electricity</td>
<td>Biogas, heat, electricity</td>
<td></td>
</tr>
<tr>
<td>Other products</td>
<td>Biochar, ash</td>
<td>Ash, compost, liquid fertiliser</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Gasification/combustion/pyrolysis, boiler (heat), cogeneration (heat and electricity)</td>
<td>Steam explosion, enzymatic saccharification, fermentation, distillation, cogeneration (heat and electricity)</td>
<td>Biogas digester, gasholder biogas boiler (heat), cogeneration (heat and electricity); engine or turbine, generator (heat exchangers)</td>
</tr>
</tbody>
</table>
Cellulosic ethanol is discussed here rather than traditional sugar or starch ethanol production because it can use purpose-grown biomass or crop waste as feedstock, both of which could be produced in the Pilbara.

Ethanol production requires significant infrastructure to create the economies of scale required to bring the unit energy cost down to a competitive level. Global experience suggests that the minimum infrastructure cost is about $250 million. It is likely that this cost would be higher in the Pilbara, to account for extra costs associated with building and operating in a remote location. While ethanol production may be an attractive option, the substantial infrastructure costs involved will require long-term, secure offtake and biomass supply contracts to make investment worthwhile.

GHD (2015) estimated that in the Pilbara, a minimum viable scale ethanol plant — producing 80 million litres of ethanol per year and requiring 15 000ha of irrigated sorghum feedstock (their best crop choice) — could produce ethanol with a break-even value of $1.18 per litre ($46.56 per gigajoule [GJ]), which is considerably higher than diesel at $14.04/GJ (excluding excise and goods and services tax) at the Port Hedland terminal and liquefied natural gas at $7/GJ delivered. GHD (2015) suggest that ethanol plants are likely to be built only after a range of other agricultural industries have been developed and matured and some of the barriers to bioenergy’s success (discussed earlier) are overcome.

While biodiesel production might appear to be an attractive option for the Pilbara, given that it could be a direct replacement for the mineral diesel currently being used, we conclude it is not viable at this stage because most biodiesel feedstocks that could be grown (including sunflower, oil palm and olives) have higher value as food or industrial products.

Syngas is derived from gasification of biomass and can be burned to provide heat and to power engines or turbines to generate electricity. The drawbacks are that gasifiers are expensive and complex purification is required to bring the gas to a quality suitable for engines and turbines. In addition, syngas has significantly lower energy content than diesel or conventional gas so the generators are larger and more costly. In WA, there are a number of commercial-scale plants, which plan to produce syngas for use in stationary engines and turbines, funded for construction. However, most of these installations rely on organic material diverted from landfill and their business case relies on a zero or negative feedstock cost. It is unlikely that purpose-grown biomass could be produced at a low enough cost to make this technology financially viable in the Pilbara.

Where substantial volumes of waste biomass are available and heat or heat and electricity is required, biogas may be an option. Biogas production is a well-established process underpinned by a mature global industry, and the technology and expertise to build and operate biogas production facilities are available in WA. Biogas offers an additional opportunity to extract extra value from waste streams and by-products. Digester effluent has high nutrient content and can be applied as a fertiliser to enhance crops and soils.
One option for viable bioenergy production is to use the waste streams that would become available if a beef feedlot was built close to an irrigated farming system. A biogas digester would provide a means for disposing of the waste while generating energy and enabling the nutrients in the digested manure to be spread back onto the cropped area. One such facility is under construction on a farm at the fringe of the South West Interconnected System. The facility will produce electrical energy from biogas and will include a battery energy storage system.

Bioenergy technologies that convert biomass to electricity (syngas, biogas) produce most of their energy as heat. The ability to use this thermal energy often results in a sound business case and a reasonable payback period for a bioenergy installation. Currently, there are no significant requirements for thermal energy in the Pilbara, which limits the commercial viability of bioenergy projects. To overcome this limitation it would be worth investigating the collocation of complementary enterprises that are able to use the thermal energy produced.

Appendix B lists sources of more detailed information about these technologies and related topics.

2.4 Feedstock species options

The ideal biomass resource is high yielding, readily available, has low production costs and desirable characteristics. For cellulosic ethanol or syngas production, high cellulose and low moisture content is optimal. For biogas production, a higher proportion of sugar, starch and protein is desired, as well as a high moisture content. The feasibility of a new energy crop will depend largely on its production costs, the cost of converting the biomass to usable energy and the price of competing fuels.

Irrigated production in the Pilbara has so far been limited to cattle fodder. Growth data from the Pilbara and similar arid areas in Australia and overseas has shown a wide range of yields to be achievable (Table 2.2). Yields are likely to become more consistent as growers become more experienced, the varieties selected are more suited to the area, and the agronomics become more defined.

Table 2.2 Potential fodder crop dry matter (DM) and fuel yields

<table>
<thead>
<tr>
<th>Species</th>
<th>Reported DM yield range (t/ha)</th>
<th>Estimated DM yield achievable (t/ha)</th>
<th>Reported ethanol yield range (L/t DM)</th>
<th>Reported biogas yield (m³/t DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhodes grass</td>
<td>18–50</td>
<td>20</td>
<td>80–380</td>
<td>300</td>
</tr>
<tr>
<td>Lucerne</td>
<td>18–24</td>
<td>18</td>
<td>80–250</td>
<td>400</td>
</tr>
<tr>
<td>Sorghum</td>
<td>40–60</td>
<td>40</td>
<td>80–380</td>
<td>300</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>8</td>
<td>80–250</td>
<td>300</td>
</tr>
<tr>
<td>Maize</td>
<td>20</td>
<td>20</td>
<td>80–418</td>
<td>350</td>
</tr>
</tbody>
</table>
2.5 Large energy users in the Pilbara

A large proportion of the energy demand in the Pilbara is off-grid, where the preferred conventional power generation fuels are diesel and natural gas. Resource companies own most of the energy infrastructure. The government-owned energy utility, Horizon Power, supplies electricity to towns and communities. Horizon Power owns a 220 kilovolt (kV) transmission system that links Karratha and Port Hedland and is connected to the BHP Billiton and Rio Tinto grids to form the North West Interconnected System (Figure 2.1).

There is no formal electricity market in the Pilbara. Of the 3000 megawatts (MW) of generation capacity currently installed, 554MW is attached to the North West Interconnected System, fuelled by diesel and gas. Most of the remaining capacity is designated as off-grid and is fuelled by diesel and gas. Solar and diesel power is currently generating 2.5MW at Marble Bar and Nullagine.

Although it is technically viable, it is unlikely there would be enough feedstock available in the Pilbara for a biogas digester to make a significant contribution to a typical mine site power supply. For example, it has been estimated that a feedlot with 10 000 cows would produce enough biogas to generate between 0.4 and 4MW of electricity, depending on the properties of the waste and the daily hours of use of the generator. Comparing these values with typical figures for mine site power stations (Appendix C) reveals that this would provide a very small contribution to the total power requirements of even the smallest mine site.
Figure 2.1 Electricity generation sites in the Pilbara with transmission lines and known water resources
2.6 Subsidies available

2.6.1 Australian Renewable Energy Agency

The Australian Renewable Energy Agency (ARENA) provides grants to renewable energy projects that are deemed novel in some way and too risky for traditional lenders.

ARENA’s focus is providing financial support to help prove technology to a point where it is investment-ready. ARENA will not support projects that are using well-proven technologies, unless there is some aspect to those projects that would make it difficult to secure finance from elsewhere. ARENA provides grants (not loans) on the understanding that learning from the project will be made available to the public to enable similar projects to benefit from the experience gained.

For ARENA to support a bioenergy project in the Pilbara, it will need to accept that there are risks involved for Pilbara biomass developments that mean the project proponent is unable to secure funding from another source.

2.6.2 Clean Energy Finance Corporation

The Clean Energy Finance Corporation (CEFC) provides commercial loans for projects deemed ready for commercial-scale deployment but still considered too risky by traditional lenders; it fills the gap between the ARENA grants and commercial finance. The CEFC get involved when proponents are using proven technology, but for some reason the risk profile of the project is beyond what would be considered acceptable by traditional lenders. This is likely to be the case for many renewable energy projects in the Pilbara and we recommend that proponents discuss their projects with the CEFC early in their planning process to ascertain if the CEFC could fund all or some of the project. Typically, the CEFC will lend up to half the cost of the project at slightly better interest rates than banks. The remainder can be financed through commercial institutions.

2.6.3 Renewable Energy Target (RET)

The Large-scale Renewable Energy Target (LRET) creates a financial incentive to establish or expand renewable energy power stations, such as wind and solar farms, bioenergy plants or hydroelectric power stations. It does this by legislating demand for Large-scale Generation Certificates (LGCs). One LGC can be created for each megawatt-hour of eligible renewable electricity produced by an accredited renewable power station. LGCs can be sold to entities (mainly electricity retailers) that surrender them annually to the Clean Energy Regulator to demonstrate compliance with the LRET scheme’s annual targets. The revenue earned by the power station for the sale of LGCs is additional to that received for the sale of the electricity generated.

The LRET includes legislated annual targets that will require significant investment in new renewable energy generation capacity in coming years. The large-scale targets ramp up until 2020, when the target is 33 000 gigawatt-hours of renewable electricity generation.
3 Carbon farming

3.1 Summary
Carbon farming presents an opportunity for land managers to benefit financially from providing the ecosystem service of mitigating carbon pollution. Given the likely risks and costs involved, carbon farming activities need to return multiple economic and environmental co-benefits to be attractive to land managers.

Methodologies currently available to land managers in the Pilbara primarily relate to activities that reduce enteric emissions from beef cattle. There are limited opportunities for sequestration activities.

There are examples of carbon emission avoidance projects running on leased Crown land in WA, but there are no sequestration projects on Crown land and the state government is yet to develop a policy to deal with sequestration projects on Crown land.

Land managers contemplating a carbon farming project should seek independent technical, financial and legal advice about their particular circumstances. Land managers considering activities on leased Crown land need to be aware of lease conditions and need to obtain consent from the Minister of Lands.

3.2 Introduction
Carbon farming offers an opportunity for agricultural producers and land managers to benefit financially from providing the ecosystem service of mitigating greenhouse gas pollution. Carbon farming involves changing agricultural technologies, management or practices to reduce greenhouse gas emissions from soil, vegetation or livestock (emissions abatement) or to remove carbon dioxide from the atmosphere by storing (sequestering) carbon in vegetation and the soil. In many cases, carbon farming activities also offer productivity benefits.

Agriculture was responsible for about 16% of Australia’s greenhouse gas emissions in 2013, with ruminant livestock (cattle, sheep, buffalo, goats, deer and camels) contributing 66% of this (Appendix D). Livestock and the manure they create are the dominant sources of methane emissions, accounting for 52% of all the methane emitted nationally. Agricultural soils are the dominant source of nitrous oxide, accounting for 62% of national emissions (Department of the Environment 2015a, 2015b).

The Australian Government has committed to reducing greenhouse gas emissions to 26–28% below 2005 levels by 2030. Eligible carbon farming projects can contribute to reaching this goal and generate saleable carbon offsets called Australian Carbon Credit Units (ACCUs). The ACCUs generated from carbon farming projects can be sold into the Emissions Reduction Fund (ERF) or voluntary markets.

The following sections outline carbon farming activities that can be undertaken in the Pilbara, how to participate in the ERF and some of the risks involved. More detailed information about these and related topics are available from the sources listed in Appendix A.
3.3 Carbon farming project activities

Project methodologies set out how to conduct the project and how to measure (or estimate) and report the abatement. Carbon farming methodologies currently available to Pilbara land managers primarily relate to activities that reduce enteric emissions from beef cattle. There are limited opportunities for sequestration activities.

Methods for reducing methane emissions from livestock include providing dietary supplements, improving growth rates by improving the amount or quality of fodder, improving reproductive rates, removing unproductive animals and managing manure. While many of these techniques are already used in the livestock industry to increase livestock productivity and resilience, their use in the Pilbara could be increased by introducing irrigated fodder production systems. An assessment of the potential for mosaic irrigation in northern Australia found that carefully designed, constructed and managed systems that provide forage grown on pastoral stations could drive positive change to beef production systems and boost productivity at the enterprise scale (Grice et al. 2013).

Reducing methane emissions from livestock can increase feed conversion efficiency and reduce the intensity of emissions from livestock (methane production per unit of animal product). It may also allow livestock producers to increase stocking rates. If stocking rates are increased, emission intensity may reduce, but total emissions will remain the same. It is important for producers to understand this concept when considering emission offset trading schemes.

Carbon project proponents must also consider the important differences between abatement and sequestration projects. Sequestration activities involve maintaining carbon stores for at least 25 years and usually involve changing land use. Abatement activities avoid the need to maintain carbon stores. Consequently, abatement activities allow project operators to benefit from carbon farming without affecting their ability to change operational and land-use management in the future. Greenhouse gas emissions can also represent a loss of valuable resources from farming systems, for example, nitrogen in fertiliser or the energy and protein in fodder lost to the atmosphere. If land managers can improve the efficiency with which these resources are used, there is potential to reduce greenhouse gas emissions and improve enterprise productivity.

Assessments of the economics of carbon farming in WA have concluded that carbon farming activities are best undertaken where the activity provides a clear productivity benefit other than just carbon credits. That is, the economic viability of the activity is not wholly reliant on the generation of carbon credits (Sudmeyer et al. 2014, The Centre for International Economics 2015). Those contemplating a carbon farming project should seek independent technical, financial and legal advice about their particular circumstances.

Chapter 3.4 describes activities with methodology determinations applicable to the Pilbara. Appendix E describes activities that are currently not applicable to the Pilbara.
3.4 Methodologies currently applicable in the Pilbara

The principal greenhouse gas generated by livestock is methane, and ruminants (cattle, sheep, buffalo, goats, deer and camels) are the main source because they produce the most methane per unit of feed consumed. Ruminants have a forestomach (or rumen) containing microbes called methanogens. These methanogens are capable of digesting coarse plant material (enteric fermentation) and produce methane as a by-product, which the animal voids by belching. The amount of methane produced depends on the number of animals and the type and amount of feed consumed (O’Mara 2011).

3.4.1 Dietary supplements

Dietary supplements and feed alternatives have the potential to reduce methane emissions, primarily by suppressing the activity of methanogens. Supplements include oils, fats, tannins, probiotics, nitrates, enzymes, marine algae and Australian native vegetation. However, most of these are not yet included in an approved methodology.

The methodology, Reducing greenhouse gas emissions in beef cattle through feeding nitrate containing supplements, sets out how to estimate abatement by replacing or supplementing urea lick-blocks with nitrate lick-blocks. This methodology applies to pasture-fed and rangeland beef cattle.

3.4.2 Improved feed quality and grazing practices

Plant structural fibres (cellulose and hemicellulose) ferment more slowly and yield more methane per unit of feed digested than non-structural carbohydrates (Eckard et al. 2010). Consequently, animal growth can be increased and methane emissions can be reduced by improving stock diet. Stock diet can be improved by improving forage quality (for example, by increasing the proportion of forage legumes in the diet) or providing access to grain feed supplements with lower fibre and higher soluble carbohydrates (Beauchemin et al. 2008, Ulyatt et al. 2002). However, high concentrations of condensed tannins in some legumes can reduce voluntary feed intake and digestibility (Waghrorn et al. 2002, Min et al. 2003, Woodward 2004, Carulla et al. 2005, Beauchemin et al. 2008, Grainger et al. 2009).

Methods for improving feed quality and quantity in the Pilbara include:

- providing higher quality forages that are produced under irrigation
- managing rangelands to improve forage quality and quantity by:
  - installing fences to control herd movements
  - adding watering points to allow cattle to graze more widely and make better use of available pasture.

The methodology, Beef cattle herd management, sets out how to estimate abatement by improving feed quality for pasture-fed and rangeland beef cattle.
3.4.3 Stocking rates and herd management practices

Improving breeding practices and removing less productive animals can reduce the average herd age and increase weight gain relative to age. Reducing the number of unproductive animals can potentially reduce emissions intensity, increase profits and maintain the quantity of meat that is produced (Garnett 2007).

The methodology, *Beef cattle herd management*, sets out how to estimate abatement by improving herd management for pasture-fed and rangeland beef cattle. Activities that can reduce emissions include:

- installing fences to control herd movements and improve mating practices
- improving weaning percentage by culling unproductive cows.

3.4.4 Manure management

Livestock urine and manure are significant sources of methane and nitrous oxide when they break down under anaerobic conditions. Anaerobic conditions often occur where large numbers of animals are managed in a confined area, such as beef feedlots, piggeries and poultry farms, where manure is stored in large piles or settlement ponds (de Klein & Eckard 2008).

There is increasing interest in biogas (methane) capture-and-use technologies, such as covered ponds or biodigesters, to provide heat or power for large, intensive livestock facilities (see Chapter 2). These systems may be profitable, regardless of offset income, because of the energy production and the trading of renewable energy certificates (Hertle 2008).

There are methods established under the ERF for manure management in *piggeries* and *dairies* that could be used if such enterprises were established in the Pilbara.

3.4.5 Reforestation, afforestation, revegetation and avoiding deforestation

Developing irrigation to provide new sources of fodder in the Pilbara may provide opportunities to improve grazing management and regenerate degraded rangeland areas. While there are methodology determinations for *Avoided clearing of native regrowth*, *Avoided deforestation*, *Native forest from managed regrowth*, *Reforestation and afforestation* and *Human-induced regeneration of a permanent even-aged native forest*, which estimate the amount of carbon sequestered in forest biomass, these activities are generally not applicable in the Pilbara. Most of the Pilbara’s vegetation does not meet the criteria for forest, which are:

- woody vegetation covering an area greater than 0.2ha
- canopy covers (or has the potential to cover) more than 20% of the land area
- vegetation is (or has the potential to be) more than 2m tall.

The *Carbon Farming Mapping Tool* shows that forest (fitting these criteria) in the Pilbara region is largely confined to the creeks and rivers of the headwaters of the Ashburton and Gascoyne rivers. Outside of these areas, it may be possible to apply the *Carbon Credits (Carbon Farming Initiative) (Measurement Based Methods for*
Bioenergy and carbon farming in the Pilbara

New Farm Forestry Plantations) Methodology Determination 2014 if irrigated tree crops, such as sandalwood, were established. Such a project would need to operate within the following conditions:

- no native forest can be removed to establish the plantation
- no individual trees taller than 2m can be removed to establish the plantation
- the minimum 25 year permanence requirement must be met
- allometric relationships to estimate sequestration rates must be established.

3.5 Participating in the Emissions Reduction Fund

Carbon farming activities are conducted under the Carbon Credits (Carbon Farming Initiative) Act 2011, the Carbon Credits (Carbon Farming Initiative) Regulations 2011 and the Carbon Credits (Carbon Farming Initiative) Rule 2015.

Land managers contemplating undertaking a carbon farming project should seek independent technical, financial and legal advice about their particular circumstances. The steps to undertake a carbon farming project are outlined below.

**Step 1 Consent**

Proponents must have the consent of any person or organisation with an eligible interest in the land on which the project will run (eligible interest holder consent). Eligible interest holders may include financial institutions that hold a mortgage over the land, registered native title corporate bodies and the Minister for Lands (for Crown land).

Proponents wishing to undertake a project on leased Crown land must obtain the consent of the Minister for Lands. There are 11 emissions avoidance projects running in the north of WA; 10 of which are savanna burning projects and 1 is a herd management project registered in the Kimberley. Some of these are on Crown land so there is some experience with these types of projects. However, there are no sequestration projects operating on Crown land in WA and the state government has yet to develop a policy in relation to carbon sequestration activities on Crown land.

**Step 2 Method**

Determine if there is a suitable methodology. Project methodologies set out how the project will be undertaken and how the abatement will be estimated (or measured) and reported.

**Step 3 Feasibility**

Investigate the feasibility of the project. Land managers considering a carbon farming project should seek independent legal, financial and technical advice. Things to consider include:

- understand participant obligations
- understand the technological and management requirements of the project:
Bioenergy and carbon farming in the Pilbara

- assess relevant technology options, quality assurance requirements and warranties
- assess what equipment to install and which species to plant
- determine what management changes are required
- determine what systems will be used to monitor the project and collect, collate and record all relevant data

- understand the amount of emission abatement or sequestration that can be achieved by undertaking a particular activity

- understand your organisational capacity and the likely amount of ACCUs generated; for smaller projects, engaging an aggregator may be an option — engaging third-party managers to provide knowledge, business advice, managerial capacity and the ability to pool projects and capital investment could reduce risk

- know what state and local government approvals are required, for example, projects on leased Crown land need to comply with WA’s Land Administration Act 1997 and proponents of savanna burning projects need to contact the local government authority, the Department of Parks and Wildlife and the Office of Bushfire Risk Management in the Department of Fire and Emergency Services for advice about bushfire regulations

- understand what co-benefits can be achieved

- investigate the financial feasibility of the project (Figure 3.1).
Figure 3.1 Factors to consider when investigating the feasibility of a carbon farming project (The Centre for International Economics 2015)
**Step 4 Register**

**Apply** to register the project:

- Projects must meet the following **eligibility, additionality and newness requirements**:
  - project has not started before registration
  - project is not required to be carried out by or under a Commonwealth or state law
  - project is not likely to be carried out under another Commonwealth or state government program or in the absence of registration under the ERF.

- The proponent must demonstrate they have the **legal right** to carry out the project. This involves providing the Clean Energy Regulator with:
  - a description of project activities and associated obligations
  - proof of consent of eligible interest holders
  - statements about their legal right to be issued with the ACCUs resulting from the project activities, the duration of that right and an explanation of how the legal right was obtained.

- The proponent must demonstrate they meet the **fit and proper person** requirements.

- The proponent must provide a **forward abatement estimate** of the number of ACCUs likely to be issued over the crediting period: 25 years for savanna burning projects, 20 years for avoided deforestation projects, 25 years for all other sequestration projects and 7 years for all other emissions avoidance projects.

**Step 5 Bid**

The proponent needs to **register to participate in an ERF auction and submit a bid**. If successful, the proponent then applies to enter into a contract with the Clean Energy Regulator to sell their ACCUs. Under the auction process, offset providers tender to supply the lowest cost ACCUs in a type of reverse auction process.

**Step 6 ACCUs**

**Delivery and payment** for ACCUs must be made in accordance with the contract made at step 5.

**Step 7 Auditing and reporting**

Proponents must **report** on their projects at least once every two years for abatement projects and at least once every five years for sequestration projects. Generally, projects must have a minimum of three scheduled **audits** done by a registered auditor over a seven-year crediting period. The number of scheduled audits depends on the number of ACCUs generated per year.

Carbon farming in WA may be facilitated by the **Carbon Rights Act 2003**, which allows a carbon right to be registered on a land title as a separate interest in that land (Government of Western Australia 2005). Registration of a carbon right clarifies the ownership of the benefits and liabilities arising from carbon sequestration or emissions abatement on that land. This legislation could be used for projects...
undertaken outside of the Commonwealth’s ERF framework, where offsets would be sold into voluntary markets. Land managers considering a carbon farming project should seek independent legal advice about entering into a carbon right arrangement under WA laws.

3.6 Risk

Since carbon farming projects are not free of risk, the risk–return trade-off will be critical in determining at what rate of return projects will appeal to investors. Before commencing a carbon farming project, proponents should seek independent technical, financial and legal advice about their particular circumstances. Some of the critical risk factors to consider are:

- sequestration and mitigation rates
- offset price trajectory
- cost of sequestration or mitigation
- permanence (for sequestration projects)
- the proponent’s experience and knowledge of carbon farming.

The permanence requirement — that sequestered carbon should not re-enter the atmosphere for 25 or 100 years — presents some issues that project proponents need to consider.

First, revegetation, reforestation and soil carbon projects are expected to stop being a net carbon sink about 40–100 years after establishment, when the soil or vegetation reaches carbon equilibrium. At this time, the amount of carbon being sequestered is equal to the amount being emitted, as vegetation dies and rots or soil carbon is oxidised. Depending on when carbon equilibrium is reached, the administrative and operational costs associated with maintaining a sequestration project for more than 25 years may continue well after the income from carbon abatement ceases.

Second, predicted reductions in rainfall and increased temperatures associated with global warming are likely to reduce the growth rates of plants in some areas of WA (Baldock et al. 2012, Australian Bureau of Agricultural and Resource Economics and Sciences 2011). Changing climate means that selecting suitably resilient species and agricultural and forestry regimes is critical for the long-term success of sequestration projects.

Third, replacing relatively flexible agricultural systems with long-term sequestration plantings may reduce the ability of land managers to take advantage of future changes in technological, economic and climatic conditions.

And, capital gains for land with carbon rights registered on the title may be less than for unencumbered land.

While there is provision to transfer or terminate a carbon farming project at any time, native vegetation is protected under WA laws, and in some circumstances a clearing permit may be required before vegetation can be cleared. A clearing permit is not
required if vegetation had been planted with the intent to exploit it commercially. This specifically includes harvesting and may include afforestation with native species for sequestration purposes.

A landowner may need to obtain a permit to clear native vegetation if:

- the planting was funded (wholly or partly) by a person who was not the owner of the land and it was established for biodiversity conservation or land conservation (including salinity or soil acidity) purposes
- there is a statutory covenant or other binding form of undertaking to establish and maintain the vegetation
- it is regrowth of cleared native vegetation and more than 20 years old
- it is regrowth of any age in an environmentally sensitive area as defined in regulations.

Please seek advice from the Department of Environment Regulation about the scope of the relevant exemptions.

Currently, there is uncertainty surrounding carbon rights and undertaking sequestration carbon farming activities on rangelands leased from the state or on unallocated Crown land. Proposals to amend the *Land Administration Act 1997* and introduce a rangelands lease may facilitate carbon farming activities. Those interested in carbon farming on leased Crown land need to ensure they have consent from the Minister of Lands.
Appendices

A Further information
B Biofuel technologies
C Licensed power stations in the Pilbara
D How Australia accounts for greenhouse gas emissions
E Carbon farming activities that do not have methods applicable to the Pilbara
Appendix A: Biofuel technologies

Combustion, gasification and pyrolysis

Processes

Combustion, gasification and pyrolysis are processes that occur when relatively dry biomass, such as woodchips, straw, rice or grain husks, are heated. Biomass with a moisture content below 60% can be used, but generally, only feeds with a moisture content below 50% are used. Generally, it is better to dry feedstock down to 20–30% moisture content prior to use to avoid the energy losses associated with evaporating the additional moisture.

The three processes differ in the amount of oxygen, or other oxidising agent, added during heating.

Combustion

Combustion refers to burning biomass in the presence of sufficient oxygen to enable complete oxidation to occur. It is employed in modern biomass boilers to produce hot water or steam for domestic or industrial processes. Combustion steam can also be used to drive a turbine for generating electricity.

Pyrolysis

Pyrolysis occurs when biomass is heated without oxygen or other oxidising agents. First, the moisture is driven off and then the volatile compounds (mainly hydrocarbons) in the biomass are vaporised. The smaller molecules in the vapours will remain in the gaseous state when cooled (e.g. carbon monoxide, carbon dioxide, light hydrocarbons) whereas the larger molecules will condense to form a liquid referred to as tar, bio-oil or pyrolysis liquid. The solids remaining after the volatile compounds have been driven off are referred to as char or biochar and can be a useful soil ameliorant.

Generally, the liquids produced cannot be used directly as a fuel and must undergo further processing to convert them to a useful fuel. However, some more sophisticated processes can finely tune the composition of the vapours so they condense to form liquid fuels that are suitable for direct use in modern diesel or petrol engines. The most common example of this process is the Fischer-Tropsch process, which has been proven in a number of demonstration and pilot plants around the world, but is not yet employed widely as a commercial process.

Gasification

Gasification is an intermediate process between combustion and pyrolysis, because limited oxygen is provided to the process. Practical gasifiers typically have zones of combustion (to generate heat), pyrolysis (to drive off the volatile compounds) and reduction (to reform the gas into a higher quality fuel). The focus of gasification is on the quality of the gas produced, which is referred to as syngas or producer gas. Table A1 lists the compounds of syngas.
Table A1 Typical concentrations of syngas from gasification with air as the oxidising agent

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon monoxide (CO)</td>
<td>15–20</td>
</tr>
<tr>
<td>hydrogen gas (H₂)</td>
<td>15–20</td>
</tr>
<tr>
<td>methane (CH₄)</td>
<td>0.5–2</td>
</tr>
<tr>
<td>carbon dioxide (CO₂)</td>
<td>10–15</td>
</tr>
<tr>
<td>nitrogen gas (N₂)</td>
<td>40–60</td>
</tr>
<tr>
<td>oxygen gas (O₂), hydrocarbons(CₓHᵧ)</td>
<td>5–10</td>
</tr>
</tbody>
</table>

Syngas is a useful fuel which can be burned in a boiler to produce heat, or used in an engine or turbine connected to a generator to produce electricity. Before use in an engine, syngas must be cleaned to remove tars and other undesirable compounds that can damage mechanical parts. Figure A4 shows an example of a gasification installation.

If steam or oxygen is used as the oxidising agent, the composition of carbon monoxide and hydrogen gas (and therefore the energy content) is significantly higher than if air is used because of the absence of nitrogen, but more energy is required to drive the process.

The biomass used in combustion, gasification, or pyrolysis must first be physically treated to make the size of the particles small enough for the device used. Feedstock can include small logs, woodchips, waste wood offcuts and purpose-made wood pellets, or agricultural products such as oat husks, coconut and macadamia shells.

Feedstocks with too much sand or gravel can be problematic because they block up boilers leading to the need for frequent cleaning. This should be considered when collecting and stockpiling the biomass feedstock and one way to minimise this issue is to place stockpiles on concrete pads.

**Conversion technologies**

Many types of equipment have been developed for converting wood, straw and other dry forms of biomass into useful energy. For industrial process-heating, a biomass-fired steam boiler or gasifier can be used (Figures A1 and A2). When electricity is desired, a steam boiler can drive a steam turbine, or a gasifier can supply syngas to an engine generator. The conversion efficiency of wood fuel to electricity is typically 10–25%. Efficiencies of 80–90% can be obtained when electricity and heat from an engine or turbine are used. This is referred to as ‘cogeneration’ or combined heat and power.

Industrial biomass plants are usually fed automatically. Trucks or loaders fill a hopper with chips or pellets. Screw conveyors typically take the feed from the hopper to the boiler or gasifier. The speed of the conveyors is automatically varied according to the demand for heat or electricity.
Bioenergy and carbon farming in the Pilbara

Figure A1 Phil Beresford showing the viewing port to the combustion chamber on the gasification boiler at Macco Feeds, Williams, WA. About 3500–4000t/y of mallee woodchips are used to generate up to 1.7MW of thermal power to produce steam for direct injection to soften the stockfeed product.

Figure A2 Infeed system to a boiler: a screw conveyor automatically feeds woodchips from the hopper to the boiler at a speed controlled to match steam demand

**Environmental impacts**

In an ideal situation, biomass is burned completely in the presence of oxygen and the only end products are carbon dioxide and water vapour. In practice, however, a
range of pollutants may be present in the exhaust gases. Incomplete combustion as a result of insufficient air mixing or low combustion temperatures can leave a range of unburnt pollutants including carbon monoxide, hydrocarbons, tar and ammonia. Complete combustion can lead to the production of nitrogen oxides because of the nitrogen content of the fuel. Combustion in excess air may produce additional nitrogen oxides. Other contaminants can include sulfur dioxide, hydrochloric acid, heavy metals and ash particles. The specific nature of the contaminants depends on the combustion process and the composition of the fuel.

With proper emission control measures, biomass combustion can be carried out with lower emissions than burning coal. One measure to reduce emissions is to ensure good mixing of the air and gases so that complete combustion can be obtained without using excessive air. This is achieved in modern biomass devices by a two-stage combustion process. Primary air is injected into the fuel bed and secondary air is injected at multiple points in the combustion chamber to ensure good mixing with the combustible gases formed. Large combustion chambers resulting in longer flames and longer residence times also minimise the presence of unburnt pollutants. Good insulation of the combustion chamber allows higher temperatures to be reached, which improves the degree of combustion.

By adjusting the mixing of fuel and air, temperature and residence time, emissions can be minimised. Beyond this, additional emission reduction measures can be carried out. In general, biomass combustion is considered carbon neutral from a life cycle perspective because the carbon released as carbon dioxide during combustion is sequestered during plant growth. In reality, carbon neutrality relies on the feedstock being sourced from sustainably-managed forestry or agricultural practices. Greenhouse gas emissions during production, harvest and transport should also be considered. Small amounts of methane or nitrous oxide (N₂O) in the exhaust gases can negatively affect greenhouse gas emissions because these gases have much higher global warming potentials than carbon dioxide (Appendix D).

With complete combustion, such as is required in biomass boilers, the char formed by pyrolysis is burned and the solid residue is a fine ash. With pyrolysis and gasification, some unburnt char remains (referred to as charcoal or biochar depending on the application), which can be added to soil to enhance carbon levels and microbial activity. The properties and benefits of ash or char depend on many factors including the type of feedstock used, the temperatures used in the process, the soil type and the climate. In any situation, gasification products and soils should be tested and field trials should be carried out before the products are applied on a broad scale.

**Financial viability**

In Australia, the cost (excluding transport) of suitable agricultural and forestry residues, such as woodchips, straw or other dry biomass, is typically 20–25% of the cost of LPG (bottled gas) or natural gas for the same energy content. In some cases, the biomass cost can be zero or negative, which can occur if the feedstock is available onsite or would otherwise cost money to dispose of.
On the other hand, the capital cost of biomass combustion or gasification equipment can be higher than gas- or electricity-based equipment. This is because handling solids is more complex than gas or electricity and additional land and buildings are required to maintain stockpiles and feedstock delivery equipment. Additional operating costs apply because of the extra labour needed to manage stockpiles, load hoppers, remove ash and clean boiler tubes, which may foul more frequently than for gas.

Taking all these factors into account, typical payback periods for a business with a high demand for process heat can be in the range of four to six years.

Where electricity generation is also employed, payback periods will be higher because of the additional costs of generating equipment. A key factor in determining the financial viability of a gasification process is how many hours per day the plant is operating. Equipment that is running for longer periods will take less time to offset the capital cost with energy savings. There is no minimum or maximum scale for potentially viable projects because appropriate technologies have been developed at most scales. Suitable situations arise where there is a significant demand for heat or electricity combined with the availability of cheap feedstock.

It is also important to investigate the reliability of fuel supplies. For example, forestry waste may have established supply chains backed by long-term contracts with plantation owners. Cereal straw or grain husks are more seasonal and a number of sources may be needed to ensure feedstocks are available during low harvest or drought years. New enterprises can potentially be developed around providing reliable supply chains for agricultural residues.

Although there are thousands of biomass boilers, steam turbines, gasifiers and syngas engines and generators around the world, there is only a handful operating in WA. Possibly the greatest barrier to wider adoption is simply the lack of knowledge. Even under the most promising financial circumstances, there may be reluctance to switch to an unfamiliar process.

If the prices of conventional energy sources rise and public awareness of environmental impacts grows, it is likely that combustion and gasification technologies will become increasingly attractive in WA. Knowledge will improve as more local examples are built.
Ankur gasification system providing 500KW electrical power to a site in the United States

**Anaerobic digestion**

**Processes**

When moist organic materials, such as manure, food or agricultural wastes, are placed in a warm, sealed tank with limited air, they will be broken down by naturally-occurring microorganisms and a combustible gas will be produced. It is called biogas and typically contains 50–70% methane and the rest is mostly carbon dioxide. Biogas is valuable because it can be burned to produce energy for heating, lighting, cooking and transport.

Although the biochemical pathways involved in anaerobic digestion are complex, the process is frequently described in a simplified sequence of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Different groups of microorganisms are involved in each stage.

Figure B5 shows a simplified representation of the overall anaerobic digestion process. Note that in this diagram, the term ‘fermentation’ is used instead of acidogenesis for the second stage.
Conversion technologies

The tank used to make biogas is called a biogas digester. Biogas digesters have been developed at scales ranging from household to farm to industrial. As the scale increases, more equipment is needed to handle the increasing volumes of feedstock to be supplied to the digester and even greater volumes of liquid and solid by-product need to be removed.

Suitable situations for anaerobic digestion arise where there is a demand for heat and/or electricity and an availability of putrescible waste. Silage is sometimes used and it digests well because the initial stages of digestion start outside the digester. Dry biomass with high carbon content, such as straw, digests slowly on its own, but when mixed with high-nitrogen putrescibles, the digestion of both is improved. Biogas digesters can be installed in farms, towns, dairies, piggeries, sewage treatment plants and waste processing facilities.

In some European countries, biogas is widely used in agricultural regions to supply heat and electricity.

In Australia, the use of biogas digesters is small but growing. At the Woodman Point sewage treatment facility in WA, there is a biogas digester that has been producing electricity from waste-activated sludge for over a decade.

There are also two relatively new biogas plants — one at the Shenton Park waste facility and one at Richgro Fertilisers in Jandakot — which make biogas from waste and generate electricity for export to the grid.
Jühnde, a ‘bioenergy village’ in Germany, has completely replaced its use of fossil fuels with bioenergy from agricultural wastes. The domes are biogas digesters that use local crops and waste to produce electricity and household heating.

**Environmental impacts**

The environmental impacts from biogas include those associated with the discharge of liquid and solid effluent from the digester or covered pond, and those associated with combustion of the biogas itself, although the digestion of the waste also significantly reduces odour issues associated with traditional effluent treatment options.
Since biogas digesters are also a form of effluent treatment, the solid and liquid products produced should be beneficial to the soil and not produce any adverse effects. Nevertheless, it is important to test the effluent and soils, and where necessary obtain environmental approvals, to ensure the environment is not contaminated by nutrient run-off.

Gas scrubbers and clean-burning combustion equipment with pollution controls are generally included in modern biogas equipment. Biogas digesters reduce greenhouse gas emissions because they convert methane (global warming potential of about 23) to carbon dioxide (global warming potential of 1; see Appendix D for an explanation of global warming potential). If the biogas is used to generate heat and/or electricity, the reduction in greenhouse gases is further enhanced because the use of an equivalent amount of fossil fuels (e.g. LPG, natural gas or coal) is also prevented.

**Financial viability**

Until recently, it was considered in Australia that biogas was only financially viable at the large scale associated with centralised sewage treatment facilities. However, in recent years there has been a growing interest in the use of biogas at dairies, beef feedlots and piggeries.

In dairies, the biogas can be burned to provide hot water for wash-down and sterilising equipment. In piggeries, it can be used for heating farrowing sheds. In beef feedlots, it can be used to convert straw and grain into feed pellets.

Factors that determine the financial viability of biogas projects at dairies, feedlots and piggeries include the number of livestock, the time each day they spend on concrete or in stalls, the climate, the retail price of gas and electricity, and any government incentives which may be available. International and Australian case studies show that, in general, biogas projects are more likely to be viable when there are at least 1000 cows for dairies or feedlots and at least 500 sows for piggeries (about 5000 pigs for grow-out piggeries). They are less likely to be viable when the livestock spend a lot of time grazing pasture because the manure is difficult to collect.

An additional income stream has recently become available to biogas projects due to Australian Government initiatives to provide credits for reductions in greenhouse gas emissions caused by flaring biogas. These credits are not sufficient to justify flaring biogas alone but they do provide an additional incentive. For a solid financial case, the biogas needs to be used for heat and/or electricity generation. In suitable situations, it can take about six years for the initial capital expenditure to be repaid in energy savings. The cost of biogas plants is decreasing as more companies enter the market, and the cost of electricity and gas will probably continue rising, so it is likely that the business case for biogas projects in WA will continue to improve. Renewable energy certificates can also be generated to help offset some of the cost.

**Fuel ethanol**

Ethanol, or ethyl alcohol, can be used as a liquid fuel for transport, heating or electricity production. It can be blended with petrol at a concentration of up to 10%. This mix can be used in existing petrol engines. With modifications to the fuel
system, up to 100% ethanol can be used in engines. The most convenient configuration is a ‘flexi-fuel’ vehicle that can run on any combination of petrol and ethanol. Conversion kits are available for many makes of petrol vehicles.

Fuel ethanol has traditionally been made from sugar- or starch-based crops (sometimes referred to as ‘first generation ethanol’). Potential crops suited to the Pilbara climate include sugar cane, sorghum and corn.

Fuel ethanol can also be made from cellulose, the fibrous part of plants (referred to as ‘second generation ethanol’). Cellulosic ethanol has been drawing increasing attention because it is possible to use the non-food portion of food crops — cereal straw, corn stover (leaves and stalks), sugar cane bagasse — or non-food cellulosic crops (grasses, canes).

**Conversion process and technologies**

Making ethanol from biomass is fundamentally a biological process. With limited oxygen, yeasts ferment sugars into ethanol and carbon dioxide. The main differences between fuel ethanol and beverage alcohol are taste and toxicity. The taste of fuel ethanol is not a consideration in the selection of feedstock (inedible feedstocks can be used), and high concentrations of ethanol are required for fuel. The specific details of conversion processes vary according to feedstock but in general, they include the following steps.

**Pre-treatment**

The biomass is physically reduced by pulping, grinding, milling or chopping. For cellulosic ethanol, additional thermal or chemical treatment is used to make the cellulose more accessible. Water is added and a slurry is formed. Physical pre-treatment is usually carried out with an appropriate milling machine or grinder. Thermal and chemical pre-treatment takes place in a pressurised reactor.

**Hydrolysis or saccharification**

Large starch or cellulose molecules are broken down into fermentable sugars using a combination of high temperatures and specialised microorganisms or the enzymes obtained from them. The use of high temperatures not only facilitates hydrolysis but also helps to sterilise the mixture. Contaminating bacteria can reduce ethanol yields by consuming sugars and producing unwanted by-products. An advantage of sugar-based feedstocks, such as molasses (from sugar cane) or fruit, is that they already contain simple sugars so this step is not required, resulting in a simpler overall process.

**Fermentation**

Yeasts are added to the hydrolysed ‘mash’ and left to ferment for a few hours to a few days as they consume the sugars and produce ethanol. Typical fermentation temperatures are 30–40°C. Some form of gentle mixing is generally employed. Saccharification and fermentation can be carried out either in a single, stirred tank or in separate vessels. Separate saccharification and fermentation allow for better control and optimisation of individual processes which can be carried out at different
temperatures, pH values and mixing regimes. Combined or simultaneous saccharification and fermentation, in a single vessel, requires a compromise on optimum conditions of saccharification versus fermentation, but can be more efficient overall because the end products of saccharification are removed as they are produced, allowing the saccharification reactions to proceed at a faster rate.

**Distillation**

When the fermentation is complete, the resulting ‘beer’ typically contains 10–15% ethanol for sugar- or starch-based feedstocks, or 4–6% for cellulosic feedstocks. Ethanol is separated from water and other unwanted compounds by distillation in one or two columns. The maximum ethanol concentration obtainable by conventional distillation is 96%. The vapour is removed and passed through a condenser where it returns to the liquid state and is collected. Remaining in the vessel at the bottom of the column is a liquid–solid mixture with most of the ethanol removed. The columns (tall thin vessels) contain plates or packing which enable the continuous condensation and re-vaporisation of ethanol–water vapours. The water trickles down and the ethanol vapours rise, so that the overall ethanol concentration increases further up the column. The ethanol vapours from the top of the column are then condensed into liquid with a water-cooled condenser. A low ethanol concentration liquid ‘stillage’ (as well as some solid residue) remains at the bottom of the column. Substantial quantities of water are required for the production of ethanol, and this factor may compromise the potential viability of ethanol production in the Pilbara.

**Additional processing**

Quality control, licensing or excise may dictate a higher purity than that obtainable by conventional distillation. Further dehydration can be carried out by the use of molecular sieves or specialised distillation techniques. The Australian Government has proposed quality standards for fuel grade ethanol, which specify a minimum purity of 94%. The standards also specify that the ethanol be denatured, which means substances are added to render it poisonous to discourage recreational drinking.

The process for making fuel ethanol from traditional sugar- and starch-based feedstocks is well established. There are hundreds of medium- and large-scale operating facilities around the world. The biggest ethanol producing countries are the United States, which produces most of its ethanol from corn, and Brazil, which uses mainly molasses, a by-product of making sugar from sugar cane. There are three ethanol refineries in Australia (Table A2).

**Table A2** Production capacity (ML/y) of ethanol refineries currently operating in Australia

<table>
<thead>
<tr>
<th>Location</th>
<th>Capacity (ML/y)</th>
<th>Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarina, Queensland</td>
<td>60</td>
<td>Molasses</td>
</tr>
<tr>
<td>Dalby, Queensland</td>
<td>80</td>
<td>Sorghum</td>
</tr>
<tr>
<td>Nowra, New South Wales</td>
<td>300</td>
<td>Residual flour</td>
</tr>
</tbody>
</table>
There are also a number of cellulosic ethanol pilot and demonstration plants around the world (including two in Australia), producing 0.1–5ML/y. A rapidly increasing number of commercial-scale plants are under development in the range of 20–75ML/y.

Renewable energy can be used to reduce fossil fuel consumed in the production of ethanol. Solar hot water, photovoltaics (solar electric), biogas and combustion of processed solid residues can provide process heat and electricity.

The liquid residue from distillation columns (stillage) has a high organic loading and is a good source of energy for biogas digesters, as is manure. When grains are used as feedstock, the solid residue is a high quality livestock feed (‘distillers’ grains). Integrated ethanol distilleries can achieve high efficiencies when they are close to the source of feedstock and use by-products or surplus energy from an adjacent facility such as a sugar refinery, brewery or flour mill.

Compared to making ethanol from sugar- or starch-based feedstocks, cellulosic ethanol production has some drawbacks. Cellulose is more difficult than starch to break down into simple sugars so pre-treatments involving physical, chemical or thermal processes can be energy intensive. The ‘beer’ from cellulosic ethanol fermentation has a low ethanol concentration (4–6%), so significantly more distillation energy is required compared to conventional ethanol. However, the heat for distillation can be obtained by burning lignin, which is separated from the cellulose during pre-treatment. Enzymes that break down cellulose are more complex and energy intensive to produce than enzymes that break down starch (and none are required for sugar-based crops).

Environmental impacts

The environmental impacts from the production and use of ethanol include greenhouse gas emissions and associated reduced air quality.

Since the crops for ethanol feedstocks draw carbon from the atmosphere when growing, greenhouse gas emissions when burning ethanol are less than when burning the same amount of petrol. While there is broad consensus on this point among the life cycle studies (Quirin et al. 2004, Farrel et al. 2006, Von Blottnitz & Curran 2007), the degree of reduction varies widely among reports.

There are mixed findings on air quality impacts from the production and use of ethanol (Brown 2008), with some emissions (particulate matter) reportedly decreasing, and others (hydrocarbons, aldehydes) reportedly increasing. There are mixed findings on the impacts of using fuel ethanol on the same pollutants (carbon monoxide, nitric oxide and nitrogen dioxide), with some reports claiming a decrease in emissions compared to 100% petrol and others claiming an increase.

In a similar manner to energy ratios and greenhouse impacts, air quality impacts depend on many factors including fuel composition, engine technology and practices associated with growing crops and processing into ethanol. For example, it has been common practice in Brazil to burn sugar cane fields prior to harvest to remove the dried leaves and this practice increases volatile organic compounds, and nitrogen dioxide and carbon
monoxide levels (Tsao et al. 2012). So while there is broad consensus that using ethanol blends of up to 100% can have a positive overall effect on air quality, it is essential to ensure proper design, monitoring and environmentally sound practices are employed throughout the life cycle of the fuel for the benefits to be realised.

Pollutants are associated with the input of fossil fuels required to grow, harvest and transport the crops, such as fertiliser, pesticides and machinery fuel. For cellulosic ethanol, based on the residue of a food crop, these inputs would normally be allocated to production of the food crop (e.g. wheat, corn, sugar) rather than to ethanol production because food is the primary reason for the crop.

The emissions associated with the use of the residue (e.g. straw) are consequently less than those associated with the use of a sugar- or starch-based crop. It is for this reason, as well as the limited availability of additional land for dedicated ethanol crops, that cellulosic ethanol is often reported as the most viable renewable transport fuel in the long term (Farrel et al. 2006, Hill et al. 2006).

Additional impacts may arise from the disposal of wastewater and solid waste from distilleries. These impacts can be reduced and productivity improved by reusing the waste streams for energy or other products. Liquid stillage from distillation columns is a good source of feed for biogas digesters. Solid residue from starch ethanol is a good stock feed, and solid residue from cellulosic ethanol (lignin) can be burned to provide heat for the conversion process. Alternatively, solid residues can be fed to a biogas digester, composted aerobically or applied directly to soils.
Appendix B: Further information

Biofuels

Websites
Australian Renewable Energy Agency arena.gov.au/
Bioenergy Australia bioenergyaustralia.org/
Biomass Producer – Bioenergy information for Australia’s primary industries biomassproducer.com.au/
Renewable Energy Target cleanenergyregulator.gov.au/RET/

Reports and presentations


Carbon farming

Websites


DAFWA – Carbon Farming agric.wa.gov.au/climate-land-water/carbon-farming


Reports and presentations


## Appendix C: Licensed power stations in the Pilbara

**Table C1 North West Interconnected System**

<table>
<thead>
<tr>
<th>Power station</th>
<th>Owner</th>
<th>Fuel</th>
<th>2014 rated capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karratha TM2500</td>
<td>Horizon Power</td>
<td>diesel</td>
<td>20</td>
</tr>
<tr>
<td>Boodarie</td>
<td>Alinta Energy</td>
<td>gas</td>
<td>82</td>
</tr>
<tr>
<td>Karratha Power Station</td>
<td>Horizon Power</td>
<td>gas</td>
<td>86</td>
</tr>
<tr>
<td>Pilbara Temporary Generation</td>
<td>APR</td>
<td>gas</td>
<td>60</td>
</tr>
<tr>
<td>Port Hedland Power Station</td>
<td>Alinta Energy</td>
<td>gas</td>
<td>126</td>
</tr>
<tr>
<td>Yurralyi Maya (7 Mile)</td>
<td>Rio Tinto</td>
<td>gas</td>
<td>180</td>
</tr>
</tbody>
</table>

**Table C2 Non-interconnected systems (off-grid)**

<table>
<thead>
<tr>
<th>Power station</th>
<th>Owner</th>
<th>Fuel</th>
<th>2014 rated capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christmas Creek Iron Ore Mine</td>
<td>Contract Power Holdings</td>
<td>diesel</td>
<td>56</td>
</tr>
<tr>
<td>Cloudbreak Mine</td>
<td>Contract Power Holdings</td>
<td>diesel</td>
<td>44</td>
</tr>
<tr>
<td>Cloudbreak Mine (emergency backup units)</td>
<td>Contract Power Holdings</td>
<td>diesel</td>
<td>2</td>
</tr>
<tr>
<td>Onslow Temporary Generation</td>
<td>Horizon Power</td>
<td>diesel</td>
<td>3</td>
</tr>
<tr>
<td>Roy Hill Port Temporary Generation</td>
<td>Alinta Energy Transmission (Roy Hill) Pty Ltd</td>
<td>diesel</td>
<td>35</td>
</tr>
<tr>
<td>CITIC Pacific Mining</td>
<td>CITIC Pacific Mining</td>
<td>gas</td>
<td>450</td>
</tr>
<tr>
<td>Gorgon</td>
<td>Chevron Australia Pty Ltd</td>
<td>gas</td>
<td>584</td>
</tr>
<tr>
<td>Hamersley Iron Dampier</td>
<td>Rio Tinto</td>
<td>gas</td>
<td>120</td>
</tr>
<tr>
<td>Karratha Gas Plant (Burrup Peninsula)</td>
<td>Woodside</td>
<td>gas</td>
<td>240</td>
</tr>
<tr>
<td>Newman, BHP Billiton (Iron Ore Mine)</td>
<td>Alinta Energy</td>
<td>gas</td>
<td>140</td>
</tr>
<tr>
<td>Old Onslow Power Station</td>
<td>Onslow Electric Power</td>
<td>gas</td>
<td>3.6</td>
</tr>
<tr>
<td>Paraburdoo</td>
<td>Rio Tinto</td>
<td>gas</td>
<td>140</td>
</tr>
<tr>
<td>Pluto Phase 1 (Burrup Peninsula)</td>
<td>Woodside</td>
<td>gas</td>
<td>160</td>
</tr>
<tr>
<td>Power station</td>
<td>Owner</td>
<td>Fuel</td>
<td>2014 rated capacity (MW)</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>West Angelas</td>
<td>Rio Tinto</td>
<td>gas</td>
<td>40</td>
</tr>
<tr>
<td>Yarnima</td>
<td>BHP Billiton Iron Ore Pty Ltd</td>
<td>gas</td>
<td>190</td>
</tr>
<tr>
<td>Solomon Hub Power</td>
<td>Fortescue Metals Group Ltd</td>
<td>Gas, diesel</td>
<td>125</td>
</tr>
<tr>
<td>Telfer Gold Mine</td>
<td>Newcrest Mining</td>
<td>Gas, diesel</td>
<td>161</td>
</tr>
<tr>
<td>Wodgina</td>
<td>Energy Developments Remote Energy</td>
<td>Gas, diesel</td>
<td>13.7</td>
</tr>
<tr>
<td>Marble Bar</td>
<td>Horizon Power</td>
<td>solar-photovoltaic, diesel</td>
<td>1.31</td>
</tr>
<tr>
<td>Nullagine</td>
<td>Horizon Power</td>
<td>solar-photovoltaic, diesel</td>
<td>1.16</td>
</tr>
</tbody>
</table>
Appendix D: How Australia accounts for greenhouse gas emissions

Agriculture was responsible for about 16% (85 CO₂-eMt) of Australia’s greenhouse gas emissions in 2013, with enteric fermentation in ruminant livestock contributing 66% (56 CO₂-eMt) of the sector’s emissions (Table D1). The next largest source of emissions was agricultural soils (15.5%), followed by prescribed burning of savannas (10.8%), manure management (3.9%) and liming and urea application (2.4%) with rice cultivation and field burning of agricultural residues contributing the remainder. Livestock and its manure were the dominant source of methane, accounting for 52% of total national emissions. Agricultural soils were the dominant source of nitrous oxide, accounting for 62% of total national emissions (Department of the Environment 2015a, 2015b).

Table D1 Greenhouse gas emissions (carbon dioxide CO₂, methane CH₄ and nitrous oxide N₂O) from Australian agriculture in 2013, expressed as megatonnes of carbon dioxide equivalent (CO₂-eMt)

<table>
<thead>
<tr>
<th>Greenhouse gas source</th>
<th>CO₂ (CO₂-eMt)</th>
<th>CH₄ (CO₂-eMt)</th>
<th>N₂O (CO₂-eMt)</th>
<th>Total (CO₂-eMt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2.04</td>
<td>66.46</td>
<td>16.53</td>
<td>85.02</td>
</tr>
<tr>
<td>Enteric fermentation</td>
<td>na</td>
<td>56.38</td>
<td>na</td>
<td>56.38</td>
</tr>
<tr>
<td>Manure management</td>
<td>na</td>
<td>2.42</td>
<td>0.89</td>
<td>3.31</td>
</tr>
<tr>
<td>Rice cultivation</td>
<td>na</td>
<td>0.56</td>
<td>na</td>
<td>0.56</td>
</tr>
<tr>
<td>Agricultural soils</td>
<td>na</td>
<td>na</td>
<td>13.16</td>
<td>13.16</td>
</tr>
<tr>
<td>Prescribed burning of savanna</td>
<td>na</td>
<td>6.87</td>
<td>2.33</td>
<td>9.20</td>
</tr>
<tr>
<td>Field burning of agricultural residues</td>
<td>na</td>
<td>0.24</td>
<td>0.15</td>
<td>0.39</td>
</tr>
<tr>
<td>Liming</td>
<td>0.76</td>
<td>na</td>
<td>na</td>
<td>0.76</td>
</tr>
<tr>
<td>Urea application</td>
<td>1.28</td>
<td>na</td>
<td>na</td>
<td>1.28</td>
</tr>
</tbody>
</table>

na not assessed
Source: Department of the Environment 2015a, 2015b

Because each greenhouse gas has a unique residence time in the atmosphere and unique heat-trapping potential, the global warming potential is used to express the ability of each greenhouse gas to trap heat in the atmosphere relative to carbon dioxide over a specified period. The Intergovernmental Panel on Climate Change’s convention is to express the global warming potential of greenhouse gases in terms of how much carbon dioxide would be required to produce a similar warming effect over 100 years. This expression is termed the carbon dioxide equivalent value (CO₂-e) (Solomon et al. 2007).

The global warming potential of methane and nitrous oxide is 25 and 298 times that of carbon dioxide respectively, so 1t of methane is equivalent to 298t of carbon dioxide (Department of the Environment 2015a). Based on the molecular weight of
carbon dioxide, the sequestration of 1t of carbon is equivalent to 3.67t of carbon dioxide (Department of Climate Change and Energy Efficiency 2012).

Under current accounting rules, emissions generated during the manufacture and transport of agricultural inputs, such as fertilisers, herbicides, pesticides and agricultural machinery, are not counted as agricultural emissions. Emissions from the fuel used by agricultural vehicles on-farm and for transporting produce, and the fuel used to generate electricity consumed on-farm are also excluded.
Appendix E: Carbon farming activities that do not have methodology determinations applicable to the Pilbara

Reducing methane emissions from livestock – animal breeding

There are variations between animals in methane emissions per unit of feed intake and these variations suggest that there may be heritable differences of 10–20% in methane production (Clark et al. 2005, Eckard et al. 2010, Hegarty et al. 2007, Pinares-Patiño et al. 2003, Waghorn et al. 2006).

While breeding for reduced methane emissions may not be compatible with other breeding objectives, breeding for improved feed conversion efficiency (lower net feed intake) should be compatible and is likely to reduce both methane emissions and the greenhouse gas intensity of animal products.

Savanna fire management

The approved methods for savanna fire management apply to areas of northern Australia receiving more than 600mm of average annual rainfall, so they cannot be used in the Pilbara. Several savanna fire management projects are registered in the Kimberley.

Developing a savanna fire management method for regions receiving less than 600mm rainfall may benefit pastoral managers who are contemplating or engaged in activities to mitigate the damage that extensive wildfires can do to stock feed and infrastructure (Legge et al. 2011). Only the nitrous oxide and methane emitted during fire events are accounted for, because it is assumed that the carbon dioxide emitted during the fire is subsequently removed from the atmosphere by regrowing vegetation.

Strategic fire management, as required under the savanna fire management method, uses planned mosaic fire reduction burns in the early dry season to reduce the incidence and extent of late dry-season fires. The West Arnhem Land Fire Abatement project showed that early dry-season fires are more patchy, leaving 29% unburnt, compared to 11% in late dry-season fires (Russell-Smith et al. 2009, Price et al. 2003, Whitehead 1995). Early dry-season fires also burn at a lower intensity, typically emitting 52% less methane and nitrous oxide than late dry-season fires (Williams et al. 2003, Russell-Smith & Edwards 2006, Russell-Smith et al. 2009).

Fertiliser management

The Carbon Credits (Carbon Farming Initiative—Reducing Greenhouse Gas Emissions from Fertiliser in Irrigated Cotton) Methodology Determination 2015 supports various activities to improve the efficiency (reduce the emissions intensity) of nitrogen fertiliser use in irrigated cotton.

This determination cannot be used immediately in the Pilbara because cotton has to have been grown on the project area for at least three of the previous six years to determine the baseline emissions intensity.

It is likely that any new irrigated cotton enterprise in the Pilbara would be established with best practice fertiliser management, making any subsequent improvements purely to generate ACCUs unlikely.
Nitrous oxide emissions from the soil result from biological and chemical processes that use inorganic nitrogen compounds (ammonium, nitrite and nitrate). Emissions of nitrite from farming systems involve the loss of nitrogen, a valuable nutrient resource. Taking action to reduce this loss has the potential to reduce greenhouse gas emissions and fertiliser costs and may increase agricultural productivity (Grains Research and Development Corporation 2012a, 2012b).

**Soil organic carbon**

Soil organic carbon plays a critical role in the productive capacity of soils, so maintaining or increasing soil organic carbon for this reason alone makes environmental and economic sense (Hoyle et al. 2011). While many factors interact to influence the amount of organic carbon in the soil, the two overriding natural determinants of the potential amount of soil organic carbon are clay content and climate (rainfall and temperature) (Carson 2012). Clay can act to protect soil organic carbon from decomposition, so soils with naturally high clay contents are capable of holding more soil organic carbon than sandy soils. Rainfall and temperature influence the amount of plant biomass produced (i.e. the potential input of new organic matter) and the rate at which the soil organic carbon decomposes. Where there is sufficient soil water, higher temperatures increase the rate of breakdown.

Within the range of potential soil organic carbon concentrations set by soil type and climate, land use and land management practices have a significant role in determining the actual soil organic carbon concentration at a particular site.

A potential area of development for land managers with plans for irrigation enterprises in the Pilbara is to expand the application area of the Carbon Credits (Carbon Farming Initiative—Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination 2015. This method sets out how to estimate abatement by sustainable intensification that involves new irrigation plus nutrient and/or soil acidity management on land previously used for grazing or dryland cropping. The Pilbara is currently outside the eligible area for this method and the sequestration value of sustainable intensification has not been modelled.

**Rangelands restoration**

Rangelands occupy 87% of WA’s land area, with 40% of this area covered by pastoral leases for grazing livestock on native vegetation. Some people view carbon farming revegetation activities on rangelands as a way to improve the financial and ecological sustainability of pastoral enterprises. Carbon sequestration could be achieved through reducing grazing pressure, increasing vegetation cover and improving the long-term productivity of the land. For pastoralists, the opportunity cost of changing land use is low and although the sequestration potential is also relatively low on a per hectare basis, the geographical extent of the rangelands means it has the potential to sequester large amounts of carbon. The Department of the Environment and Energy has not identified rangelands restoration as a priority for method development.
## Shortened forms

<table>
<thead>
<tr>
<th>Short form</th>
<th>Long form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCU</td>
<td>Australian carbon credit unit</td>
</tr>
<tr>
<td>ARENA</td>
<td>Australian Renewable Energy Agency</td>
</tr>
<tr>
<td>CH₄</td>
<td>methane</td>
</tr>
<tr>
<td>CEFC</td>
<td>Clean Energy Finance Corporation</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>CO₂-e</td>
<td>carbon dioxide equivalent value</td>
</tr>
<tr>
<td>ERF</td>
<td>Emissions Reduction Fund</td>
</tr>
<tr>
<td>GJ</td>
<td>gigajoule ((J \times 10^9))</td>
</tr>
<tr>
<td>ha</td>
<td>hectare ((10 000;\text{square metres}))</td>
</tr>
<tr>
<td>kV</td>
<td>kilovolt ((V \times 10^3))</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>LGC</td>
<td>Large-scale Generation Certificate</td>
</tr>
<tr>
<td>LRET</td>
<td>Large-scale Renewable Energy Target</td>
</tr>
<tr>
<td>L/t DM</td>
<td>litres per tonne of dry matter</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
</tr>
<tr>
<td>m³/t DM</td>
<td>cubic metres of gas produced per tonne of dry matter</td>
</tr>
<tr>
<td>ML/y</td>
<td>megalitres per year ((L \times 10^6;\text{per year}))</td>
</tr>
<tr>
<td>Mt</td>
<td>megatonne ((t \times 10^6))</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt ((W \times 10^6))</td>
</tr>
<tr>
<td>N</td>
<td>nitrogen</td>
</tr>
<tr>
<td>N₂O</td>
<td>nitrous oxide</td>
</tr>
<tr>
<td>NO₂</td>
<td>nitrite</td>
</tr>
<tr>
<td>NO₃</td>
<td>nitrate</td>
</tr>
<tr>
<td>t</td>
<td>tonne</td>
</tr>
<tr>
<td>t/ha</td>
<td>tonnes per hectare</td>
</tr>
<tr>
<td>tCO₂-e</td>
<td>tonnes of carbon dioxide equivalent value</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
</tr>
</tbody>
</table>
References


