Identification of the Optimum Sites for Industrial-scale Microalgae Biofuel Production in WA using a GIS Model

Final Report

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1 Algal biofuel production: history and context

The purpose of this study was to identify the best locations for constructing commercial-scale algae-to-biofuel production facilities in Western Australia (WA). The following document provides an overview of the study identifying a GIS modelling approach to locate optimal locations for production. Chapter one sets the context for the study positing algal biofuel manufacturing within the rubric of global renewable energy production. Chapter two focuses on methods used for site targeting in general, followed by a more specific discussion of site targeting approaches used to identify appropriate locations for algal biofuel production facilities. Chapter three outlines the area under study as well as the specific methods used to develop the GIS based site targeting model. Chapter four provides the results of the analysis followed by general conclusions in Chapter five.

1.1 Renewable energy: a global perspective

The decline in available fossil fuel resources coupled with an ever increasing global demand for energy, have led to substantial interest in the development of renewable biofuels. Biomass has been used for millennia as a source of energy. Modern commercial liquid biofuels such as bioethanol and biodiesel are commonly derived from short-rotation crops, perennial crops or waste fat. For example, bioethanol is produced by fermenting sugar from maize in the USA, sugarcane in Brazil or starch from wheat in Australia, and biodiesel is produced from a range of fat sources such as tallow, rapeseed oil or palm oil. Bioethanol can also be produced from various sources of cellulose such as sugarcane or the perennial grass *Miscanthus giganteus*.

According to the OECD (2009) the global annual production of bioethanol is projected to increase from 93 to 115 GL between 2010 and 2019, and biodiesel production from 21 to 41 GL. However, the production of renewable transport fuels from crops such as oilseed and sugarcane faces economic and environmental challenges, largely due to the potential competition with food crop production. Therefore, there is an urgent need for alternative sources of raw material for biofuel production.

Biofuels from algae, especially liquid fuels produced from algae lipids (oils), are seen as an important component of the future biofuels mix.

1.2 Algal biofuel: uses

Algae are macroscopic and microscopic, plant-like, largely photosynthetic, organisms belonging to a number of Phyla. They are extremely diverse and can be found in most habitats of the world including fresh and sea water, salt lakes, soil, snow and on surfaces such as rocks and the bark of trees. Their size ranges from about 1 μm (nanoplankton) to more than 40 m (kelp), with many microalgae used for biofuels production in the size range 10-60 μm.

Because of their fast growth rate and high lipid content, microalgae appear to be especially well suited for renewable biodiesel production. The use of algae as a source of biofuel offers an attractive sustainable alternative to other raw materials, as algae production does not necessarily compete for limiting resources such as fresh water (e.g. marine algae) or arable land (Borowitzka and Moheimani 2010). Furthermore, algae photosynthesis rates are higher on an area basis compared with land plants, thus requiring less land to achieve the same level of production. Algae are therefore very attractive as potential sources of renewable biofuels and
the Pacific Northwest National Laboratory, US Department of Energy, has reported that renewable fuel from algae alone could replace 17% of US oil imports (Roesijadi et al. 2008).

To date the cost of producing microalgae biomass and fuels from microalgae is too high to be competitive with fossil fuels, highlighting the need for continued research and development to reduce production costs. Despite over 30 years of exploration on algae as a source of biofuels, it is only in the last few years that research has effectively moved from the laboratory to pilot-scale production facilities and in Australia we now have two algae biofuel pilot plants currently located in Karratha, W.A., and operated by Muradel Pty Ltd and Aurora Algae.

1.3 Algal biofuel process

A typical algae-to-biofuel production consists of: a) growth (cultivation) of the algae, b) harvesting and dewatering of the algal biomass, and c) extraction of the lipids and conversion to fuel (Figure 1).

![Algae to biofuel production process](image)

Figure 1: Algae to biofuel production process

1.3.1 Growth technology

There are two main types of algae cultivation systems: open ponds and closed photobioreactors (Moheimani and Borowitzka 2006; Moheimani et al. 2011a) and open ponds are the most widely used systems for commercial large-scale outdoor microalgae cultivation (Borowitzka & Hallegraeff 2007). There are many types of open cultivation systems which vary in: (1) size; (2) shape; (3) material used for construction; (4) type of agitation; and (5) inclination. Open systems
are easier to build and less expensive to operate when compared to closed photobioreactors (Fon Sing et al. 2011). Currently only a few species of microalgae producing high value products (e.g. Dunaliella salina, Spirulina spp., Chlorella spp.) are grown commercially in open ponds in Australia, Israel, Japan, Thailand, India, China and the USA, although many other species can be grown reliably in these systems.

1.3.2 Harvesting and dewatering

One of the main hurdles to the future success of large-scale commercial microalgae operations is the efficient recovery of the biomass (Moheimani et al. 2011b). Irrespective of the cultivation system (i.e. open ponds or enclosed photobioreactors), the biomass concentration of the algae culture is generally low and often lies between 0.1 and 4.0 g L\(^{-1}\). For oil extraction, the algae have to be concentrated to at least 15% (150 g L\(^{-1}\)). This concentration process is typically energy intensive and results in high harvesting, thickening and dewatering costs (Mohn 1988; Moheimani et al. 2011b).

1.3.3 Extraction and conversion

The three different pathways that can be used to extract and convert algae biomass to bioenergy are summarized in Figure 2 (see de Boer et al. 2012 for details). Extensive research and development is still required to determine the most energetically favorable and economically feasible process for extracting and converting the algal biomass for renewable bioenergy.

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**Figure 2: Classification of conversion pathways for microalgae to fuel**

*Source: de Boer et al. (2012)*
1.4 Algal biofuel production: a global perspective

Microalgae are becoming the favoured raw feedstock for the production of biodiesel, and there are more than 25 companies worldwide trying to establish an economical process for growing microalgae. While most microalgae biofuel activity is in the USA, companies also are active in Australia, Israel, Brazil, China, and some European countries. Research and development is occurring in most other countries of the world. The most important advantages of microalgae over any other oil containing crops are their capability to grow on saline and hypersaline water, and also the possibility of growing them on land not suitable for agriculture. This means that microalgae can be cultivated in places that are not suitable for many other crop plants (i.e. coastal regions and even on the surface of the ocean). However, the process of growing algae as a source of raw material for biodiesel production is not yet commercially viable. Although commercial production of microalgae for biofuels does not yet occur, commercial production of microalgae for high value products such as pharmaceuticals, nutraceuticals and health food has been carried out for over 60 years.

Commercial microalgae culture began with *Chlorella* production as a health food in the 1950s in Japan and Taiwan, followed by *Spirulina (Arthrospira)* in the 1970s in Mexico and the USA, *Dunaliella salina* for the production of β-carotene in the 1970s in Australia, Israel and the USA, *Haematococcus pluvialis* for astaxanthin production in the 1980s in the USA, and *Cryptothecodinium cohnii* for production of the polyunsaturated long-chain fatty acid docosahexaenoic acid in the USA. Australia has the two largest commercial algae production plants in the world at Hutt Lagoon Western Australia (Figure 3), and Whyalla, South Australia.
1.5 Algal biofuel production in Australia

Several Australian companies and research groups are working on developing algal biofuels. Most are still at the research and development stage, although some larger scale pilot and demonstration facilities have been recently constructed or will be constructed soon. Some details of these are presented here.

**Algae.Tec**: was listed on the Australian Stock Exchange in January 2011. The company has a patented modular system based on closed photobioreactors contained in 40 foot shipping containers using sunlight captured by solar collectors and transmitted to the algae through an internal illumination system. The company installed the first test units in Nowra, NSW in May 2012.

**Aurora Algae**: is a US company located in Perth and Karratha, W.A. In May 2011, Aurora Algae opened its first demonstration facility in Karratha in Western Australia with six 1 ha open production ponds (see image on cover). The company plans to expand with the number of ponds expected to grow to 400 ha ponds and produce 28.8 kt y\(^{-1}\) of algae biomass (equivalent to 72 t ha\(^{-1}\) y\(^{-1}\)) by 2014.

**Muradel Pty Ltd**: is a joint venture company between Murdoch University, the University of Adelaide and SQC Pty Ltd established in 2011 to further develop and commercialise Commonwealth Government funded research (AUD$1.9 million from the Commonwealth and over AUD$2 million from the project partners). Production is focused on a fully integrated process using an elite saline microalga isolated and characterised by Murdoch University over the last 15 years, and new harvesting and extraction processes developed at the University of Adelaide. A 1 ha pilot plant, located next to the Rio Tinto Yurralyi Maya Power Station in Karratha, Western Australia, was constructed and commissioned in November 2010 to test the process at scale and allow further development of downstream processes.

**MBD Energy**: is focusing on carbon sequestration combined with the production of algal oil and algal meal for livestock feed. Their Bio-CCS (Bio-based Carbon Capture and Storage) Algal Synthesiser is modular and scalable, and benefits from a model of feedstock supply from CO\(_2\) emitters. They have a research agreement with James Cook University and have constructed a 5 000 m\(^2\) research and development facility located at James Cook University. They have also purchased oil extraction technology from Origin Oil in the USA. MBD is currently commissioning a 1 ha proof-of-concept module facility at the coal-fired Tarong Power Station in southeast Queensland. MBD has signed MOUs with Loy Yang and Eraring power stations to construct pilot units at their sites.

**SQC Pty Ltd**: is a South Australian based technology development company that was established 11 years ago with the research and development objectives to propagate, harvest, and process microalgae biomass (especially *Botryococcus braunii*). The SQC Port Lincoln facility is being used to grow and study selected algae strains.

**Other Research Activities**: Other research groups in Australia working on algae biofuels include the University of Technology Sydney, University of Queensland, Monash University, Flinders University, University of Melbourne, RMIT, CSIRO and SARDI in South Australia and there are several other companies as well.
1.6 Economics of algal biofuel production

A dominant factor for commercial microalgae production is the relative price of crude oil. A reasonable medium-term price target for microalgae oil for biofuel production to become cost competitive with petroleum diesel is AUD$ 0.48 L⁻¹ pre-tax. To date, the lowest cost commercially produced microalgae (mostly for high value products) is greater than AUD$ 5 kg⁻¹ (Stephens et al. 2010). Considering that no more than 40% of microalgae biomass can be oil, the cheapest microalgae oil produced to date costs more than AUD$ 12 L⁻¹. The only way to reduce costs is to either increase the biomass productivity of algae, or reduce the total capital expenditure (Capex) and operating expenses (Opex). There is very little that can be done to improve current algae productivities but it may be possible to reduce the costs of Capex and Opex. Extensive R&D is still required to make biofuels from algae economically viable. One of the most important aspects for progress to commercialisation is to find suitable sites for economic large scale production.

1.7 Site requirements for algal biofuel development

In general, identification of an appropriate location for an algal biofuel production facility is a function of the physical suitability of the location, the political availability of the land, and the affordability of the property (Maxwell 1985). More specifically, algae biomass productivity and associated lipid production is highly dependent upon climate conditions (especially irradiance and temperature range), CO₂ availability, nutrients such as nitrogen and phosphorous, water, and a host of social, economic and political aspects (Darzins et al. 2010; Fon Sing et al. 2011). There is however a sequence of controlling factors that need to be considered when identifying an appropriate location for algae biofuel production (Figure 4). First, land exhibiting appropriate topographic requirements must be identified along with the availability of water and an optimum climate. Once identified, the availability of land in terms of ownership, and any legislative restrictions must be considered, followed by economic considerations including land value and production costs.

The ideal location for algal biofuel production may vary based on the specific requirements of an algal strain, the economic, political and environmental context of the broader region in question, and the availability of geospatial data. Whilst Maxwell (1985) provides a guiding framework, identifying and integrating factors for production is more complicated.
Identification of algal biofuel production sites using a GIS model

Introduction

Figure 4: Controlling factors for the identification of algal biofuel production facilities

*Modified from Maxwell (1985)*

A range of current options exist for each factor in Maxwell’s (1985) framework and are summarized in Table 1. In terms of land requirements, large tracts of level topography with workable soils are important as well as land that can be purchased for a reasonable price. Furthermore, impact on cultural values should be considered, in addition to environmental sensitivity and the economic viability of production. Climatic considerations include the amount of incoming solar radiation, minimum daily temperatures, the length of the growing season, the amount of precipitation and evaporation, and the frequency and intensity of severe storms. Whilst water is an important component, the ocean, saline aquifers, lakes and rivers, and waste water treatment plants (WWTP) are all feasible sources, however when assessing the viability of saline aquifer use, quantity, chemistry and withdrawal capacity are important considerations (USDOE 2010).

Almost all algae mass cultures are carbon (C) limited. Addition of CO₂ can significantly increase the biomass, and in certain species also the lipid productivity of microalgae. Therefore CO₂ is a critical component of the production process, the use of which can be facilitated through co-location with a feasible source such as fossil fuel-fired power plants, ammonia production facilities or cement plants. Nutrient availability in the form of nitrogen and phosphorus can be supplied as traditional fertilizers or potentially from sources such as food production facilities, WWTP or as agricultural runoff. Although not included in Table 1, access to transportation infrastructure is important to the supply of resources for the production process as well as for export to markets and should be included in any robust algal biofuel production assessment.
Table 1: Factors for consideration in site targeting for algal biofuel production locations

Compiled from: Maxwell (1985), FAO (2009), Lundquist et al. (2010) and USDOE (2010).

<table>
<thead>
<tr>
<th>Land</th>
<th>Climate</th>
<th>Water</th>
<th>CO₂</th>
<th>Nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Slope</td>
<td>- Solar Radiation</td>
<td>- Ocean</td>
<td>- Power Plants</td>
<td>- Food Production</td>
</tr>
<tr>
<td>- Land use/Land cover</td>
<td>- Temperature (maximum + minimum)</td>
<td>- Saline aquifers</td>
<td>- Industrial Plants</td>
<td>Facilities</td>
</tr>
<tr>
<td>- Ownership</td>
<td>- Growing Season Length</td>
<td>- Lakes/Rivers</td>
<td>- Chemical Production Facilities</td>
<td>- Confined Animal</td>
</tr>
<tr>
<td>- Economic, Cultural</td>
<td>- Precipitation</td>
<td>- Waste Water Treatment Plant</td>
<td>- Cement Plants</td>
<td>Facilities</td>
</tr>
<tr>
<td>and Environmental</td>
<td>- Wind</td>
<td></td>
<td>- Waste Water Treatment Plants</td>
<td>- Agricultural Runoff</td>
</tr>
<tr>
<td>Value</td>
<td>- Evaporation</td>
<td></td>
<td>- Petroleum and Natural Gas Processing</td>
<td>- Waste Water Treatment</td>
</tr>
<tr>
<td>- Soils</td>
<td>- Severe Storms</td>
<td></td>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td>- Geology</td>
<td></td>
<td></td>
<td></td>
<td>- Fertilizers</td>
</tr>
</tbody>
</table>

1.8 Scale of production

The production of microalgae for fuel and energy will need to be at a much greater scale than the current scale of commercial algae production for valuable products. For example, in 2010/11 Australia consumed 18 725 ML of petrol, 20 054 ML of diesel, and 7 067 ML of jet fuel.

The productivity of algae in open pond culture is usually measured in gram per square meter per day (g m⁻² day⁻¹) and the best annual average long term productivity that has been achieved to date is approximately 20 g m⁻² day⁻¹ with algae that have an average total lipid content of 30%. Therefore, in order to produce 10% of Australia’s diesel requirement for one day, approximately 110 km² of algae ponds would be required. The figure below (Figure 5) compares the land requirement assuming microalgae productivities ranging from 20 to 30 g m⁻² day⁻¹ with algae biomass lipid contents ranging from 30 to 50%. Algae production in open ponds (currently the only system which has potential economical feasibility) also requires a large volume of water. Our calculations (see Borowitzka and Moheimani 2011) suggest that a 100 km² plant would use about 65 GL of water, mainly due to evaporation losses¹ from the ponds. Probably the only sustainable source of water is seawater from the ocean. In order to achieve high productivities and lipid contents, the selection of the site for the algae plant(s) with the optimum climatic conditions and available sources of water and CO₂ is of critical importance.

¹ Assuming an annual evaporation rate of 2 m
Figure 5: Calculated land area requirement to produce 10% of Australia’s daily diesel requirement (2010/11 data) using microalgae based on varying annual average areal productivity and total lipid content.

● = 30% lipid content; ○ = 40% lipid content; ■ = 50% lipid content. The conversion efficiency of the total lipid to biodiesel was assumed to be 75%. The arrow indicates the currently achieved best annual average biomass productivity at a 30% lipid content.

1.9 Prospects for algal biofuel development in Western Australia

Western Australia already hosts the largest commercial microalgae production plant in the world, the *Dunaliella salina* plant producing the valuable carotenoid β-carotene from this alga. The plant is located in Hutt Lagoon, north of Geraldton and comprises a total pond area of over 740 ha (Figure 3). Together with a sister plant at Whyalla, South Australia, these two facilities produce the bulk of the worlds supply of natural β-carotene which is used in the food, nutraceutical and pharmaceutical industries.

Western Australia has several key advantages as the location for algae biofuel plants:

1. abundant sunshine, especially in the Pilbara,
2. extensive land area unsuitable for agriculture and
3. an abundant water source in the Indian Ocean.

These advantages have already been recognised by at least one other overseas company, Aurora Algae, a US company which located their pilot plant in Karratha.

Australia also has the advantage of a stable political and business environment, compared to some other locations potentially suitable for large-scale algae biofuel production around the world.
1.10 Conclusions

Western Australia has great potential as a location for large scale microalgae cultivation as a raw material for biofuel production. The fact that the largest commercial algae farm in the world is based in Hutt Lagoon indicates the suitability of Western Australia for algae production. Western Australia has a long coastline, much of which is undeveloped and which is potentially suitable for the development of microalgae production plants. There is also access to an unlimited source of water (Indian Ocean), and Western Australia is one of the sunniest places in the world. Industrial development in many parts of the state also provide infrastructure, potential sources of waste carbon dioxide and a nearby market for the biofuel produced.
2 Geographical information systems and algal biofuel production site targeting

2.1 Traditional GIS site targeting

A small number of studies reflect an interest in identifying the optimum location for constructing open pond algal biofuel production facilities (Table 2). The earliest was that by Maxwell et al., (1985) who used a quasi GIS approach to identify locations for production in the south western US. The approach focused primarily on the physical characteristics of optimal locations including land-use/land-cover and slope, and climatic considerations such as insolation, temperature, precipitation and evaporation. Their study included the location of saline aquifers as a production input criterion but did not examine proximity to CO2 or nutrient sources for fertilization. The most suitable locations were identified by subjectively weighting (weights loosely based on cost) input criteria which were then combined using an additive model.

Several decades later, the United States Department of Energy (USDOE) (2010) provided a cursory overview of possible production locations across the US. A binary approach (i.e. meets the identified criteria or not) was used, incorporating climate parameters including annual average cumulative sun hours, average daily temperatures and number of frost free days.

A much more sophisticated approach was applied to the state of California by Lundquist et al. (2010). Like Maxwell et al. (1985), Lundquist and colleagues used a cost-based weighting of selected criteria in an additive model to identify the most appropriate algal biofuel production locations. Their approach focused on physical characteristics such as land-use/land-cover and slope, and climatic considerations such as solar radiation, temperature, precipitation, and evaporation but furthered the analysis by incorporating access to production input requirements such as saline water, CO2 and nutrient sources.

More recent GIS-based algal biofuel production facility site targeting includes estimates of production potential (Wigmosta et al., 2011; Klise et al., 2011; Quinn et al., 2012). Leading the way was the work by Wigmosta and colleagues (2011) from the Pacific Northwest National Laboratory (PNNL). Their approach first identified appropriate locations based on environmental considerations (land-cover, topography and climate) then modelled production potential based on climate (30m x 30m grid cells across the US). Whilst their initial assessment did not incorporate water or nutrient sources, a more sophisticated web-based GIS modelling tool, the Biomass Assessment Tool (BAT), is under development and will include capabilities for integrating nutrient and CO2 requirements for a specific site based on user defined parameters (Skaggs, 2011).

Klise et al., (2011) applied a similar approach first selecting production locations in coastal and central Canada based on environmental considerations (land-cover, topography and climate) and production input requirements (CO2 and nutrients). Potential production locations were then narrowed to four for a more detailed study. Whilst they examined only a limited number of sites, their approach provides a realistic scenario by siting potential production facilities within close proximity to known CO2 sources then modelling production potential and costs associated with various scenarios. Quinn et al., (2012) adopt a comparable approach modelling production potential across the entire US based on 90m x 90m grid cells.
Our study, the first of its kind in Australia, builds upon previous approaches whilst incorporating factors unique to the Western Australian context. We limit production facilities based on environmental characteristics such as topography, climate, and availability of CO₂ but also incorporate construction considerations such as soil workability. Given Western Australia’s vast area, we include factors such as employment availability and distances for transportation both in terms of production inputs and outputs. Whilst we have not included transportation and production costs in our final model, our approach lends for easy incorporation at a later date.
Table 2: Summary of GIS approaches for algal biofuel production site targeting.

<table>
<thead>
<tr>
<th>Spatial Variable</th>
<th>Maxwell et al., 1985</th>
<th>USDOE, 2010</th>
<th>Lundquist et al., 2010</th>
<th>Wigmosta et al., 2011</th>
<th>Klise et al., 2011</th>
<th>Quinn et al., 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production Type</strong></td>
<td>Open Pond</td>
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<td>Open Pond</td>
<td>Open Pond</td>
<td>Open Pond</td>
<td>Open Pond</td>
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<tr>
<td><strong>Approach</strong></td>
<td>Subjective weighting of criteria in an additive model</td>
<td>Seive mapping – binary classification</td>
<td>Cost based weighting of ranked criteria in an additive model</td>
<td>Model oil production - Biomass Assessment Tool</td>
<td>Model oil production - Scenarios for 4 areas post site targeting - Incorporates costs</td>
<td>Model oil production - Interpolation of productivity at 864 locations</td>
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<td><strong>Study Area</strong></td>
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<td>United States</td>
<td>California</td>
<td>United States - ≥490 ha</td>
<td>Coastal and inland Canadian location</td>
<td>United States</td>
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<td>30m x 30m</td>
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<td>Area of scenario location</td>
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<td>Land Ownership</td>
<td>- Public - Government - Private - Cultural - Environmentally Sensitive</td>
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<tr>
<td><strong>Slope</strong></td>
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<td>Sunlight</td>
<td>Annual average of daily total global horizontal Insolation</td>
<td>Annual average cumulative sun hours</td>
<td>Solar Radiation</td>
<td>Daily estimates of incident solar radiation - Disaggregated to</td>
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<td>Daily estimates of precipitation</td>
<td>Disaggregated to hourly values</td>
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<td>Temperature</td>
<td>Annual freeze-free period, Annual average daily temperatures, Annual average freeze free days</td>
<td>Minimum average temp month of March</td>
<td>Daily estimates of temperature, Disaggregated to hourly values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Daily estimates of dewpoint, Disaggregated to hourly values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation</td>
<td>Annual pan evaporation</td>
<td>Annual pan evaporation</td>
<td>Daily estimates of pan evaporation, Disaggregated to hourly values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Annual thunderstorm days</td>
<td></td>
<td>Daily estimates of wind, Disaggregated to hourly values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Saline ground water, depth, salinity</td>
<td>Saline ground water</td>
<td>Waste water treatment, distance, lift due to elevation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Irrigated agricultural waste water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2</td>
<td>Power plants</td>
<td></td>
<td>Various point source</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>Waste Water</td>
<td>Infrastructure</td>
<td>Road</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>-----------</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste water treatment plants</td>
<td>Waste water treatment plants</td>
<td>Distance to road</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 50,000 ton/year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Methods

3.1 Study area

Figure 6 identifies the boundary delineating the study area for this project. The area encompasses over 2,250 km of coastline extending from Lancelin in the south to Broome in the north. The study area extends 170 km inland from the coast and encompasses over 350,000 km$^2$. The southern boundary was selected as the location for which development pressures from the Perth metropolitan region (to the south) begins to decrease, allowing for more cost-effective production with less land use conflicts. The northern boundary of the study area, delineated by the city of Broome, identifies the area at which point seasonal rains begin to affect the ability to maintain consistent salinity levels in open pond production. Whilst this study primarily focus on algal biofuel production using sea water, the inland extent of 170 km identifies the easternmost extent at which pumping water from the coast becomes cost prohibitive.

Geographically, the study area falls within Western Australia’s Wheatbelt to the south followed by the Midwest, Gascoyne, Pilbara and Kimberley regions moving north. The physical geography of the study area varies from rolling sand plains to deep gorges shaped by millions of years of geological processes. Climatically, the study area encompasses subtropical, semi-arid and arid climate zones with average mean daily temperatures ranging from 18$^\circ$C in the south to 30$^\circ$C in the north and precipitation ranging from 200 to 1000 mm respectively (BOM 2012). Tropical cyclones are a threat across the northern reaches of the study area and can produce significant precipitation, which could affect open pond production and result in flooding that renders transportation infrastructure unusable for periods of time.

Human population within the study area is concentrated in several coastal centres including Geraldton, Carnarvon, Exmouth, Karratha, Port Hedland and Broome. Economically, the southern portion of the study area is dominated by agriculture, with the north dominated by mining oil and gas extraction and pastoralism. Tourism, to a lesser degree, provides economic input throughout the study area but is predominantly concentrated along the coast.
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Methods

3.2 Data sources

Geographic data used in this application were identified from the literature and through consultation with experts from the Algal R&D Centre, Murdoch University. The data used in this study include solar radiation information, topography, land use/land cover data, environmentally and culturally sensitive lands, and the location of roads, settlements (including work force statistics), ports and harbours, CO₂ point source locations, and water features (Table 3). This information was combined using a GIS to identify the most suitable locations for medium- to large-scale algal biofuel production facilities along the central Western Australian coast.
Table 3: Data sources used to identify appropriate sites for biofuel production facilities

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (90mx90m)</td>
<td>Shuttle Radar Topography Mission (SRTM)</td>
</tr>
<tr>
<td>Elevation (30mx30m)</td>
<td>ASTER Global Digital Elevation Model</td>
</tr>
<tr>
<td>Aboriginal Heritage Sites</td>
<td>Department of Indigenous Affairs</td>
</tr>
<tr>
<td>Environmentally Sensitive Areas</td>
<td>Department of Environment and Conservation</td>
</tr>
<tr>
<td>Surface Water Bodies</td>
<td>Landgate</td>
</tr>
<tr>
<td>Surface Water Bodies</td>
<td>GeoScience Australia</td>
</tr>
<tr>
<td>ABS 2011 Mesh Block Data (WA)</td>
<td>ABS 2011</td>
</tr>
<tr>
<td>Roads</td>
<td>Landgate</td>
</tr>
<tr>
<td>Settlement Locations</td>
<td>GeoScience Australia</td>
</tr>
<tr>
<td>Employment Statistics</td>
<td>ABS 2006</td>
</tr>
<tr>
<td>Ports/Harbours</td>
<td>Department of Transport</td>
</tr>
<tr>
<td>CO₂ Point Sources</td>
<td>Carbon Monitoring Action Group for Change (CARMA) / various mining and resource company websites</td>
</tr>
<tr>
<td>Coastline</td>
<td>Smartline</td>
</tr>
<tr>
<td>Soils</td>
<td>Department of Agriculture and Food WA</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>Bureau of Meteorology (BOM)</td>
</tr>
</tbody>
</table>

3.3 Data handling and layer development

3.3.1 Slope mask
As identified by the USDOE (2010) and Fon Sing (2011) a commercially viable open pond biofuel production facility requires at least 325 ha of flat, workable land. To help identify viable development locations, a GIS slope layer was calculated from a digital elevation model (DEM) collected by the Shuttle Radar Topography Mission (SRTM) with a grid cell resolution of 90 m x 90 m. Previous studies identify viable development of land ranging from 1% to 10% in slope (Table 1). However, for this study, construction feasibility was limited to SRTM grid cells with a slope value ≤4%. Given the large expanses of flat land available within the study area, viable locations were restricted to areas of 500 ha, which is roughly equivalent to 14 contiguous 90 m x 90 m grid cells.

3.3.2 Aboriginal heritage
Development on gazetted Aboriginal heritage lands within Australia requires significant negotiation and permitting, and in some cases must be avoided altogether. A GIS polygon layer was acquired from the Department of Indigenous Affairs (DIA 2008) identifying locations contained within the Aboriginal Sites Register as areas with historical, archaeological and cultural significance.

3.3.3 Environmentally sensitive areas
Clearing restrictions for lands identified as environmentally sensitive within Australia apply across the nation and in some cases they must be avoided altogether. A GIS polygon layer was
acquired from the Department of Environment and Conservation (DEC 2005) identifying areas designated as environmentally sensitive.

3.3.4 Water features

It is not possible to develop an algal biofuel production facility on a natural water body such as a lake, river or estuary. To avoid identifying a production site within a water body, a GIS layer of surface water features was compiled from two sources to capture all possible features (GA 2003; Landgate 2011).

3.3.5 Land use/land cover

To avoid selecting a site with a conflicting land use, it was important to identify areas that were not previously developed or used for a more economically viable use. The most current land use/land cover classification of Australia was developed for the Australia Bureau of Statistics’ meshblocks (ABS 2011). A meshblock is the smallest geographic region for which ABS data is collected and in residential areas comprise between 30-60 dwellings. Each meshblock is classified as either ‘parkland,’ ‘residential,’ ‘industrial,’ ‘commercial,’ ‘education,’ ‘hospital/medical,’ ‘agricultural,’ ‘transport’ or ‘other.’ Meshblocks identified as ‘parkland,’ ‘residential,’ ‘industrial,’ ‘commercial,’ ‘education,’ ‘hospital/medical,’ and ‘transport’ were classified as unable to support an algal biofuel production facility whilst areas classified as ‘agricultural’ and ‘other’ could support a facility (these two classes comprised the majority of the study area).

3.3.6 Roads

Road infrastructure data was acquired from Landgate (2011), Western Australia’s primary geospatial data provider, as a requirement for calculating distances from potential algal biofuel production facilities to necessary infrastructure and resources. Landgate’s road dataset provides information for all roads in the state including dirt tracks, roads under construction and roads proposed for construction. Road types not suitable for heavy truck traffic were excluded from the dataset to produce a final road network GIS layer used to calculate distances from potential production sites to settlements, and ports. As settlements and ports could fall outside the study area, the road network was extended to capture all viable employment supplies and harbours.

3.3.7 Settlements

With large distances between settlements in northwest Western Australia, and a skilled labour shortage fuelled by the mining industry, proximity to labour and services is an important factor in sitting any production facility. A GIS point layer representing settlements with necessary skill requirements was developed as a component of the capability model. Settlement point locations were acquired from GeoScience Australia (2003) for the entire state and filtered based on the availability of skilled labour and services in each locality. Initially 79 settlements within or in close proximity to the study area were identified and further reduced to 46 viable locations based on appropriate skill sets of the labour force.

To identify localities with a skilled labour force and services, Community Profiles (Urban Centre/ Locality / SLA) acquired from the Australian Bureau of Statistics (ABS) (2006) were used to identify the types of employment residents within the study area were engaged in. Based on ABS employment categories, residents engaged in ‘mining,’ ‘electricity, gas, water and waste
services; ‘construction;’ ‘accommodation and food services;’ and ‘manufacturing’ were all identified as providing potential skills and service required for a production facility. Localities with at least one resident identifying employment in 4 of the 5 categories listed above were considered a viable labour and service provider for this study.

3.3.8 Ports

Due to the region’s geographic isolation, bulk resources primarily enter and leave Western Australia through the state’s ports and harbours. To identify locations for which fertilizers and other resources could be brought to the production facility and major transport nodes for export, a GIS point layer of ports and harbours in Western Australian was compiled from the Ports Handbook, Western Australia (DoT 2011) and mapped using GoogleEarth. Only ports and harbours with facilities to receive tankers were included in the final data set excluding small boat harbours and mooring facilities.

To develop a layer measuring access to a port facility, a grid based cost-distance approach was used. Using the SRTM 90 m x 90 m DEM as a base, the distance from each grid cell to the nearest port was calculated. To provide a more realistic scenario of movement from a port to a production facility (and vice versa), the distance was first calculated as the overland distance of each grid cell to the nearest road followed by the distance along the road network to the nearest port. This approach assumes that in an instance where a grid cell is not adjacent to a road, then a road would be built from the grid cell to the nearest road. As a barrier for movement across the 90 m x 90 m grid, the shortest distance from a grid cell to the nearest road could not include a grid cell classified as an Aboriginal heritage site, environmentally sensitive land, a surface water feature or a more economically viable land use/land cover. In this case, the shortest route to a road was calculated based on the shortest path not encountering a previously mentioned barrier.

3.3.9 Carbon dioxide

Carbon dioxide (CO₂) is an integral component of the algal biofuel production process and can be provided via pipeline from a point source location or trucked to the production site, however, with the vast empty spaces and limited road networks within the state, only the former was assessed. Whilst companies within Australia are legally required to report their level of emissions, this information is found within annual reports and is not available as a compiled data set for public use. Furthermore, company emission reports generally incorporate emissions from all of a company’s assets and are not general disaggregated by specific assets.

As a proxy for an Australia specific CO₂ point source data set, the Carbon Monitoring Action Group for Change (CARMA) has compiled global information on large CO₂ emitters, modeling the amount of emissions for each source per year (Wheeler et al. 2008). The group provides modelled data for the years 2000, 2007 and an estimated projection for an arbitrary time point within the next 10 years. It has been estimated that for a 500 ha algae farm a minimum of 134 000 t CO₂ year⁻¹ is required (Borowitzka and Moheimani 2010; Fon Sing 2011), therefore (to allow for modelling errors) this study includes all CARMA point sources identified as producing a minimum of 100 000 t CO₂ year⁻¹. Whilst CARMA did supply geographic coordinates for the location of most CO₂ emitters in their data base, additional location information was required and sourced using GoogleEarth. Results identified 10 possible sources within or in close proximity to the study area.
3.3.10 Coastal boundary

One of the major considerations for a successful algae plant is access to a saline water source. Using freshwater for growing algae for biofuel is not sustainable (Borowitzka and Moheimani 2010). Due to the large geographic extent of Western Australia and the limited availability of bore data throughout central and northwestern portions of the state, this study focused on the provision of ocean water for the production process. The 170 km inland extent of the study area identified an ambitious distance for which saline water could be transported from the ocean to a potential production site but provided for a robust assessment of land capability. The state’s coastline was based on the Smartline map which provides the most accurate general representation of the nation’s coastline and in most cases is based on the High Water Mark line (Sharples et al., 2009).

3.3.11 Soils

Soil workability was assessed as an indication of the construction development of a site and is based on the Department of Agriculture and Food of Western Australia’s (DAFWA) Soil Groups (Schoknecht 2002). The soils of Western Australia have been mapped according to the proportion of Soil Supergroups and Soil Groups that occur within a mapping unit (represented as a vector polygon within a GIS). Soil Groups signify a finer level of classification than Soil Supergroups; up to four Soil Groups may occur within a mapping unit. For example, a mapping unit from the Great Sandy Desert could be classified as 56% red deep sands (Soil Group 445), 29% red sandy earth (SG 463), 10% shallow gravel (SG 304) and 5% calcareous shallow sand (SG 421).

Each Soil Group has been described in terms of a number of properties however; of particular relevance to construction (and ultimately this project) is unrestricted rooting depth. This is related to the presence of a hardpan or cemented layer. It should be noted that this property is tied to soil sampling locations on the landscape and actual rooting depth is likely to vary within a mapping unit according to topography.

Each of the 66 Soil Groups have been classified according to unrestricted rooting depth from ‘least favourable’ to ‘most favourable’ based on the classification provided by DAFWA (
Table 4). Each mapping unit was reclassified from 0 (least favourable) to 6 (most favourable), then standardized to a scale from 0 to 1 and converted from vector format to a 90 m x 90 m resolution grid for integration with other data layers.
Table 4: Unrestricted rooting depth classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Unrestricted rooting depth (DAFWA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (least favourable)</td>
<td>Very shallow; N/A (includes bare rock)</td>
</tr>
<tr>
<td>1</td>
<td>Shallow; very shallow to moderate</td>
</tr>
<tr>
<td>2</td>
<td>Shallow to moderate</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Moderate to deep</td>
</tr>
<tr>
<td>5</td>
<td>Deep</td>
</tr>
<tr>
<td>6 (most favourable)</td>
<td>Deep to very deep</td>
</tr>
</tbody>
</table>

3.3.12 Productivity

Solar radiation information was used to calculate the production potential of algal biofuel production facilities across the region; solar radiation is the main factor affecting the productivity of microalgae cultures in outdoors (Moheimani & Borowitzka 2006; Moheimani 2012). Eighteen years of daily, satellite derived grid data (with a resolution of 6 km x 6 km) was acquired from the Bureau of Meteorology (BOM, 2011), each grid representing total daily global solar exposure or total irradiance (direct and diffuse). Yearly production potential for each grid cell was necessary for this study; however a large number of daily grids included missing data values and required further data handling.

To derive a value for yearly production potential, yearly total global solar exposure was first calculated for each grid cell. Months with missing data values were discarded retaining only months with complete data for each day (Table 5). Total global solar exposure was then calculated for each remaining month and then averaged across corresponding months for the time period from 1999-2008. The average monthly total global solar exposure was then summed for all 12 months to produce a measure of total yearly global solar exposure across the time period.

Table 5: Number of months used to calculate the average total monthly solar exposure from 1999-2008

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of full data months with complete data</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>8</td>
</tr>
<tr>
<td>February**</td>
<td>4</td>
</tr>
<tr>
<td>March</td>
<td>10</td>
</tr>
<tr>
<td>April</td>
<td>6</td>
</tr>
<tr>
<td>May</td>
<td>5</td>
</tr>
<tr>
<td>June</td>
<td>3</td>
</tr>
<tr>
<td>July</td>
<td>6</td>
</tr>
<tr>
<td>August</td>
<td>8</td>
</tr>
<tr>
<td>September</td>
<td>9</td>
</tr>
<tr>
<td>October</td>
<td>10</td>
</tr>
<tr>
<td>November</td>
<td>10</td>
</tr>
<tr>
<td>December</td>
<td>7</td>
</tr>
</tbody>
</table>

** Only months with 28 days in February were used for calculating average monthly total solar radiation.
Next, annual algae production per day was calculated for each grid cell based on a generalised algae production model derived from long-term studies of the growth of several species of microalgae in outdoor raceway-type ponds for periods exceeding one year (Equation 1 - Equation source: Murdoch University, Algae R & D Centre).

Equation 1:

\[ P = \frac{A S R}{60 \times 24} \]

Where \( P \) is microalgae areal ash free dry weight biomass productivity (g m\(^{-2}\) d\(^{-1}\)) and ASR is annual solar radiation (MJ m\(^{-2}\) y\(^{-1}\)). The 6 km x 6 km productivity grid was resampled to the 90 m x 90 m resolution of the SRTM DEM used to calculate slope, and adjusted for change in grid cell area, for integration with other data layers.

### 3.4 Land suitability mask

To produce a suitability mask identifying lands unsuitable for an algal biofuel production facility, suitable locations were identified by combining information on environmentally sensitive lands, Aboriginal heritage sites, water features and land use/land cover (Figure 7). The vector based environmentally sensitive lands dataset was converted to a continuous grid, corresponding to the 90 m x 90 m SRTM DEM used to calculate slope. Areas of environmental sensitivity were given a value of 0 and all others a value of 1.

![Figure 7: Flow diagram of land suitability modelling](image)

A similar procedure was conducted for Aboriginal heritage sites and water features where both vector based datasets were converted to continuous grids, again corresponding to the 90 m x 90 m SRTM DEM used to calculate slope. Areas of Aboriginal heritage and water features where converted to 0 and all others given a value of 1.

The reclassified land use/land cover polygon layer was also converted to a grid corresponding to the 90 m x 90 m SRTM DEM. Areas with competing land use/land cover were given a value of 0 and others a value of 1. Finally, all four binary layers (environmentally sensitive lands,
Aboriginal heritage sites, water features and land use/land cover) were summed and reclassified so that any cell with environmentally sensitive lands, Aboriginal heritage sites, water features or competing land use/land cover were converted to 0 and all others given a value of 1 (Figure 8).

Figure 8: Land suitability mask
3.5 Land capability model

To identify locations viable for algal biofuel production, information concerning access to roads, settlements (and associated labour force), ports (to import resources and export fuel products), CO₂, saline water sources, and appropriate physical and climate conditions were combined to spatially model production capability (Figure 9). As a base for modelling, the 90 m x 90 m SRTM DEM was used to represent a continuous grid surface across the entire study area. First, the distances to roads were calculated as the distance of each grid cell to the nearest existing road. The suitability mask was used as a barrier for movement from each grid cell to the nearest road so that if a road was constructed from a potential production site to the closest existing road, the new road could not be built through environmentally sensitive lands, Aboriginal heritage sites, water features and conflicting land use/land cover (i.e. the suitability mask). The resulting values were then further filtered so that only grid cells with topographic relief ≤4% slope were retained. The resulting grid was then rescaled from 0 to 1 to combine with other layers in the model.

To develop a layer representing access to settlements and port facilities a grid based cost-distance approach was used. Using the SRTM 90 m x 90 m DEM as a base, the distance from each grid cell to the nearest settlement was calculated. To provide a more realistic scenario of movement from a settlement or a port to a production facility (and vice versa), the distance was first calculated as the overland distance of each grid cell to the nearest road, followed by the distance along the road network to the nearest settlement or port. This approach assumes that in an instance where a grid cell was not adjacent to a road, then a road would be built from the grid cell to the nearest road. As a barrier for movement across the grid cell to the nearest existing road. As a barrier for movement across the 90 m x 90 m grid, the shortest distance from a grid cell to the nearest road could not include a grid cell classified as unsuitable (environmentally sensitive lands, Aboriginal heritage sites, water features and conflicting land use/land cover). In this case, the shortest route to a road was calculated based on the shortest path not encountering a previously mentioned barrier (i.e. path must go around the barrier). The resulting values were then further filtered so that only grid cells with topographic relief of ≤4% slope were retained. The resulting grid was then rescaled from 0 to 1 to combine with other layers in the model.

To develop a layer measuring access to a CO₂ point source, a grid based cost-distance approach was used. Using the SRTM 90 m x 90 m DEM as a base, the distance from each grid cell to the nearest CO₂ point source was calculated. As a barrier for movement across the grid, the shortest distance from a grid cell to the nearest CO₂ point source could not include a grid cell classified as unsuitable (suitability mask). However, for this study it was assumed that CO₂ would be delivered to a production facility via pipeline and a pipeline could be built through an Aboriginal heritage site, environmentally sensitive land, a surface water feature or more economically viable land use/land cover if it followed an existing road (constructed along the right of way). The resulting values were then further filtered so that only grid cells with topographic relief ≤4% slope were retained. The resulting grid was then rescaled from 0 to 1 to combine with other layers in the model.

Distance from each grid cell to the coast was calculated to assess the distance required to pipe saline water to the potential production site. The distance was calculated as the distance from each grid cell to the coast however, as a barrier for movement across the grid, the shortest distance from a grid cell to the coast could not include a cell classified as unsuitable (suitability mask). It was assumed that saline water would be delivered to a production facility via pipeline and a pipeline could be built through an Aboriginal heritage site, environmentally sensitive land, a surface water feature or a more economically viable land use/land cover if it followed an existing road which (constructed along the right of way). Furthermore, grid cells with an
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Elevation of >50 m were excluded from the distance calculation to filter out paths requiring extensive pumping (uphill) and greater associated costs. The resulting values were then further filtered so that only grid cells with topographic relief ≤4% slope were retained. The resulting grid was then rescaled from 0 to 1 to combine with other layers in the model.

![Flow diagram of land capability modelling](image)

Figure 9: Flow diagram of land capability modelling

Finally, the reclassified and rescaled soil grid, and the rescaled productivity grid were further filtered to remove grid cells with topographic relief ≤4% slope. The resulting road, settlement, port, CO₂, and coastal distance grids were combined with the soils and productivity grids (sum) and rescaled from 0 to 1 providing a continuous grid surface representing relative algal biofuel production capability across the study area (Figure 10).
Figure 10: Algal biofuel production capability map
4 Results

The procedures outlined in Section 3 enabled the identification of areas of relative capability for algal biofuel production based on land suitability, access to infrastructure, and climatic conditions. Whilst Figure 10 provides a relative picture of overall production potential, further refinement of these data is necessary to enable actual site identification. This was conducted through highlighting areas where overall potential was more than one standard deviation above the mean. Figure 11 illustrates the distribution of regions with the highest overall modeled algal biofuel production potential.

High levels of algal biofuel production capability exist along the southern coastal reaches of the study area just south of Geraldton. This area is representative of locations with limiting land use conflicts, relatively flat topography, workable soils, access to infrastructure (deep water port and roads) and an available labour force. This region is susceptible to further residential and commercial development as well as tourism which may provide competing economic uses.

A few locations with high production capability exist along the coast between Geraldton and Carnarvon mainly due to close access to the ocean (saline water), limiting land use conflicts, relatively flat topography, workable soils and increasingly ideal climatic conditions. As a limiting factor these areas tend to be further from necessary infrastructure and available viable labour forces.

Moving north, production potential exists in the vicinity of Carnarvon, both north and south of the regional centre. This again, is due to limited competing land use, appropriate biophysical parameters and access to necessary infrastructure. It should be noted that Carnarvon does not contain a deepwater port and therefore any resource importation and product exportation would require road transport to Geraldton over 200 km to the south or Exmouth over 200 km to the north. Furthermore, there is a question concerning the ability of the Exmouth harbour to provide the required infrastructure which would necessitate further road transport to the Dampier Port facility over 400 km north of Carnarvon.

Areas just to the south and southeast of Exmouth also provide algal biofuel production potential as a result of ideal climatic conditions, limited competing land use, high soil workability, and access to necessary infrastructure including a viable labour force. If the town’s port facility is able to provide the necessary infrastructure for production, the region provides many advantages in terms of siting a facility. A large and growing skilled labour force is punctuated by limited economic competition in terms of land use outside the township, and the potential exists for use of either the Indian Ocean or Exmouth Gulf as a saline water source.

The largest areas identified as capable for algal biofuel production exist along the coast from the southwest of Karratha to the northeast of Port Hedland (see Figure 12 for detail). This region provides ideal climatic conditions and suitable land in terms of limited topographic relief and competing land use. This region has access to viable labour forces in Dampier, Karratha, Roebourne, Wickham and Port Hedland and access to port facilities in both Dampier and Port Hedland. Potential limiting factors include low workability of coastal soils and the high frequency of cyclone development during the summer months.

Broome, representing the northern boundary of the study area, does not offer any locations with high algal biofuel production capability.
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Results

Figure 11: Areas identifying highest modelled algal biofuel production potential. Areas with highest capability are shown in red. STD = standard deviation

The above figure represents the whole study area, however the model provides a much more detailed picture if required. To further illustrate the scale of our analysis, Figure X shows a portion of the study area between Karratha and Port Hedland. The minimum mapping unit of 90m x 90m grid cells allows for a high resolution examination algal biofuel production capability across the region. With a fine grained pixel size, identifying contiguous tracks of land...
capably of production with various orientations and configurations is possible. This allows for a more accurate depiction of the suitability of the landscape in identifying a potential production location.

Figure 12 Detail of the region between Karratha and Port Hedland identifying the highest modelled algal biofuel production potential. Areas with highest capability are shown in red. STD = standard deviation
5 Conclusions

In conclusion, our study provides that first detailed geographic assessment of algal biofuel production in Western Australia (and Australia as a whole). We have highlighted the potential for algal biofuel production within the Australian context identifying both opportunities and constraints. We provide a detailed assessment of the most appropriate production facilities within WA incorporating factors specific to the state. Our results identify suitable location along the north western coastline of the WA where ideal environmental characteristics are coupled with access to production input requirements. Our method provides a robust approach for further analysis through the incorporation of production costs and the inclusion of additional parameters as needed. An examination of economic considerations unique to algal biofuel production within WA provides the logical next step in the development of this promising industry with the state. We have developed a detailed techno-economic model of the whole algae biofuels production process based on experience with existing commercial production plant and smaller-scale trials and the best available information on downstream processes such as oil extraction and conversion. In future assessment of suitable sites for algae biofuels production this techno-economic model can be integrated with the current GIS model once some additional data matrices (e.g. the relative construction costs at different locations) can be established allowing the mapping of suitable locations based on the estimated costs of production.
6 References


Identification of algal biofuel production sites using GIS model


Landgate (2011) Topography Data Set. Midland, WA: Western Australian Land Information Authority.


