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Perdaman Chemicals & Fertilisers

**Collie Urea Project
Greenhouse Gas Assessment
and Management Plan**

30 July 2009



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1. Introduction

1.1 Overview

Perdaman Chemicals and Fertilisers (PCF), a wholly owned subsidiary of Perdaman Industries (Perdaman), propose to construct a plant in the Shotts Industrial Park (SIP) to convert sub bituminous coal to urea fertiliser. SIP is located about 7.5 km east of Collie and has a total area of about 250 hectares (ha). The Coal to Urea Plant footprint covers an area of approximately 137 ha. The urea will be transported by rail to the Bunbury Port where it will be exported, from Berth Five, to India. Coal will be supplied by Griffin Coal. The Plant is expected to produce approximately 2 million tonnes per annum (Mtpa) of urea.

1.2 Scope of Work

GHD Pty Ltd (GHD) was commissioned by PCF to complete environmental approvals for the Coal to Urea Project. As part of this commission, GHD was required to prepare a greenhouse gas (GHG) assessment, addressing the items outlined in the WA EPA's Guidance Statement No. 12 "Guidance Statement for Minimising Greenhouse Gas Emissions" (October 2002).

This reports scope is to address:

1. A Greenhouse gas emissions inventory, with benchmarking against industry standards;
 - What/where are the emissions of significance;
 - Where did the data come from, how was it estimated;
 - What emission reduction technology is being proposed;
 - Benchmarking and "best practice" assessment;
2. Emission reduction options/alternatives considered;
 - Measures proposed to minimise emissions;
 - Justification for selection of proposed technologies;
3. Consideration of carbon sequestration and offsets;
4. Minimising emissions over the life of the project;
5. Benefits on a national or global scale;
6. Impact Assessment;
 - Assessed impact of the proposed emissions;
 - Management options and recommendations.



2. Project Overview

2.1 Plant Concept

The Project involves conveying coal from the nearby Griffin coal mine to the Shotts Industrial Park, converting this to urea and transporting the final product by rail to the Bunbury Port for export. Some urea may also be supplied by road to the local market from truck loading facilities at the Collie plant, or alternately by rail.

This project is being developed on a commercial basis using proven process technology units and scale. The Plant will incorporate Shell's gasification and gas treatment technology, Haldor Topsoe ammonia synthesis technology and Stamicarbon Urea melt and granulation technologies.

The project consists of:

- » The proposed Urea Plant is supported by:
 - The coal preparation facility;
 - Coal Gasification plant;
 - Acid Gas Removal;
 - Ammonia plant;
 - Power Generation.
- » A coal conveyor to be located in existing Western Power owned electricity transmission corridors connecting the plant and the Griffin Coal Mine;
- » A water supply pipeline to supply water from Wellington Dam to the Plant. The pipeline will be located in existing corridors, subject to the approval of the relevant parties. In the event that PCF contracts the provision of water supply to the PCF site from third parties, these parties may assume responsibility for all approvals required to provide water to the PCF site. Water may also be obtained from the proposed DoW Upper Collie Desalination plant at mine void 5H, in which case a pump station and pipeline infrastructure to convey water to the site will be co-located with the conveyor in the power transmission line corridor
- » A rail siding will be connected to the existing rail network to facilitate loading of urea within the project site; and
- » A storage shed, railcar unloading facilities, conveyor and ship loading facilities at Bunbury Port.

Figure 1 conceptually illustrates the plant proposal.

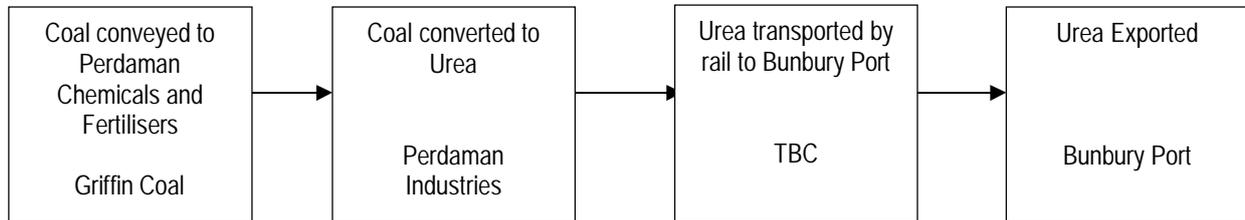


Figure 1 Conceptual overview of the proposal

2.2 Overview urea production process

The conversion of coal to urea is a seven step process (see Figure 2).

1. *Coal Preparation:* Initially the raw coal is milled and dried, making it suitable for gasification. Drying improves the thermal conversion efficiency of the coal. The enclosed coal powder is pressurized with nitrogen (from air separation) to be injected in the gasifiers.
2. *Gasification:* Gasification converts coal to (synthesis) gas at a high efficiency under pressure (i.e. closed to atmosphere) by partial oxidation of coal with oxygen, to mainly CO (carbon monoxide) and hydrogen. The coal ash melts during the gasification process and is recovered as a marketable stable glassy slag. The oxygen is obtained from an Air Separation unit which concentrates oxygen from air for efficient use in coal Gasification.
3. *Gas adjustment:* The H₂ concentration in the syngas is maximized by converting the CO with steam to H₂ and CO₂. This also hydrolyses various trace contaminants.
4. *Acid gas cleanup:* The CO₂ and sulphur components are removed from the synthesis gas. Sulphur compounds are recovered as a saleable sulphur by-product. The cleaned synthesis gas (mainly hydrogen) is blended with nitrogen from Air Separation to the correct mixture required for ammonia synthesis. A fuel gas side-stream for internal power generation will be substantially (> 95%) desulphurised, leading to very low SO₂ emissions during power generation. Over 30 per cent of the CO₂ is used during Urea synthesis. The remaining CO₂ is carbon capture ready – that is, it is in a concentrated stream (over 98% CO₂, not diluted by N₂) and could be applied to bio-or geo-sequestration options as and when these are commercially and technically approved by Government. The State Government is actively considering sequestration options within a 70 km radius of Collie and PCF has contributed funding to assist research and possible development of a geo-sequestration project.
5. *Ammonia synthesis:* The hydrogen and nitrogen mixture is compressed and reacted (with the help of a catalyst) to form ammonia. This chemical reaction releases heat which is recovered as steam which improves the overall process thermal efficiency, consequently lowering emissions.
6. *Urea Synthesis:* Ammonia and CO₂ are reacted to form urea (solution) in a two stage process which includes a carbamate intermediate. The urea solution is concentrated to over 98 per cent.
7. *Urea granulation:* The concentrated urea solution is dried and granulated, with addition of a small quantity (0.3%) of formaldehyde (as urea formaldehyde) to increase granule strength.

Urea granules are a strong, easily handled product, which minimises potential dust formation during the logistics process of taking the urea from the plant to its end use point.

8. *Storage and warehousing:* The urea granules are cooled and stored in a shed before being loaded on a rail wagon and transported to Bunbury Port. Here the urea is unloaded from the train into a second storage shed and then loaded onto bulk cargo ships for export.

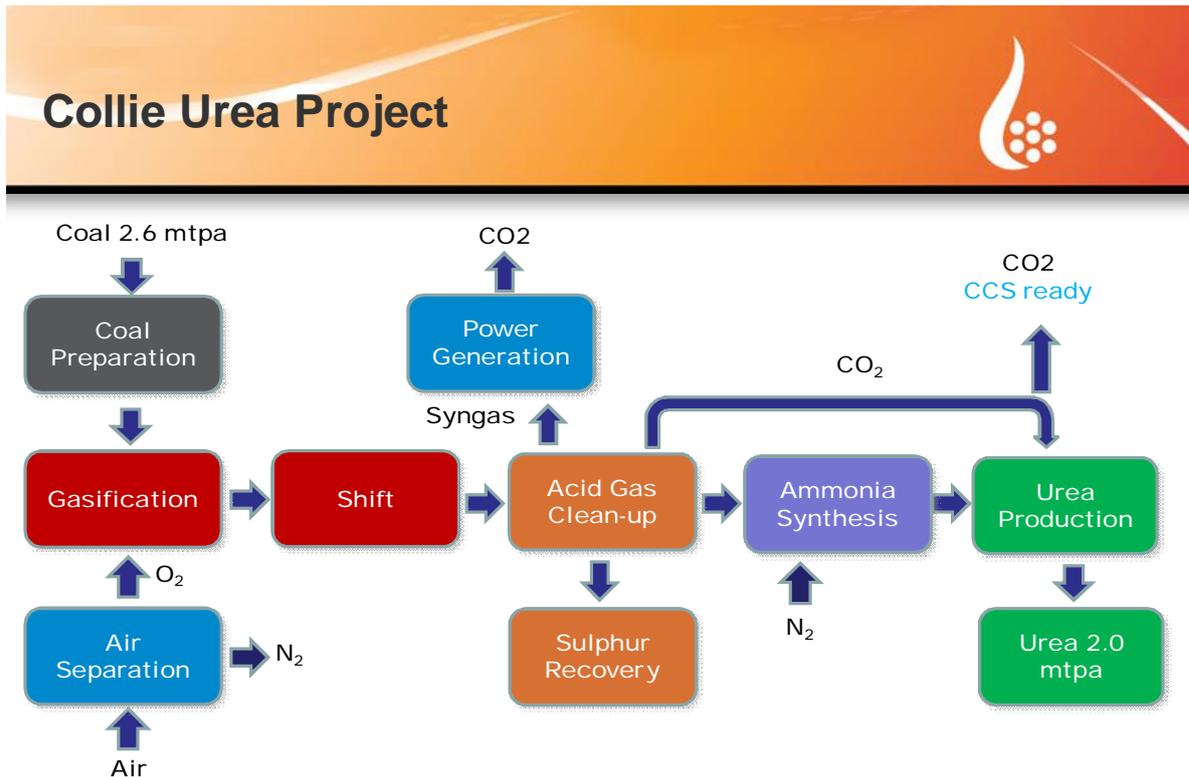


Figure 2 PCF Project Major Process Blocks



3. Greenhouse Gas Emissions Inventory

3.1 Perdaman Urea Project Emissions

3.1.1 Construction Phase

The main GHG emissions related to the construction of the plant will be generated mainly as direct emissions from the transportation of goods and materials to and from the site and operation of the heavy construction vehicles and machines on-site, and indirect emissions associated with the manufacture of the construction materials. Some small emissions will be generated during this phase from the removal of vegetation on the site, electricity from construction buildings and fuel usage in light vehicles.

It is noted that the GHG emissions from the construction of the PCF Project will be very small compared to the operational GHG emissions. Therefore, priority has been given to the study of operational emissions from the plant. The EMP will include measures to minimise the GHG emissions from the construction of the plant where possible and practical.

It is estimated that the current uncleared vegetation on the proposed PCF site holds around 62 tC/ha – including trees, debris, and soil. Approximately 50% of the 137 hectares of land proposed for the plant site is already cleared, and 15 ha of vegetation will be retained. The GHG emissions from land clearing of the site are estimated at 227 t CO₂/ha. The total CO₂ emissions from land clearing are estimated at about 12,100 t CO₂.

3.1.2 Operational Phase

A summary of the GHG emissions of the proposed PCF project provided by Perdaman is presented in Table 1. The GHG emissions estimates are based on the current concept design of the PCF project and process specific analysis, and may therefore be subject to changes as the project design progresses.

The major GHG relevant to the PCF project is carbon dioxide. In this assessment, both carbon dioxide and methane emissions have been estimated. A review of the methane emissions is covered by the Air Quality Assessment undertaken for the PCF project (GHD, 2009). Other GHG emissions, such as perfluorocarbons (CF_x), sulphur hexafluoride (SF₆), and nitrous oxide (N₂O) are estimated to be negligible emissions of these gases respectively.

The proposed PCF facilities will produce approximately 3.3 Mtpa of greenhouse gas in its operational phase, predominantly in the form of CO₂, from process gas emissions and power generation combustion emissions:

- The CO₂ from the process unit (approx 75% of total GHG emissions) is 99.5% pure CO₂ with a modest pressure and is sequester ready for either geo-sequestration or chemical sequestration when a commercial scale facility or combination of facilities is available. This is key advance of the proposed PCF project.
- The CO₂ emissions from the power plant within the facility will be from a fully integrated power and steam generation system, but these will not be sequester ready given their lower CO₂ concentration. These emissions (0.87 t/MWh) will be lower than an equivalently sized non integrated power facility.



From Table 1 it is clear that the gas clean up and power island are by far the largest emitters of carbon dioxide emissions, accounting for approx 95% of the total estimated GHG emissions. These two sources are therefore the key focus of the GHG reduction and management strategies for the PCF Project.

Table 1 Estimated Annual Greenhouse Gas Emissions – PCF Project¹

Plant Section	Estimated Greenhouse Gas Emissions (tpa)		
	CO ₂	CH ₄	Description (Source and Use of CO ₂)
Coal milling and drying	83,200 (2.5%)	<1	Emissions from burning of syngas for heating.
Gasification	50,900 (1.5%)	<1	Partial oxidation of coal. CO ₂ will end up as part of the syngas.
Gas clean up	2,468,400 (74.6%)	<18	Removal of all the CO ₂ after the shift reaction. A portion of this is used for urea synthesis. The rest is pure and carbon capture ready. The CO ₂ will be at a pressure of ca. 5 bar from Gas clean up.
Ammonia synthesis	Minimal (0%)	0	Minimal GHG emissions (carbon free), mainly heat integration.
Urea synthesis and granulations	29,900 (0.9%)	0	From CO ₂ stripping and some slippage (losses to atmosphere) in the process.
Power island	669,700 (20.2%)	<1	Desulphurised syngas is combusted. The PCF plant is an integrated facility. The coal is the process feedstock but also the source of internal power required.
Air separation	0 (0%)	0	This is outside PCF battery limit and the products are mainly nitrogen and oxygen. The air separation unit is powered by the PCF power island.
Sheds & logistics SIP & Bunbury	Minimal (0%)	0	The loading facility at the Bunbury port will be managed by PCF.
Other	6,700 (0.2%)	0	There are various operations on site and represents a fair sum total of their emissions. This gets emitted straight to atmosphere.
Total	3,308,800 (100%)	18	

¹ Source: Data provided in document "Perdaman Chemicals & Fertilisers. Emissions Estimate for Proposed Coal to Urea Plant". March 2009.



3.2 WA Emissions

The GHG emissions from WA were formally estimated in 2007 as part of the National Greenhouse Gas Inventory. The table below details the emissions by industry sector.

Table 2 Estimated Greenhouse Gas Emissions in Western Australia – 2007²

Sector	2007 GHG Emissions (Mtpa)
Energy	55.5
Industrial process	7.1
Agriculture	13.5
Land use change and forestry	-1.2
Waste	1.3
Total (net) emissions	76.3

The Department of Climate Change estimated that Western Australia emits about 76.3 Mtpa of greenhouse gas emissions in 2007. This accounts for about 12.8% of the total greenhouse gas emissions in Australia (597.2 Mtpa in 2007). Overall, Australia emits about 1% of the total global greenhouse gas emissions (Western Australian Taskforce 2004).

As outlined in previous section, it is estimated that the PCF plant will emit about 3.3 Mtpa of GHG emissions. This represents about 4.3% of the total GHG emissions in WA in 2007. It is noted that a significant proportion of this amount (75%) will be 99.5% pure CO₂ and therefore sequester ready.

² Source: Department of Climate Change, 2007, Australian National Greenhouse Accounts – State & Territory Greenhouse Gas Inventories 2007.



4. Benchmarking

4.1 Introduction

This section on benchmarking has two main objectives. The first is to place the GHG emissions from PCF in perspective with other Collie coal users in the region. The second objective is to provide a comparison against other ammonia and urea facilities worldwide to illustrate that the PCF plant applies best-practice technologies to minimise its GHG emissions and maximise its energy efficiency.

Urea plants require ammonia and carbon dioxide as raw materials. The urea process is independent of the technology used to produce ammonia. Thus the benchmarking treats PCF's ammonia and urea facility as two separate entities, the first producing ammonia and the second producing urea. This ensures that the comparison is relevant and realistic.

4.2 PCF Compared to Other Collie Coal Users

Shott's Industrial Park (SIP) has been designated as an industrial area. PCF's facilities at SIP would be in close proximity to other large coal users. The primary use of coal by the other Collie coal users is to provide power as electricity to the grid, or for their own operations as well as process steam (Worsley Alumina).

The main users of coal in the Collie region are:

- The Muja Power Station;
- Collie Power;
- Bluewaters (I&I);
- Worsley Alumina (internal use);
- PCF (new user).

The coal consumption and estimated CO₂ emissions from the industries listed above are presented in Table 3. The PCF plant would account for an estimated 19.3% of the total CO₂ emissions from these major Collie coal users. Compared to the other Collie users, the PCF plant has the lowest CO₂ emissions relative to its coal consumption (1.3 t CO₂/t coal). For example, the PCF plant will use about the same amount of coal as Muja CD, but the PCF plant will have a lower emission of carbon dioxide.

Furthermore, PCF generates and utilises its own power and does not impose any significant requirement on the grid. The coal provides the energy for synthesis but also the plant energy requirements. PCF requires about 610 MW-e of power from coal energy. This is similar to the energy required by Worsley Alumina (~650 MW-e).

About 75% of the CO₂ produced by the PCF plant is almost pure carbon dioxide (>99.5%). It is noted that urea synthesis requires this purity of CO₂ as feedstock. Thus the CO₂ that is finally released from the acid gas recovery is Carbon Capture Ready (sequester ready), because it does not require further processing to extract the CO₂ from other gases in the stream. It can be compressed and piped to a suitable geo-sequestration site should one become available. Alternatively, again because of its purity it can be used for chemical sequestration in conjunction with one or more of the surrounding alumina refineries. In the case of traditional coal fired power stations, the CO₂ is emitted with the flue gases.



These flue gases have a much lower CO₂ concentration (5-6%), making them less attractive and higher cost for carbon capture and storage. It is important to note this distinction as it means that 75% of the CO₂ released from the PCF Plant can be easily removed when appropriate sink sources become available and economically viable.

Department of Industry and Resources and the Coal Futures Group recently commissioned a study on geo-sequestration. The report identified and prioritised potential CO₂ geological storage opportunities in the Collie Basin and in the onshore region of SW Western Australia. The study identified potential environmentally sustainable sites for CO₂ injection within a 50 km radius of Collie (Varma, 2007). Thus PCF is well positioned to take advantage of geo-sequestration should it go ahead in Western Australia.

Table 3 Benchmarking of PCF Plant against Other Collie Coal Users

Facility	Power Generation ^a	Coal Consumption ^b		CO ₂ Emissions ^c		CO ₂ Emissions Relative to Coal Consumption t CO ₂ /t coal
		tpa	%	tpa	%	
Muja AB	4*60 MW	1,000,000	10.8	2,499,000	14.4	2.5
Muja CD	2*200 MW 2*227 MW	2,590,000	27.8	5,557,000	32.0	2.1
Collie	300 MW	910,000	9.8	2,387,000	13.8	2.6
Bluewaters (I & II)	2*200 MW	1,400,000	15.1	2,600,000	15.0	1.9
Worsley	650 MW-e ^d	800,000	8.6	1,203,000	6.9	1.5
PCF Plant	610 MW-e ^e	2,600,000	28	3,356,000	19.3	1.3

- a) Power generation equivalent by Worsley and PCF plant as used for internal use, and not for external supply.
- b) Source: Information sourced from the Sleeman Consulting Report on Energy for Minerals Development in the South West Coast Region of WA (total coal consumption). Information then extracted for individual facilities. PCF consumption has been provided by PCF.
- c) Source: Carbon Monitoring for Action, Centre for Global Development, www.carma.org.
- d) Note 50% Coal and 50% Natural Gas.
- e) This is the total power equivalent generated by PCF for internal use.
- f) Comment Bluewaters coal is too low for power output – PER indicates operating rate is ~78% for coal used - Bluewaters CO₂ should be similar to Muja CD (it is the same efficiency power plant).

In support of the data provided above, CSIRO (<http://www.csiro.au/science/coal-gasification.html#1>) states that coal gasification is cleaner than coal combustion for power generation. Integrated gasification combined cycle produces lower emissions, high efficiencies and the potential to capture carbon dioxide as a relatively pure stream (carbon capture ready). This is consistent with the PCF's technology pathway.



4.3 PCF Ammonia Production

4.3.1 International

Ammonia is produced by the synthesis of nitrogen and hydrogen. Nitrogen is readily available from the air whereas hydrogen must be generated. Hydrogen for ammonia synthesis is normally produced from naphtha reforming, steam reforming of natural gas, gasification (partial oxidation) of heavy oil and gasification of coal. In the PCF process, ammonia is then reacted with CO₂ to produce urea, which effectively sequesters CO₂.

The most common method of producing hydrogen, and then subsequently ammonia, is by the steam reforming of natural gas. An exhaustive literature review reflects this bias. Notwithstanding the significant number of coal to ammonia plants worldwide (30% of capacity) there is not much information, due to perhaps the less rigorous requirement for GHG reporting in those countries where coal to ammonia technology has been employed. The literature search revealed a single paper that comments on “Energy efficiency improvements in ammonia production – perspectives and uncertainties” (Rafiqul et al. 2005).

The Dakota Gasification Company (USA) produces between 1,000 to 1,200 tonnes/day of ammonia from lignite coal. For this ammonia production they export about 150 million standard cubic feet of CO₂ a day for oil recovery which is about 50% of the total CO₂ produced. Ammonia is one of their products and it appears that they use about 18% of their synthesis gas for ammonia synthesis and the rest is exported via a pipeline. A clear breakdown is not available to provide a specific tonne CO₂/tonne ammonia produced, but it is fair to infer that the capture of 50% of the carbon dioxide brings the emission factor closer to that of natural gas.

Table 4 provides a comparison of the emissions in the context of industry practice for ammonia production since 1990. Rafiqul et al. (2005) state that with a theoretical Best Available Technology energy consumption level of 28 GJ/t (LHV), the GHG emissions could reduce to 1.56 t CO₂ / t ammonia. This is the IPCC recommended standard, which is based on steam reforming of natural gas. As can be seen in Table 4 this is not easy to achieve despite the best intentions. This is due to different technology approaches, CO₂ containing natural gas and local site conditions that require higher cost utilities such as sea water.

It is noted that some 40-45% of ammonia plants do not produce urea.



Table 4 Benchmarking of PCF Ammonia Production - International

Fuel Used	Technology	Period	Country / Region	GJ / t ammonia	t CO ₂ / t ammonia
Natural gas ^a	Steam reforming	'94-'96	US	41.3	2.3
		'94-'96	EU	34.9	1.9
		'94-'95	India	38.7	2.2
Heavy fuel oil ^a	Partial oxidation	'94-'95	India	59.8	4.7
Coal (est.) ^b	Gasification	1995+	China		3.8-4.0
Coal ^a	Partial oxidation	'94-'95	India	165.9	16.7
Coal (PCF Plant)	Gasification (no urea credit)	2013	Australia	34	3.6
	(With urea credit)				(2.31)

a) Source: Rafiqul, I, Weber, C., Lehmann, B., Voss, A., (2005), "Energy", 30, pp 2487-2504.

b) Estimate based on scale, insight to layout and equipment efficiency.

PCF reports a total emission of 2.67 Mtpa of CO₂ excluding 635,000 tpa ascribed to the production (steam and power) for urea and a further 1.5 Mtpa consumed in urea synthesis. It is reiterated here that all the carbon dioxide post acid gas recovery (2.5 Mtpa) is pure carbon dioxide and is carbon capture ready. Assigning the CO₂ from coal preparation, gasification and power generation to the ammonia unit of the facility implies a value of 3.6 t CO₂/ t ammonia. This value for PCF plant is more than 4.5 times better than that reported for old coal to ammonia production in India (16.7 t CO₂ / t ammonia, see Table 4). Furthermore PCF compares favourably with ammonia production from heavy fuel oil.

Taking into account that the data in table above is somewhat outdated it is clear that the estimated performance by PCF is better than benchmark. This performance cannot be assigned to a specific factor, however it is not unreasonable to assume that this improvement would be due to:

- Efficient modern slagging coal gasification process;
- Combined cycle power generation;
- No electricity import;
- Waste heat integration such as using a syngas cooler layout. The hot syngas is cooled with recycled syngas and cooled further through the generation of steam;
- Improved manufacturing processes (tighter tolerances);
- Scale of units (largest commercially obtainable).

The figure below shows the global average for tCO₂/t ammonia, based on the current fleet of ammonia plants.

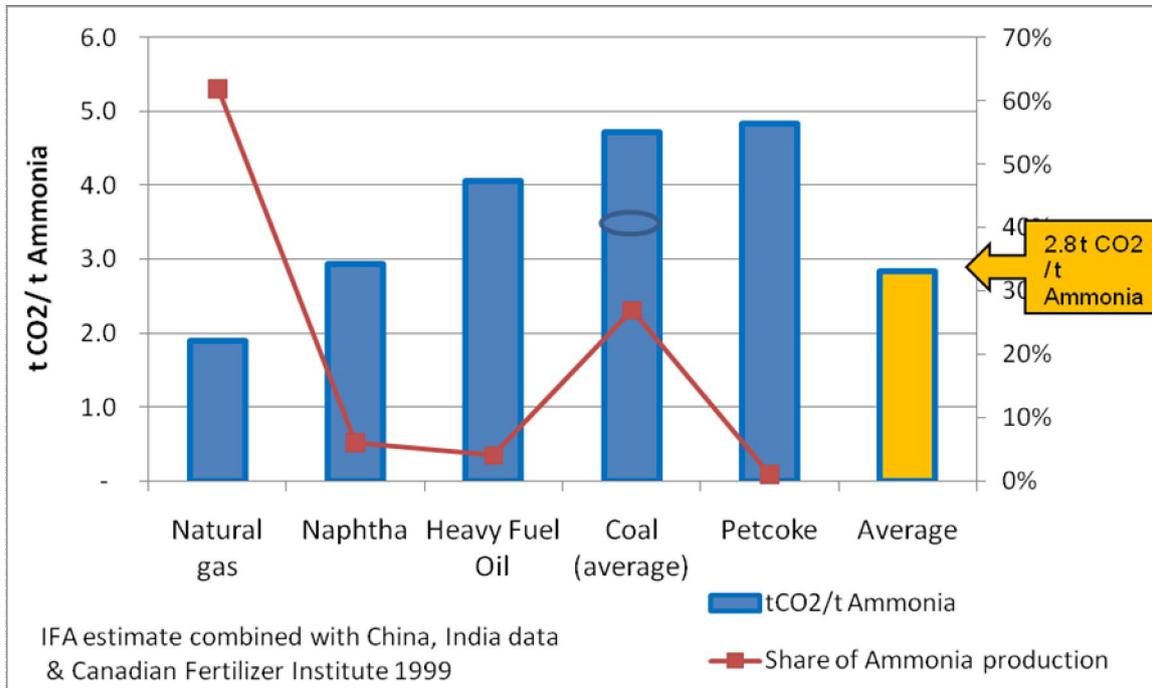


Figure 3 Global Average for tCO₂/t ammonia, based on Current Fleet of Ammonia Plants³

4.3.2 Western Australia

Table 5 provides data on energy consumption and CO₂ emissions of various ammonia plants in Western Australia, utilising the more widespread route to ammonia, steam reforming of natural gas. While not directly comparable to ammonia production from coal, the data are presented here to provide a perspective should natural gas have been chosen as the feedstock. The table illustrates that coal to ammonia production with urea as product choice by the PCF plant is competitive with ammonia production from natural gas. Furthermore, the table reflects that PCF has adopted best practice to achieve a high efficiency for the coal to urea plant while ensuring that a significant percentage of their carbon dioxide is of a purity that makes it capture ready.

³ Figure is compiled based on the following sources: International Fertilisers Association (2008). *Fertilizers and Climate Change – May (Feedstock for Ammonia Allocation)*; Canadian Fertilizer Institute (1999). *Fertilizer Production Capacity Data Canada*. www.cfi.ca; Nand, S., Goswami, M. (2005). *Energy Efficiency Gains in Indian Ammonia Plants*; Wuhuan Engineering Co. <http://www.cwcec.com/english/index.html>. China; Indian Fertilizer.Com. <http://www.indianfertilizer.com>; Indian Petro.com. <http://www.indianpetro.com>.



Table 5 Benchmarking of PCF Ammonia Production – Western Australia⁴

Project	Date	NH ₃ Prodn (tpa)	CO ₂ Emission (tpa)	Energy Cons. (GJ/t NH ₃)	Greenhouse Intensity (t CO ₂ / t NH ₃)			
					CO ₂ Stripping	Combust Gases	Export	Overall
CSBP Old Plant	1967	70,000	-	50	-	-	-	2.9
CSBP Kwinana Expansion	1997	225,000	400,000	33-35	1.27	0.51	0.0	1.8
Plenty River (excludes urea credit)	1998	620,000	1,367,500	35.5	1.27	0.93	0.0	2.2
Burrup Ammonia	2005	770,000	1,411,000	29.7	1.35	0.5	0.04	1.81
BAT KBR	2000			29.3	-	-	-	1.65 – 1.8
BAT EFMA ^a	2000	-	-	29.3 – 31.1	-	-	-	1.65 – 1.8
- CR				28.8 – 30.4				
- EAR								
PCF Plant ^b	2013	1,158,000	3,309,000	34 ^c	-	-	-	2.31 ^d

a) *BAT = Best Available Techniques; EFMA = European Fertilizers Manufacturers Association; CR = Conventional Reforming, EAR = Excess Air Reforming.*

b) *CO₂ required for urea production has been credited.*

c) *A specific number for energy per tonne of ammonia is estimated by PCF deducting urea CO₂ compression required and other urea energy inputs.*

d) *For greenhouse intensity the power plant emissions are included in the ammonia values.*

⁴ Source: SKM (2001). Public Environmental Review for Proposed 2,200 tpd Ammonia Plant, Burrup Peninsula, Western Australia (except for PCF plant data provided in last row).



4.4 PCF Urea Production

4.4.1 Urea Synthesis

The manufacture of urea from ammonia consumes carbon dioxide and in terms of reporting direct carbon dioxide emissions is considered a sink at the production facility. This is what has made some authors not consider the carbon capture aspect of urea. However, the Intergovernmental Panel on Climate Change (IPCC) in 1996 suggested that full lifecycle approach must be considered. Urea releases carbon dioxide as it is used by crops. On the other hand however, the use of urea for crop fertilisation contributes to the carbon adsorption in the form of a multiplier of biomass accumulation. This argument is discussed in Section 7.

The work of Kongshaug (1998) (later modified by Jenssen (2003)) is considered a cited reference by a number of other studies including the more recent work by Wood and Cowie (2004). Wood and Cowie reviewed GHG emission factors for fertiliser production for IEA Bioenergy, R&D Division, State Forests of NSW.

Owing to the fact that the synthesis of urea consumes carbon dioxide, Kongshaug (1998) and Jenssen (2003) have reported a negative CO₂ emission for urea synthesis. In their benchmark paper they have reported that urea synthesis consumed 0.75 tonne of CO₂ per tonne of urea produced. Stamicarbon (<http://www.stamicarbon.com>) the world leader in urea synthesis (60% of world plants are based on Stamicarbon technology) reports 0.73 tonne of CO₂ consumption per tonne of urea. The difference between the two figures is 0.02 tonne of CO₂ per tonne of urea and this is the amount that is lost or emitted (this is also known as slippage). The value reported by PCF is 30,000 tonnes of losses per annum and falls within the calculated loss of CO₂ per tonne of urea. This excludes CO₂ imparted from energy consumption in urea.

4.4.2 Urea Plant

Urea plants are always found in conjunction with ammonia facility and take advantage of the excess heat from the ammonia process as well as the carbon dioxide that is produced by the ammonia facility. All literature thus only reports the CO₂ emissions for ammonia facilities and not urea facilities.

The European Fertilizer Manufacturers' Association (EFMA 2000) has specifically discussed Production of Urea and Urea Ammonium Nitrate. They have presented a block diagram of emission sources and typical quantities for existing urea plants (Figure 4). From this figure, it is seen that there is no major CO₂ emission from a urea plant by itself. Urea plants are always found in conjunction with an ammonia facility and take advantage of the net energy supply from the ammonia process as well as the carbon dioxide that is produced by the ammonia facility. All literature thus only reports the carbon dioxide emissions for ammonia facilities and not urea facilities.

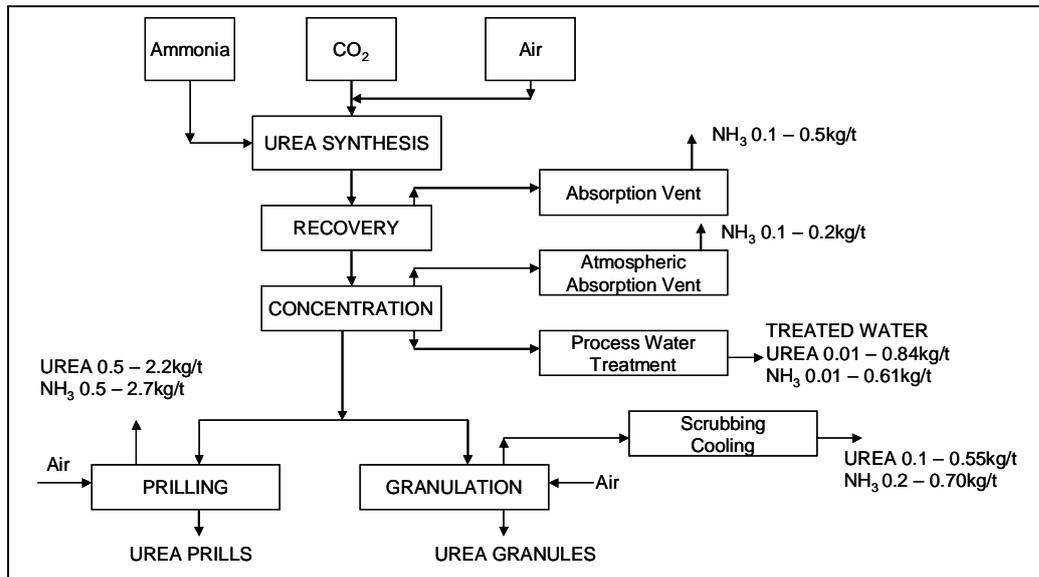


Figure 4 Block Diagram of Emission Sources and Typical Quantities for Existing Urea Plants⁵

For this benchmarking exercise, reference is made to the Canadian Fertilizer industry benchmarking study (<http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/ammonia/results.cfm?attr=24>) and Canadian Fertilizer Institute (1999). Canada has been chosen as it is an OECD country with a high level of environmental awareness. Their benchmarking report presents values of 1.68, 1.98 and 1.66 t CO₂/t ammonia for average, high and low emission values. The benchmarking study reports a recovery of CO₂ from conversion to urea is 0.61, 1.11 and 0.30 t CO₂/t ammonia respectively. This recovery value is what is used for urea production.

Using the Canadian Fertilizer Institute data for total urea and ammonia production and benchmarking data for CO₂/tonnes of ammonia, the average CO₂ emission for urea production from natural gas is 1.39 t CO₂/t Urea (2.18 and 0.713 for the high and low emission cases respectively). These calculations assume an envelope around the facility, the input being natural gas and the output being urea. This is a high level and indicative calculation.

PCF has a value of about 1.62 tonnes of CO₂ per tonne of urea produced (3.308 Mtpa of CO₂ emissions to produce 2.046 Mtpa of urea). This should be seen in the light of PCF utilising a low grade resource (sub bituminous coal) to generate its own power via an efficient process which frees up natural gas that can more efficiently displace traditional coal-fired power generation (52% combined cycle vs 35% for Collie pulverised coal boiler power). As Table 5 shows the PCF coal based ammonia plant uses a comparable energy per tonne to the existing WA ammonia plants - ie. there is minimal thermal advantage for using gas. The emissions could be further reduced should carbon sequestration facilities become available and feasible.

⁵ Source: European Fertilizer Manufacturers' Association (2000). *Best Available Techniques for Pollution Prevention and Control in the European Fertilizer Industry, Booklet 5 of 8 – Production of Urea and Urea Ammonium Nitrate*, pp 20, Belgium.



4.4.3 Conclusions from Benchmarking

The main conclusions from the benchmarking of the PCF plant are:

- The proposed PCF plant generates considerably less CO₂ (-40%) per tonne of coal used compared to burning coal for power generation.
- Coal to ammonia production (with urea) is competitive with ammonia production from natural gas;
- The PCF plant produces almost pure CO₂ (>99.5%) which is Carbon Capture Ready. In addition this CO₂ is also at a modest pressure simplifying downstream compression for gas transport, as well as a lower compression cost. In the case of traditional coal fired power stations, the CO₂ is emitted with the flue gases. These flue gases have a much lower CO₂ concentration, making them less attractive for carbon capture and storage. This positive distinction should be recognised;
- The coal gasification technologies proposed by PCF to produce ammonia from coal and its subsequent conversion to urea represent best practice in terms of minimising GHG emissions.
- Given the points above, the argument is made that natural gas should be regarded as the preferred source for power generation, while coal should be regarded as the preferred source for urea production through an energy efficient and greenhouse gas reducing coal gasification technology (rather using natural gas);



5. Measures to Minimise Greenhouse Gas Emissions

5.1 Carbon Reduction and Offset Strategy

As discussed in GHG Inventory section, the major contribution to the carbon footprint of the proposed PCF project will be from the operation of the plant, and predominantly from the gas clean up process and power island.

Perdaman's approach to minimise its GHG emissions covers the following two strategies:

- Carbon reduction: Overall, the proposed PCF Project will utilise proven, best in class technologies to transform coal into urea. Furthermore, the proponent is committed to applying the principles of continuous improvement throughout the life of the project to strive to further increase energy efficiencies and reduce greenhouse gas emissions.
- Potential offsets: Perdaman is evaluating various options which in the future are likely to enable a reduction of the CO₂ emissions from the Urea plant. Biomass co-feeding, geo-sequestration, and mineralisation have not developed yet to a commercial maturity that is suitable for inclusion in the Project basis, however it is expected that over time the feasibility of these options will become clearer. Commercial maturity implies a combination of technical, economic and risk criteria to ensure that the option is indeed a positive and not negative contribution to the Project.

These strategies are discussed in detail in the following subsections.

5.1.1 Carbon Reduction Strategy

The carbon reduction strategy of the PCF Project is summarised in Table 6, prioritised by the potential magnitude of GHG reductions. Each of the options are discussed in detailed in the following sections.

In cases where the potential GHG savings could not (yet) be quantified, the following quantity range has been applied:

- Low < 1,000 tpa GHG savings;
- Medium 1,000 to 20,000 tpa GHG savings;
- High > 20,000 tpa GHG savings.

Table 6 Summary of Perdaman Carbon Reduction Strategy

Options	Potential Magnitude of GHG Savings	Comments
Biomass co-feeding	470,000 tpa CO ₂ -e (10% biomass co-feeding) 940,000 tpa CO ₂ -e (20% biomass co-feeding)	Gasification technology is recognised as feedstock flexible. Biomass presents an opportunity to replace Collie coal with a renewable carbonaceous feedstock. Currently not developed to commercial maturity. PCF is committed to its further investigation. Shell has tested gasification with up to 35% biomass, but currently run ca. 9% in Netherlands (Nuon).



Options	Potential Magnitude of GHG Savings	Comments
		Growth of algae is another avenue to generate biomass using excess CO ₂ from the process, which could outside higher value applications be used as biomass to reduce fossil fuel to the plant.
Syngas cooling	220,000 tpa CO ₂ -e	Selection of a syngas cooler rather than Quench approach in gasification enables higher thermal efficiencies and GHG reduction.
Combined cycle power island	185,000 tpa CO ₂ -e	PCF has selected a combined cycle gas turbine approach for internal power, allowing an efficiency of 50% (syngas to power) compared to 40% (coal to power).
Urea synthesis and granulation	150,000 tpa CO ₂ -e	PCF will use steam driven compression of CO ₂ for synthesis with ammonia to urea, with high efficiency of conversion of steam energy to mechanical work (as opposed to a condensing turbine).
Air separation unit - cryogenic approach at large scale	25,000 tpa CO ₂ -e	Application of the proven cryogenic approach at a world leading scale, allowing for gain in compressor efficiency.
Limestone addition (slagging gasification)	22,000 tpa CO ₂ -e	Adding limestone as a fluxant reduces the melting point of the ash, and will reduce energy losses.
Energy recovery in ammonia synthesis	11-13,000 tpa CO ₂ -e	Exothermic reaction heat is recovered with steam generation. This is now standard practice and PCF has employed best available technology. In addition Perdaman uses a low inert loop which reduces compression power required from reduced recycle.
Acid gas recovery	Medium	PCF will use ADIP technology instead of Rectisol, which reduces refrigeration inputs and increases energy efficiencies. The recovery of CO ₂ would be at a purity and pressure that makes it ready for carbon capture.
Product selection	High	Coal to urea production has been shown on a lifecycle basis to have a GHG advantage compared to ammonium nitrate production. The main advantage of urea is no N ₂ O production as there is no nitric acid step.
Coal drying before gasification	Medium	Drying the coal to remove most of the moisture content of the sub bituminous coal is being considered. This improves the thermal efficiency of gasification.

As can be seen PCF have made significant effort to reduce the overall GHG emissions intensity for the whole plant including the combined cycle power island. The integrated nature of the plant with the power island being combined cycle powered by syngas from the plant means that it is very efficient. Further analysis of the power island emissions consistent with the DEWHA Technical Guidelines Generator efficiency will be undertaken when the final design is completed. Ongoing monitoring of CO₂ emissions will be to the accuracy required by these guidelines. During design and operation of the plant PCF will seek to comply with the Greenhouse Challenge Plus Generator Efficiency Standard Guidelines.



5.1.2 Carbon Offset Strategy

The potential carbon offset strategy of the PCF Project is summarised in Table 7, prioritised by the potential magnitude of GHG offsets. The options are discussed in detailed in the following sections.

Table 7 Summary of Perdaman Offset Strategy

Options	Potential Magnitude of GHG Savings	Comments
Geo-sequestration	Up to 2,500,000 tpa CO ₂ -e	<p>The PCF plant will produce highly concentrated CO₂ from its process suitable for geo-sequestration.</p> <p>PCF is a member of the Carbon Sequestration Task Force to ascertain the potential suitability of the Lower LeSeuer sandstone formation in the Southern Perth Basin for CO₂ storage, which is ca. 70 km from the Shotts site.</p>
Mineralisation	Up to 300,000 tpa CO ₂ -e	<p>Mineralisation involves CO₂ capture by the reaction of Ca/Na/Mg to insoluble carbonate through a reaction with the caustic bauxite residue from alumina refining⁶. Alcoa has developed a viable technology to neutralise excess caustic waste from alumina processing, which forms a sodium carbonate mineral with CO₂. This combines the benefit of solving a caustic effluent problem together with fixing of carbon in a low risk mineral sequestration.</p> <p>The PCF plant is located approx 25 km from the Worsley Alumina Refinery and approx 70 km from the Alcoa Wagerup Refinery.</p>
CO ₂ supply to other industries	Up to 40,000 tpa CO ₂ -e	<p>Highly concentrated CO₂ from PCF plant has the potential to be supplied to other industrial users (e.g. water treatment, carbonation, superficial solvent extraction, welding, dry ice).</p> <p>PCF is exploring opportunities, in conjunction with chemical manufacturing companies, to market CO₂ from the plant.</p>
Renewable energy	250,000 tpa CO ₂ -e (biodiesel facility)	<p>Perdaman is establishing a bio-diesel facility in India which would result in generation of carbon offsets.</p> <p>Furthermore, PCF is investigating investments in power generation from wind turbines in India.</p> <p>Certified emissions reduction credits (CER's) from these facilities could be used to offset emissions from the urea plant.</p>
Bio-sequestration	Up to 3.3M tpa CO ₂ -e Amount constrained by economic viability	<p>There is sufficient land available in suitable parts of Western Australia for offsetting GHG emissions from the PCF Project through bio-sequestration.</p> <p>Bio-sequestration is already a technically viable and recognised offsetting mechanism. Bio-sequestration is however constrained by cost implications and economic viability considerations. Costs to offset GHG emissions through bio-sequestration are estimated to be between \$15 and 35 t CO₂.</p> <p>PCF is investigating the fertilisation of plantation and reforestation, to accelerate biomass carbon capture – this requires developing protocols to generate formal offset credits WA sandy soils are recognised as generally being nitrogen deficient and hence limit growth of biomass.</p>

⁶ This process, and the associated CO₂ sequestration values has been proven by Alcoa at their Kwinana Refinery.



5.2 Description of Carbon Reduction Options

5.2.1 Biomass Co-Feeding

The base case feedstock of the Collie Urea plant is 100% as Collie coal. It is recognised that the Collie region has extensive plantations. There are also plans for considerable expansion of plantations with re-forestation of agricultural land that has been depleted by over-intensive cattle farming as well as rising salinity levels. This is shown by the Port of Bunbury currently exporting in the order of 1.5 m m³/a of wood chips.

Biomass presents an opportunity to replace a fossil fuel (coal) with a renewable (and sustainable) carbonaceous feedstock, which reduces the net (non-renewable) carbon impact of the Urea Plant.

Ability to use biomass

Gasification technology is recognised as feedstock flexible. Biomass tends to have a high moisture, high reactivity, little but low melting point ash and low sulphur content. For the Collie Urea plant such a biomass feedstock quality is not too different from Collie coal, and the process incorporates processing elements to handle some variance in parameters.

At Buggenum, Netherlands Shell has demonstrated with similar gasification technology use of (waste) biomass of up to 35% in the feed (this results in some capacity de-rating), and ca. 9% on a continuous basis. This allows the IGCC to have a comparable GHG profile to a gas based turbine. Various biomass feedstocks have also been tested, demonstrating flexibility.

The Perdaman gasification could as such over time, as feedstock availability is demonstrated, increase the co-feeding of biomass to over 10% of the coal feed. For 10% biomass implies a reduction in CO₂-e of ca. 470,000 tpa (assumes 2% fossil fuels used for collection and transport of biomass).

A 20% co-feeding of biomass would result in nearly 1 Mtpa of CO₂-e reduction.

A further advantage of Perdaman is that the processing scale of the plant allows comprehensive (and cost effective) treatment of various contaminants such as the ash and sulphur content in the biomass. The slagging gasification approach of a processing temperature of ~1500°C results in destruction of all polyaromatics – methane is reduced to max 100 ppm (Licensor estimate).

Potential Availability of biomass

In WA this issue of degraded land represents over 2 m ha. Some of this land is suitable for plantations, and plans have been drawn up for substantial increase of both eucalypt (e globulus) and maritime pine (pinus radiata) in the regions around Collie (200 km, and including a local sawmill). These plans consider an additional 80,000 ha for pine and 95,000 ha for eucalyptus. This results in an annualised production of some 5.2 Mtpa of biomass (at 30 t/ha/a) including waste and branches.

Commercially saleable biomass recovery is typically 45-50%, with the balance available as waste. Not all of this balance is recoverable, and includes bark, saw dust, off-cuts, low grade rejects as well as field losses with branches, leaves and stump. Taking a view of 60% recovery (developed over time) of 50% of 5.2 Mtpa = 1.5 Mtpa. As indicated a 10% co-feeding biomass requirement would require ca. 260,000 tpa.

Other parties have expressed interest in biomass use as well such as the Manjimup waste biomass 40 MW power plant, which has proposed using waste biomass collected in up to a 100 km radius from the plant.



5.2.2 Syngas Cooling

The selection of a Syngas Cooler rather than a Quench approach in gasification assists with reduction of GHG. Current practice with a requirement for converting syngas to mainly hydrogen via the Shift reaction favours a quench layout. This implies quenching hot (cooling) syngas with excess water; which results in a high steam partial pressure in the syngas, which is required for the Shift reaction. The quench approach is also results in a lower capital cost, due to simplified gas clean-up (Uhde et al).

Perdaman has selected a dry syngas cooler layout. With this approach the hot syngas is partially cooled with recycled syngas and steam is generated with further cooling of the gas. As noted this approach results in a higher capital requirement, but also higher thermal efficiency. The heat of the gasification is thus largely recovered as steam, which is used in the process for driving compressors, saving importing power. The steam generation is approximately 1.1 tonne per kNm^3 of syngas ($\text{H}_2 + \text{CO}$).

Other benefits are approximately one third of the slag is recovered in a dry format, rather than wet. This reduces water losses and waste water clean-up.

The indicative energy balance over the gasification section:

Syngas	79-81%
Steam (net)	13-15%
Water cooling	4-5%
Losses	1%
	100%

The overall thermal recovery is in the order of 94-95%. The overall efficiency gain over the quench approach is estimated as some 4-5% absolute – i.e. a reduction of 360 tpd of coal or 220,000 tpa of CO_2 -e.

5.2.3 Combined Cycle Power Island

Conventional coal based plants use boilers to raise steam for process use as well as power generation via steam turbines. Perdaman estimates to require 140-150 MW of power for internal use. This implies a sub-critical steam system (scale). A typical efficiency for sub-critical pulverised coal boilers to power (net) is 33-35% (using Collie coal) – or 10.6 GJ/MWh heat input.

Perdaman has selected a combined cycle gas turbine approach for internal power. This approach results in a higher capital than a simple boiler, but a gas turbine allows a higher thermal recovery from gas- particularly when coupled with a heat recovery steam generator (HRSG) and steam turbine. This at the required output allows an efficiency over 50% (syngas to power), and an overall efficiency of just over 40% (Collie coal to power) - or 8.9 GJ/MWh heat input. This results in reduction in coal demand and as such CO_2 -e emissions. This is estimated to be 2 PJ/a, or 100 ktpa coal or 185 ktpa CO_2 -e (based on carbon content of coal not used).

5.2.4 Urea Synthesis and Granulation

Urea synthesis and Granulation use world leading technology (more than 50% of all new urea plants) by Stamicarbon (2008/9 data). This is recognised for efficient conversion and optimised use of utilities such as steam and power. The CO_2 is compressed to ca. 140 bar for synthesis with ammonia to urea.



Perdaman will use steam driven compression, with back pressure. The high pressure steam is let down to a lower pressure, which is suitable for the urea plant processing. This results in high efficiency of conversion of steam energy to mechanical work (as opposed to a condensing turbine) and reduction in ancillary power required. This is estimated as ca. 22 MWh power reduction (if generated via condensing steam turbines) – or 150 ktpa of CO₂-e at 0.87 t/MWh. (internal number is ~0.87 t/MWh or the same as the SWIS alternative).

5.2.5 Air Separation Unit – Cryogenic Approach at Large Scale

Air separation uses the proven cryogenic approach – but at a world leading scale. This allows more efficient larger compressors to be used, which allow a 2-3% gain on compression efficiency. At the required scale this translates to 3-4 MWh – or 25,000 tpa of CO₂-e at 0.87 t/MWh. It is noted that the air separation unit will use over 100 MWh of power.

5.2.6 Limestone Addition (Slagging Gasification)

Perdaman has selected slagging gasification, which melts the ash in gasification to a slag, which is a vitreous low leaching product that is potentially saleable. The gasifier operates at over 1500°C to ensure ash melting temperatures. This also ensures destruction of complex hydrocarbons such as aromatics, and even methane is limited to ca. 100 ppm (Shell and Uhde (Licensor) design estimate). This simplifies product work-up, and minimises energy required for gas clean-up.

Some limestone will be added to the coal as fluxant to reduce the melting point of the ash. This allows the gasification to proceed at a lower temperature, which improves thermal efficiency. A rough indication of the benefit of this limestone addition is reduction of 150 tpd of oxygen, which at 0.5 MWh/t would reduce power demand by 25,000 MWh/a or 22,000 tpa of CO₂-e at the WA SWIS grid average of 0.87 t/MWh.

5.2.7 Energy Recovery in Ammonia Synthesis

Ammonia synthesis will use a pre-conversion reactor (at a lower pressure of 110 bar) with ammonia removal, followed by the conventional higher pressure synthesis. The main reactor will have a pressure of ca. 180 bar, as is typical for modern ammonia processes. The exothermic reaction heat is recovered with steam generation, which is used for process energy duty. The steam recovery is approximately 1.25 t/t NH₃.

Perdaman is using a low inert loop (lower than conventional gas based plants), and with the considerable degree of recycling in ammonia synthesis is anticipated to give a 3-4% reduction in loop compression requirement. This is estimated as 12-14,000 MWh/a - or 11-13,000 tpa CO₂-e.

5.2.8 Acid Gas Recovery

In Acid Gas Recovery (AGR) the sulphur compounds are removed from the syngas, concentrated and recovered (as a saleable product). The CO₂ portion is also separated from the syngas, in a concentrated form. This CO₂ stream is as such 'captured' CO₂ and could be used for emerging bio- or geo-sequestration applications.

Historically most coal based synthesis gas plants have used Rectisol technology for the AGR, followed by a LIN (liquid nitrogen wash) to remove residual trace contaminants. Perdaman will use Shell ADIP technology instead of Rectisol. This process uses a more modern low vapour pressure solvent allowing



recovery of the CO₂ and sulphur portion at a higher temperature (ca. ambient vs -33°C for Rectisol). This reduces the refrigeration input for the process, which saves energy and as such reduces CO₂-e emissions.

Instead of the LIN wash, a PSA (pressure swing adsorption) system will be used. This technology purifies syngas by selectively removing contaminants from the syngas using a molecular sieve. The trapped contaminants which include some hydrogen, CO₂ and CO are used as fuel gas. This uses minimal energy to achieve high purity synthesis gas for ammonia and usefully recovers the unwanted components.

This AGR approach is successfully operating at Coffeyville in the USA for over 10 years, and was recently (2008) implemented at a similar scale (ca. 600 tpd of hydrogen) at Opti in Canada.

5.2.9 Product Selection

Currently all (barring one) ammonia plants in Australia convert most of the ammonia produced to ammonium nitrate. PCF has selected urea as product for all of the ammonia produced.

For agriculture nitrogen fertiliser application, urea is nearly fully exchangeable with ammonium nitrate.

This has four major GHG advantages over ammonium nitrate:

- Urea product results in internal sequestration of some third of all the CO₂ produced in ammonia production. Ammonium nitrate has no carbon in the product structure;
- Urea does not result in concomitant co-production of NO₂ as ammonium nitrate does;
- The nitrogen content of urea is over 46% as (46.2% N) Nitrogen. Ammonium nitrate on the other hand is at best 34% N (normal blend is 27%, due to explosive regulations). This results in a lower transport cost per tonne of nitrogen (in urea) per km delivered. A lower transport tonnage implies lower transport fuel use and as such lower emissions relating to product logistics.
- Urea is slower dissolving than ammonium nitrate, which is highly water soluble. A high solubility results in greater potential for water runoff on the farm, loss of the fertiliser and impact on groundwater. Urea is somewhat more 'stable' and typically results in lower nitrogen losses compared to ammonium nitrate application. This is evidenced that urea is almost used exclusively for rice fertilisation, which is typically applied in water saturated fields (paddies). The staple grain in SEA is rice, and this reflects the predominant production, import and use of urea rather than ammonium nitrate in these regions.

5.2.10 Coal Drying before Gasification

Collie coal is a sub bituminous coal, with typically approximately 25% moisture content. While this coal could be gasified 'as is' the proposed PCF Project will dry the coal to remove most of the moisture to gain process efficiencies and thereby reduce its GHG emissions. Lower moisture coal results in lower CO₂ production in the gasifier due to lower thermal loss in heating water and evaporation. It is noted that existing Collie pulverised coal power stations in the region combust (burn) the coal as is.

5.2.11 Cleaning of CO₂ in bio-Sulphur Plant

The AGR concentrates a sulphur rich stream (mainly H₂S in CO₂) from the process gas, which is converted to elemental sulphur with the proven bio-sulphur Shell Paques process. The tail gas containing



traces of H₂S (ppm) in CO₂ is sent for CO₂ compression for urea synthesis. Note the Shell BioPaques as opposed to the traditional Claus oxidation/reduction process, is a non thermal process.

5.3 Description of Carbon Offset Options

5.3.1 Geo-sequestration

Finding a suitable geo-sequestration site

Geo-sequestration involves the deposition of pressurised CO₂ in a sandstone or saline formation geologically – typically > 800m underground. These formations need to be certified for capacity and containment integrity. The Australian govt has committed funds to developing commercial geo-sequestration sites around Australia. These sites should ideally combine a location near major CO₂-e emitting sites in Australia (preferably multi-user as well as allowing economy of scale for pipelines and injection storage) and a suitable storage formation at a distance that is not prohibitive (< 250 km).

Currently pilot tests are being on injecting CO₂ in the Otway formation in Victoria, and verifying reservoir models (2008-2010). Commercial deployment of geo-sequestration in Australia is considered several years away, with estimates in the 2016-2018+ timeframe.

In the Collie region Perdaman is a member of a Carbon Sequestration Task force which is co-funded by Industry and Government to ascertain the potential suitability of the Lower LeSeuer sandstone formation in the Southern Perth basin for CO₂ storage. This site is onshore and in the order of 60 km from Collie - which is promising in terms of the pipeline delivery cost. Industry members include the Power producers in Collie, Worsley Alumina and Perdaman.

Mines and Petroleum Minister Norman Moore announced the 'Lower Lesueur Carbon Dioxide Geosequestration Study' in June 2009. This study will assist in the further development of clean coal technology, and will determine if work progresses to drilling and assessing a test hole for carbon dioxide storage, as well as a pilot injection and monitoring program. It supports the Federal Government's National Low Emissions Coal Strategy, which is focused on driving the deployment of low emission coal technologies. The Lower Lesueur study will help contribute to the long-term viability of WA's coal industry and also to the Government's commitment to a low emissions future."

The Carbon Sequestration Task force has commissioned Schlumberger to verify seismic data and do test work to ascertain whether containment is feasible and what a likely storage capacity could be. Preliminary results are expected by July 2011, which would kick-off the next phase of the study, that being a pilot CO₂ injection to demonstrate the reservoir modelling. This stage is expected to take till 2013.

The key issue is that while the technology is considered provable, concrete demonstration and govt certification is critical to acceptance of geo-sequestration. The risk is considered mainly in the pipeline/disposal site, whilst traditionally the cost is the CO₂ recovery and compression (The COCCRC estimates ~70% in up-front cost, with ca. 30% for the pipeline and disposal (including monitoring)).

Suitability of PCF Project for geo-sequestration

Unlike conventional pulverised coal power stations, Perdaman's approach with oxygen blown gasification technology results in highly concentrated CO₂ (over 99%) as available from the process. Power stations typically result in a dilute CO₂ (4-6% by volume) in a low pressure stack emission – due to combustion



with excess air, with a large inert nitrogen (air is ca. 80% nitrogen) dilution. This is often contaminated with SO₂ and residual particulates. This requires scrubbing and concentration – and while these technologies are technically feasible, they require commercialisation for the large air flows, and result in considerable additional cost to conventional boiler power plants.

In addition Gasification results in the concentrated CO₂ at some useful pressure (PCF is expecting CO₂ at up to 5 bar) above ambient, which reduces CO₂ compression costs, and promises viable CCS should the sequestration site be risk certified by the Australian Government.

The process portion captures some 3.7 Mtpa of CO₂, of which 1.5 Mtpa (40%) is sequestered to the choice of urea product. This implies up to 2.5 Mtpa of CO₂ is ready for future sequestration, with a cost implication (assuming a pipeline connection to a certified site at the Perdaman battery limits) only of an additional CO₂ compressor.

The urea plant in fact uses CO₂ compressors very similar to those required for sequestration. Assuming 10% spare design capacity, this means that ~140,000 tpa of CO₂ could be available (at 140 bar pressure) for a demonstration sequestration project to prove up the reservoir.

The PCF Project is also the only source of concentrated CO₂ in the Collie basin, and this facilitates the use of the plant to demonstrate the CO₂ sequestration, with low cost/technical risk to the existing power plants.

The remainder of PCF Project emissions are largely related to the combined cycle gas turbine, which is comparable to dilution from natural gas fired turbines. Over time as high hydrogen firing turbines are developed, Perdaman can reduce the carbon content of the power emissions. This again is a future flexibility offered by Gasification technology.

5.3.2 Mineralisation

Mineralisation involves capture of CO₂ by reaction of Ca/Na/Mg to insoluble carbonate. This technology is emerging, with pilot projects being developed in various parts of the world, including the Latrobe valley in Victoria.

In WA, Alcoa has developed a mineralisation process to treat alumina processing caustic wastes at Kwinana. This CO₂ is transported by a pipeline from the nearby (CSBP) ammonia plant. By mixing CO₂ into the residue, its pH level is reduced to levels found naturally in alkaline soils. Alcoa plans to deploy the technology to its nine alumina refineries worldwide. Wayne Osborn, managing director of Alcoa Australia, said that at full capacity, the Kwinana Carbon Capture plant would treat the entire residue produced by the refinery, locking up 70,000 tonnes of CO₂ each year. “Across WA Alcoa could potentially save 300,000 tonnes of CO₂ each year”.

The PCF Plant is located ~25 km from the BHP-Worsley alumina refinery. Assuming the technology was available to Worsley the estimate is 130-150,000 tpa of CO₂ (Alcoa data indicates consuming 0.037 tCO₂/t alumina treated).

Initial discussions with Alcoa indicate that they would consider use of CO₂ from a Collie pipeline for their Wagerup refinery, which could add a further 150,000 tpa of CO₂. This pipeline could be combined with the geo-sequestration demonstration, allowing lower costs and a practical benefit to be derived sooner rather than later.



Transport distance from PCF to Worsley Alumina is approximately 25 km and to Alcoa's Wagerup Refinery is approximately 70 km. Based on a preliminary assessment, it will require less energy (and therefore less greenhouse emissions) over the life of the project to construct a pipeline for the transportation of CO₂ rather than using road or rail transport. The alumina plant distances and volumes are considered to allow a cost effective pipeline.

5.3.3 CO₂ Supply to Other Industries

CO₂ could be used for industrial uses - such as water treatment, carbonation, supercritical solvent extraction, welding and dry ice. Such applications have been developed for other ammonia plants such as CSBP and Incitec Pivot, Brisbane. Perdaman has been approached by Air Separation gas marketing companies to provide industrial CO₂. The tentative market size is considered in the order of 30-40,000 tpa CO₂.

5.3.4 Renewable Energy

Perdaman is pursuing the development of renewable energy facilities to offset against the GHG emissions from the PCF Plant. These include the establishment of a bio-diesel facility and investigations into power generation from wind turbines. Both potential projects are located in India.

Biodiesel

Perdaman Agro Pty Ltd PAPL is committed to the development of alternative biofuel feedstocks to participate in the growth of renewable energy sources. (PAPL) was established to engage in the production of non-edible biofuels as a source of renewable energy. The company's activities include refining and production of biofuels as well as the development, procurement and production of alternative feedstock (e.g. valuable by-products such as biomass).

PAPL has signed a Memorandum of Understanding with the Government of Madhya Pradesh in India for access to 12,500 acres of wasteland that has been earmarked for the company's use by the district administration. PAPL proposes to set up its first 100,000 tpa biodiesel refinery in India after assuring feed stock availability through its own and acquired biofuel crop plantation.

The refinery is expected to produce biodiesel using Jatropha oil but will have multi-feedstock capability allowing it to use the wide variety of non-edible feedstock oils available in India. To achieve this, PAPL plans to establish a purchasing network that will allow it to secure Jatropha seeds from other plantations elsewhere in India. The company is engaged in discussions with various parties about their participation in this network.

Because biofuels absorb CO₂ from the atmosphere when they are growing (as bio-oil), use of biodiesel drastically reduces the overall emissions associated with the use of the fuel. Emissions associated with biodiesel use vary greatly from project to project. PCF estimates that it will achieve a CO₂ emission reduction of 78% from the B100 fuel and 15.6% from the B20 fuel. Once established, the 100,000 tpa biodiesel facility proposed by PAPL will reduce GHG emissions into the atmosphere by more than 250 ktpa CO₂-e (based on Perdaman CO₂ emission reduction estimates and standard emissions factors from Department of Climate Change).

Wind Energy



PAPL is investigating investing in wind energy in India, and a 1st investment consideration is a 50 MW wind farm. The Indian market values power at a premium, and this is an opportunity to assist in supplying market demand with a renewable rather than fossil energy source.

5.3.5 Bio-sequestration

Carbon sequestration refers to the process of removing CO₂ from the atmosphere and storing it in another location (called a carbon sink). Bio-sequestration is the process of capturing and storing carbon in living organisms such as trees, plants and algae.

There is significant potential that one or more of the carbon offset options (e.g. geo-sequestration, mineralisation, CO₂ supply to other industries, renewable energy facilities) will materialise in the first five years of the operation of the PCF plant. It is noted that bio-sequestration is constrained by significant cost implications and economic viability. Costs to offset GHG emissions through bio-sequestration are considered to be between 35 and 50 \$/t CO₂.

PCF is investigating various forms of biosequestration offsets which include:

- Offsets purchased in plantations;
- Determining the protocol for offsets via promotion of the fertilisation multiplier for accelerated biomass accumulation in plantations / forests;
- Investigation of algal biomass growth, and possible internal use or substitution of other fossil fuel based products.

While the investigations into various other offsetting measures are ongoing, PCF is committed to:

- Meeting the expected CO₂ permit obligations as for the Carbon Pollution Reduction Scheme (CPRS);
- Pursuing annual improvements/offsets to reduce the carbon footprint of the facility;
- Provide support to evaluate whether geo-sequestration is technically and commercially viable in the designated potential location;
 - (with appreciation that PCF project is financially constrained in first five years of its operation);
- If the Greenhouse Challenge Plus Program is set to continue in the future, PCF will endeavour to participate in this program. It will also seek to comply with the Generator Efficiency Standards Guidelines in this program.



6. Minimising Emissions over the Life of the Project

The measures to minimise emissions, and the sequestration and sink enhancement actions to offset emissions, outlined in Section 5, represent best practice at the time of seeking project approval.

Consistent with the principles of continuous improvement, PCF is committed to an ongoing programme of monitoring, investigation, review and reporting of internal and external greenhouse gas abatement measures. It is anticipated that periodic reviews through the life of the proposed Coal to Urea project will identify opportunities to further reduce greenhouse gas emissions over time.

7. Benefits on a National and Global Scale

7.1 Overview

This section places the PCF project in a national and global context so as to provide an understanding of where broader offset benefits can be expected to occur in relation to GHG emissions, regardless of where these measures are located. Perdaman aims to provide the best possible outcome within Western Australia, but the company also want to stress the potential for benefits to accrue at the national and global scale.

7.2 Greenhouse Gas Emissions and Fertiliser Use

It is well established that various agricultural management practices can be used to increase carbon sequestration in soils, thereby reducing GHG emissions. When properly used, fertilisers assist plants to capture more carbon than is emitted during the production, transport and application of fertilisers (see Figure 5) The case is made that fertilisers foster higher yields, and thus increasing “the amount of carbon that is sequestered by the plant and re-released into the soil during growth, or when incorporating plant residues into the soil.” (Bellarby et al, 2008). Appropriate fertilizer use can also slow the decline of soil organic matter. In contrast, inadequate fertilisation limits crop biomass production and can result in lower soil organic matter and, potentially, impaired long-term soil productivity (Snyder et al., 2007).

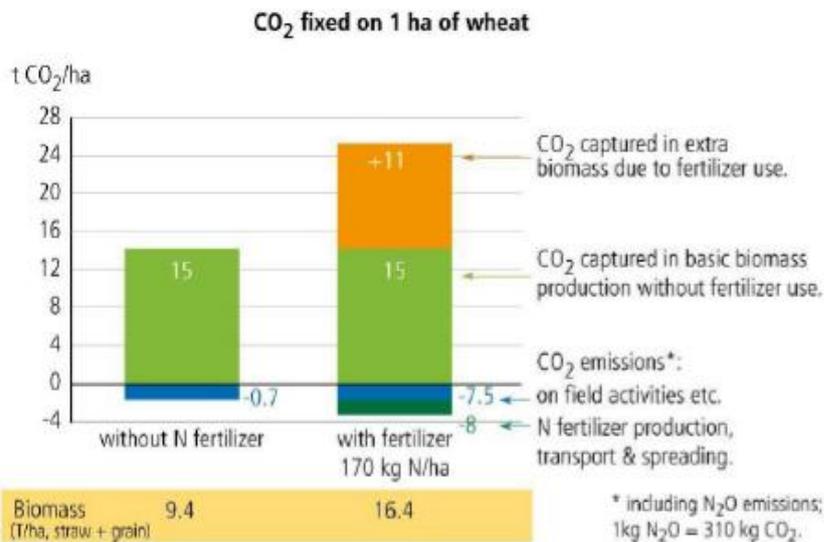


Figure 5 Life Cycle CO₂ Emissions on 1 ha of Wheat⁷

⁷ Source: Data from Kusters and Lammel (1999) quoted in EFMA (2003).



7.3 Global Carbon Footprint of PCF Project

Unlike fuels or power generation from coal, urea is a product that in use results in multiplier impact on biomass production, and therefore can result in reduction of CO₂ emissions in the atmosphere. Although it is recognised that precise numbers and methodologies would require rigorous assessments and scientific studies, the opportunity is taken here to present a perspective on the carbon life cycle emissions of the PCF project. The argument is made that climate change is a global issue and that urea has the potential to contribute to reducing CO₂ emissions globally. Based on common understanding and knowledge of publicly available research it can be demonstrated that the PCF Project could have potential negative life cycle carbon emissions.

Figure 6 indicates that the PCF Project has the potential for an overall net carbon absorption over the life time of the project (assuming that all urea from the project is exported to India, rice is the preferred crop for urea, and that rice husks are used for biofuel production). Furthermore, the potential commercial introduction of carbon capture and sequestration (ca. 2022) would have a further positive impact on the GHG emissions emitted to the atmosphere (see Figure 7).

Therefore the production of urea from coal, rather than its use for electricity generation can be seen as having potential greenhouse gas benefits when considered across the full lifecycle.

The underlying assumptions and calculations for these two diagrams are included in Appendix A.

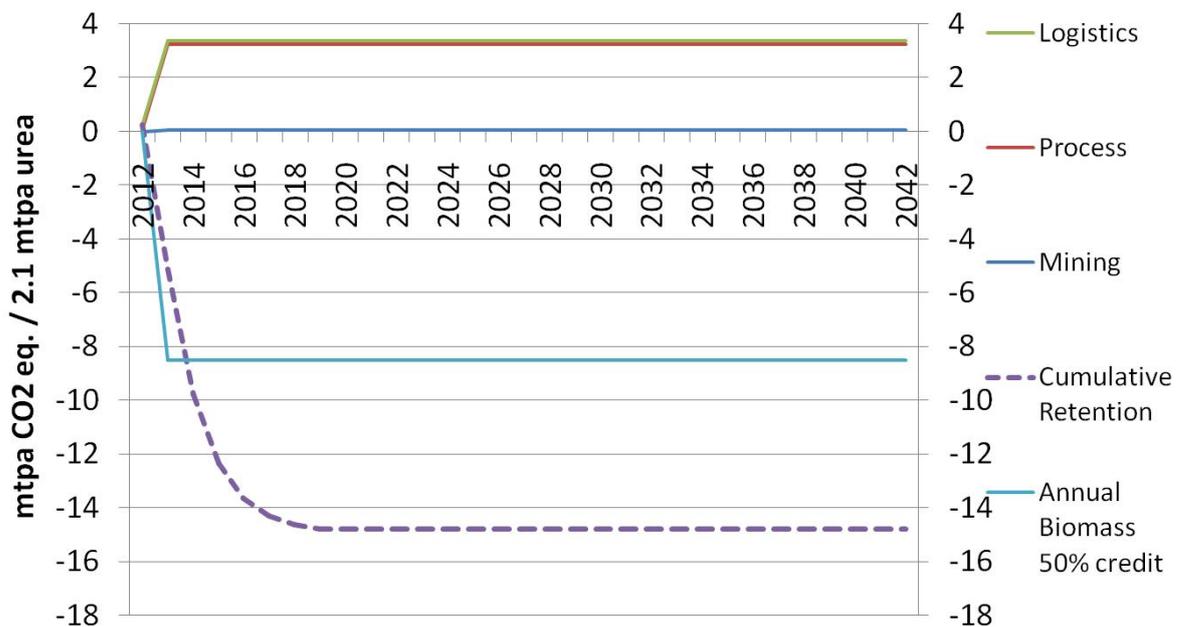


Figure 6 Projected PCF Project Lifecycle Carbon Balance 2012-2042⁸

Notes: Assumes rice as preferred crop for urea. Rice & biomass degradation estimate for India - Husks for biofuel.

⁸ Source: *Perdaman Chemicals & Fertilisers. Perdaman GHG Overview. June 2009.*

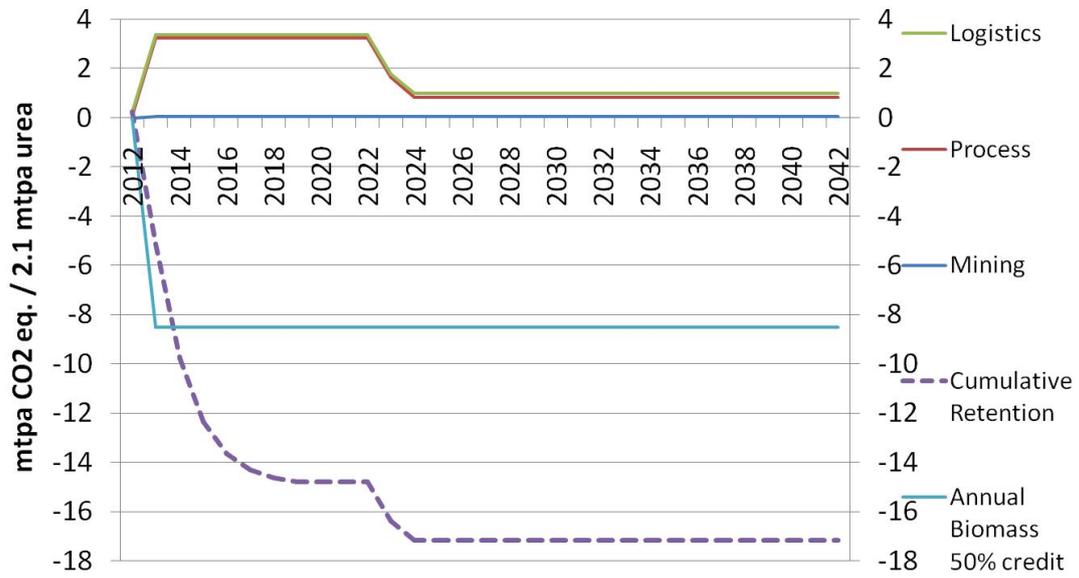


Figure 7 Projected PCF Project Lifecycle Carbon Balance 2012-2042 - CCS 2023⁹

Notes: Assumes rice as preferred crop for urea. Rice & biomass degradation estimate for India - Husks for biofuel.

⁹ Source: *Perdaman Chemicals & Fertilisers. Perdaman GHG Overview. June 2009.*



8. Impact Assessment

8.1 Assessed Impact of Proposed Emissions

Western Australia emitted an estimated 76.3 Mtpa of GHG emissions in 2007 (DCC, 2007). The total GHG emissions of the PCF plant are estimated at 3.3 Mtpa, representing about 4.3% of the total GHG emissions in WA in 2007. It is important to note that a significant proportion of this amount (about 75%) will be 99.5% pure CO₂ which is sequester ready.

Overall, Australia emits about 1% of the total global greenhouse gas emissions (Western Australian Taskforce 2004). Western Australia accounts for about 12.8% of the total greenhouse gas emissions in Australia (597.2 Mtpa in 2007). The PCF project thus represents approximately 0.61% of the total GHG emissions in Australia in 2007.

8.2 Management Options and Commitments

PCF overarching commitments to energy efficiency and reduction of GHG emissions are outlined in the company's Greenhouse Policy (Appendix B).

Table 8 summarises the management options to reduce the GHG emissions of the PCF project, including commitment of PCF to drive forward these options.

It is noted that the recommended investigations do not necessarily lead to the commitment to the implementation of the management options by default. It is acknowledged these decisions are subject to their technical and economic feasibility and overarching sustainability benefits resulting from these initiatives.

Table 8 Management Options and PCF Commitments

Management Options	PCF Commitments
<i>Carbon reduction</i>	
<ul style="list-style-type: none"> Technology selection and energy efficiency 	<ul style="list-style-type: none"> Ongoing assessment of opportunities to improve the energy efficiency of the PCF Urea Plant as part of the detailed design and operation of the plant to ensure that best-practice technologies and practices are applied. The core focus will be on those opportunities which have the most significant potential to reduce GHG emissions from the PCF plant – such as efficient application of waste heat steam to drive process compressors.
<ul style="list-style-type: none"> Use of biomass co-feeding 	<ul style="list-style-type: none"> Perdaman is undertaking an assessment of the state of biomass co-feeding technology for use in (Shell) coal gasification to evaluate the potential use of biomass as a feedstock for the plant. This allows reduction of the (non-renewable) fossil fuel portion. Should this technology proves technically and economically viable then a study will be undertaken to determine the availability of suitable biomass within a suitable distance from the plant (ca. 100 km). It is known that existing plantations generate waste biomass in the region, and local partners will be sought to deliver biomass. Algae biomass in particular could deliver a double benefit in directly harnessing excess plant CO₂ as well as displacing fossil carbon. Following evaluation of near commercial technology status selected parties will be approached to consider a



Management Options	PCF Commitments
	demonstration plant.
<i>Carbon offsets</i>	
<ul style="list-style-type: none"> Bio-sequestration 	<ul style="list-style-type: none"> Various options are being assessed for economic viability and commercial readiness.
<ul style="list-style-type: none"> Geo-sequestration 	<ul style="list-style-type: none"> Detailed investigation into the viability of geo-sequestration of GHG emissions from the PCF Project (e.g. as part of the Carbon Sequestration Task Force). Schlumberger has currently been contracted to evaluate the potential for safe storage at the identified location, with 1st phase report back by July 2010. PCF is the most suitable CO₂ source in Collie for pilot and demonstration tests for CCS in the identified Le Seuer formation to firm up model predictions and evaluate long term CCS surety. These quantities are envisaged to be 100,000-400,000 tpa for some initial years, followed by commercial volumes assuming success of the tests.
<ul style="list-style-type: none"> Mineralisation 	<ul style="list-style-type: none"> Investigating the supply of CO₂ to existing industries in proximity of the PCF Urea Plant, such as the existing alumina refinery facilities in the Collie region.
<ul style="list-style-type: none"> CO₂ supply to other industries 	<ul style="list-style-type: none"> Perdaman will undertake a regional synergy scoping study to assess the potential for the PCF Urea Plant to attract new industries in its close proximity which could utilise high purity CO₂. This study has the potential to regard the Urea plant as an anchor tenant to attract new businesses to the Shotts Industrial Park. An example is the emerging algae growing sector for CO₂ sequestration and NO_x reduction, wastewater remediation, and production of biofuels and other valuable products (e.g. plastics, fertilisers, feed for livestock and aquaculture). The study will also look, in conjunction with chemical manufacturers, at the potential for the plant's pure CO₂ output to be supplied to other industrial users (e.g. water treatment, carbonation, supercritical solvent extraction, welding, dry ice).
<ul style="list-style-type: none"> Renewable energy 	<ul style="list-style-type: none"> Perdaman is establishing a non edible oil (jatropha) bio-diesel facility in India which would result in the generation of carbon offsets. Jatropha is a tree/shrub with a productive life of some 40 years. Perdaman intends to pursue making these offset compliant in terms of international protocols. Perdaman is also investigating investments in power generation from wind turbines in India.

8.3 Monitoring and Reporting

Monitoring and reporting of the GHG emissions from the PCF project will be in accordance with the National Greenhouse and Energy Reporting (NGER) Guidelines (DCC 2008) and the Greenhouse Challenge Plus Technical Guidelines Generator Efficiency Standards (DEWHA 2006).

The National Greenhouse and Energy Reporting (Measurement) Determination 2008 outlines four methods that can be used to estimate greenhouse gas emissions and energy produced or consumed. PCF will use a combination of the four methods to monitor its GHG emissions where the selection of the appropriate methods will depend on the aspects of the process covered. The extent to which direct monitoring (method #4) will be used and the differentiation between methods #2 and #3 will be made during the detailed planning stage of the PCF Project. PCF will use the highest order method suitable in each case.



The process unit (gas clean up) and power island are by far the largest emitters of carbon dioxide emissions, accounting for approx 95% of the total estimated GHG emissions. These two sources are therefore regarded as a priority for GHG monitoring and reporting:

- The CO₂ from the process unit is 99.5% pure CO₂ and is sequester ready for either geo-sequestration or bio-sequestration when a commercial scale facility or combination of facilities is available. It is anticipated that PCF will make a direct measurement of the CO₂ released by this major sources (method #4 measurement) via regular process control parameters (e.g. flow rate and composition);
- The CO₂ emissions from the power plant within the facility will be from a combined cycle power and steam generation system. Most emissions will result in the gas turbine stack, which has flow measurement. It is anticipated that method #2 or #3 (based on measured plant operation parameters) will be appropriate to measure GHG emissions from the PCF power plant.
- With the product urea carbon and the major sources a carbon balance can be done over the process to confirm closure.



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Appendix A
PCF Life Cycle GHG Emissions –
Calculations and Assumptions



PCF Life Cycle GHG Emissions – Calculations and Assumptions

- 2.1 Mtpa urea export to India primarily for rice production (100% assumption)
- 2013-2043 period considered (30 years)

- *Production emissions (mainly Australia):*
 - Coal mining emissions based on Wesfarmers Sustainability report , 2007 for Premier mine, consisting of mainly diesel, explosive sand power
 - Production plant emissions based on Technology layout estimates, based on Attachment 11
 - Logistics estimates include rail to port (diesel), bulk shipping to India (+ return), (fuel oil) local delivery logistics estimate (diesel) truck

- *End use absorption & emissions (mainly Offshore):*
 - CO₂ absorption based on delta from urea application only
 - Biomass typically has 50% carbon on dry basis – 1.83 t CO₂-e/t biomass (dry)
 - Most biomass nitrogen is in protein (as ca. 6.25% N), with rice protein ca. 12%
 - Average Indian rice crop response 67% of IFA wheat benchmark (Kusters & Lammel) – implies + 20 t CO₂-e/t Urea applied per year.
 - Average application ~100 kg urea/ha
 - Farm related losses (considered as 91% of IFA wheat benchmark) include application and crop harvesting and nitrogen losses – leaching and N₂O; noting urea carbon content included as ‘on farm’ – ca. 3.8 t CO₂ /t urea eq. , which excludes production and logistics urea emissions
 - Urea denitrification loss ca. 12% -note granular urea better than nitrates
 - 50% of additional biomass CO₂-e credited to urea, 50% to farmer – provides incentive to enhance fertiliser management

- *End use carbon retention:*
 - Annual absorption consists of ca. 40% crop, 60% biomass (roots & stem)
 - Food portion consumed within 1 year (counted as production year) -no credit for partial weight transfer to consumer
 - Biomass portion degrades (oxidises) over time – with accelerated degradation assumption of 0% residual beyond 10 years - 50% of retention credited to urea
 - Excludes potential credits of biomass fossil fuel displacement offsets



- Cumulative carbon retention indicates (Mtpa CO₂-e) net annual carbon balance considering the multiplier impact of urea nitrogen and undegraded biomass accumulated from previous years.

- *CCS assumptions:*
 - Commercial status of CCS timeline
 - § 2007-2017 Otway pilot plant data logging
 - § 2017-2022 Zerogen semi-commercial demonstration
 - § 2011-2019 Government proves up Harvey Ridge CCS site
 - § 2023 Government acceptance of CCS for commercial deployment
 - 2023 CCS ready for project deployment
 - 85% carbon capture from process (technically feasible) + additional CO₂ compression power -2.5 Mtpa CO₂-e
 - CO₂ compression comparable to urea CO₂ compression

- *Observations:*
 - Biomass credit only reflect 50% of net 'on farm'
 - While not long term retention, achieves objective of carbon removal from atmosphere
 - Because of nitrogen biomass multiplier a net annual accumulation is feasible
 - Longer time frame soil and foliage carbon provide accrued carbon retention
 - Farm techniques can greatly improve 'on farm' emission losses
 - CCS impact is modest compared to leverage from biomass
 - Biomass provides utility value and carbon storage, CCS has some latent long run storage risk

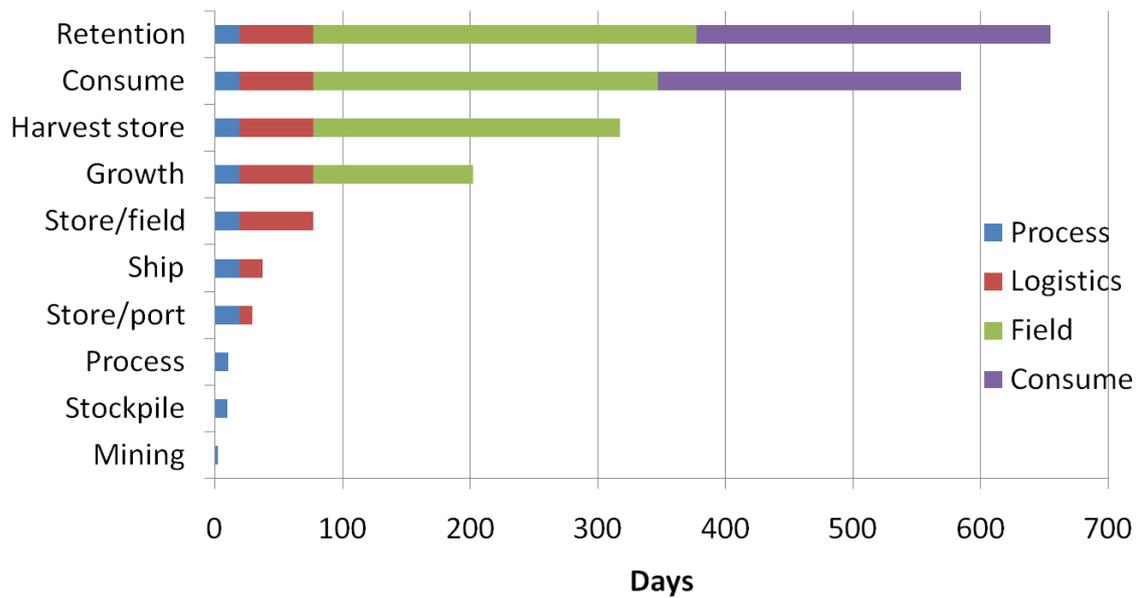


Figure 8 Estimated urea use cycle –rice India¹⁰

¹⁰ Source: *Perdaman Chemicals & Fertilisers. Perdaman GHG Overview. June 2009.*



Appendix B
PCF Greenhouse Gas Policy



Greenhouse Policy

Objectives

Perdaman Chemicals and Fertilisers Pty Ltd (PERDAMAN) is committed to demonstrating leadership in minimising the impact of its operations on the natural environment. PERDAMAN aims to increase its energy efficiency and reduce its greenhouse emissions.

Strategy

To maximize the achievement of the above objectives PERDAMAN will:

- Develop and implement cost effective greenhouse emissions reduction initiatives at its sites;
- Develop and implement cost effective greenhouse emissions offset initiatives;
- Measure and report greenhouse emissions at its manufacturing sites;
- Implement cost effective measures to improve energy efficiency at its sites
- Contribute to research in greenhouse emissions reduction technologies in the clean coal industry;
- Participate in industry and community initiatives to reduce greenhouse emissions; and
- Be proactive in anticipating potential greenhouse issues and in promoting science based climate change awareness

Implementation

All PERDAMAN employees and contractors are responsible for the implementation and maintenance of this policy.



Vikas Rambal
Chairman and Managing Director



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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Draft	Dick van Beers Srinivas Shastri Sitharama Rao	Christopher Lund		Christopher Lund		10 July 2009
0	Dick van Beers Srinivas Shastri Sitharama Rao	Christopher Lund		Christopher Lund		2 August 2009