EnAlgae in context:
An industry overview

2013

Algae: a **solar powered** source of heat, power, fuels, chemicals

Introduction

This **EnAlgae** report presents an overview of the global algae biofuels and bioenergy industry, highlighting the potential of microalgae and macroalgae to address the energy challenges of today. Information is drawn from the largest ongoing algae projects from across the globe and from a selection of the many companies involved in the process of commercialising algal biotechnologies.

Definitions

Algae are a large group of predominantly aquatic, eukaryotic, photosynthetic organisms, ranging in size from single-cell forms to giant kelps

Bioenergy refers to energy generated from any chemical product of recent biological origin

Biofuel refers to any chemical product of recent biological origin that can be used as a fuel

Biorefining refers to the processing of biomass into a spectrum of bio-based products and bioenergy

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Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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Challenges

Over the past 100 years, society has become dependent upon oil reserves and other fossil resources as a source of fuels, energy, chemicals and materials. With fossil resources declining and climate change becoming of increasing concern, it is vital that renewable and sustainable alternatives are developed.

North West Europe is a region where such developments are particularly important. The region is characterised by discrete, highly populated, industrialised zones within an extensive rural landscape containing active agricultural, fishery and tourism sectors. As a consequence, the environment and energy resources are placed under considerable pressure. So much so, that in 2008, the region was reported to have accounted for over 40 per cent of total EU greenhouse gas (GHG) emissions.

Algae could offer part of a solution.

Algae have many benefits over other natural resources as they do not compete directly for agricultural land, can adapt to a range of diverse marine and freshwater environments and can be easily manipulated to produce a wide range of products, from fuels to pharmaceuticals. Importantly, by absorbing CO_2 from the atmosphere, algae can help to mitigate climate change.

History

The idea that algae can be used as a renewable source of energy is not an entirely new concept. Production of methane gas from algae was proposed as early as the 1950s. Following the 1970s oil crisis, the US Department of Energy's Office of Fuels Development initiated the 'Aquatic Species Program' with a focus of developing renewable fuels from high oil yielding algae. The project ran for almost 20 years from 1978 and cost over $25 million. It was terminated during the 1990s once cheap oil became more readily available. In the years following, interest in algal-based technologies subsided.

However, the algae industry has been rejuvenated in recent years due to a growing need to find low carbon, renewable forms of energy. Alongside **EnAlgae**, there are now dozens of projects and more than 100 companies worldwide researching, and investing in, algal biotechnologies.

What are the **consequences** of using up our

Implications

The issues underlying our dependence on fossil resources are significant and manifold. Without the development of sustainable forms of energy and chemicals, it is not only the environment that will suffer, but the economy and society as well.

Economic impacts

The fact that oil is a limited resource means that there will come a point at which production capacity is it at its maximum – so termed ‘peak oil’ – after which a terminal decline in output is inevitable. While there is much debate over when ‘peak oil’ will be reached, the general consensus is that it will occur within 20 years. If at this point demand is still increasing, as it is today, it is possible that oil prices could spiral to the point of initiating a global economic collapse. The ‘Hirsch Report’ written by the United States Department of Energy gives predictions that the economic loss to the US alone due to oil peaking could be measured on a **“trillion-dollar scale”**.

The economic impact of climate change is one of equal concern and has been comprehensively analysed in the ‘Stern Review’, a report written by economist Baron Nicholas Stern for the UK Government. It concluded that in the absence of implementing mitigative action, the cost of climate change to the economy would be “equivalent to losing at least five per cent of global GDP each year, now and forever”. For the UK, this would be a cost of around **£120 billion** every year. When taking into account a wider range of risks, the cost of damage could be up to four times higher. Meanwhile, the cost of mitigating the worst impacts of climate change was estimated at around one per cent of global GDP. In this light, Stern has labelled climate change as

“the **greatest market failure** the **world** has ever **seen**” planet's **fossil resources?**

Environmental impacts

The burning of fossil fuels has increased the abundance of CO_2 in the atmosphere to its highest level since humans have existed on the planet. Of further concern is that the atmospheric CO_2 concentration is increasing at an unprecedented rate. As a greenhouse gas, CO_2 directly causes global warming and influences climate change.

If we fail to reduce our carbon emissions, the impacts of global warming and climate change on the environment - which include rising sea levels and ecosystem disruption and destruction - will intensify. To highlight the magnitude of the problem, the IPCC has estimated that between **20** and **30 per cent** of the **plant** and **animal species** evaluated so far in climate change studies are at risk of extinction by the end of this century if global temperatures reach predicted levels.

Atmospheric CO_2 also causes acidification of the world's oceans. The wellbeing of entire marine ecosystems is at risk from this phenomenon as ecologically important marine calcifying organisms, such as corals, are severely harmed by the carbonic acid produced by the acidification process.

Social impacts

The social implications of exhausting our fossil resources are less direct than economic and environmental impacts but equally important.

Energy shortages could potentially lead to widespread **blackouts** while the health and wellbeing of billions of people could be at risk due to the adverse impact of climate change on food production and water availability. The United Nations have estimated that the number of people affected by water scarcity will increase from 700 million to **1.8 billion** by 2025, largely on account of the effects of climate change. Moreover, by 2030 almost **half of the world's population** is expected to live in an area of high water stress. The UK Meteorological Office has also predicted that with no mitigation of climate change, severe droughts (that now occur on average once every 50 years) will happen every other year by 2100.

What is **algae** and how is it being used to tackle **climate change?**

Microalgae

Microalgae essentially act as single-celled bioreactors, using sunlight and CO_2 to produce a range of valuable products. Many species have high oil contents, which can be extracted and converted to biodiesel. Microalgae can also be used to produce other biofuels such as butanol, hydrogen, methane, ethanol, vegetable oil and aviation fuels. Moreover, these organisms can be utilised to manufacture high value products such as Omega-3 oils which can sell for up to $160 per kilogram. There even lies the potential for microalgae to produce anti-cancer drugs and medicines for malaria.

Where are they grown?

Microalgae have been cultivated on an industrial scale for decades, predominantly for manufacturing human and animal nutrition products, and have been most typically grown in open ponds or raceways. A desire to produce more specific products and use strictly regulated cultivation conditions has meant that use of closed photobioreactor systems have become increasingly common.

How do they compare to other renewable resources?

Microalgae have a photosynthetic biomolecular toolkit that is around five times more efficient than that found in plants and can generate up to 50 times more oil per acre than traditional crops used to produce vegetable oil, according to the San Diego Centre for Algae Biotechnology. They can also help to deliver significant reductions in greenhouse gas (GHG) emissions by replacing products extracted from fossil oil. Yet, importantly, algae have no requirement for agricultural land and so have very little interference with food supply chains.

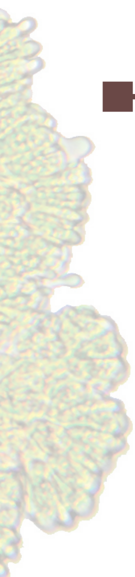
Microalgae can already be used to generate a suite of valuable, bio-based products and this list can only be expected to grow. With the cost of genomic sequencing having reduced substantially over recent years and genetic engineering techniques becoming ever more advanced, the attractiveness of using microalgae in commercial applications has never been greater.

Algae can convert
more solar energy to
than a normal

Why algae?

While many renewable resources can help mitigate climate change and have the potential to offer economic benefits in the long term, sometimes their production comes at a cost to the wellbeing of society. However, because algae do not compete directly for agricultural land, production of algal fuels and products can help to mitigate these social concerns.

As part of the **EnAlgae** project, a thorough evaluation of the political, economical, environmental, social and technological impacts of large-scale algae cultivation will be undertaken. This will help ensure that the commerical manufacture of energy products from algae is fully sustainable across the entire production life-cycle.



Macroalgae

Macroalgae can be used to produce a wide range of products, including pharmaceuticals, cosmetics and agrichemicals. They can also be used as a valuable source of heat and power and are especially suited to use in anaerobic digestion.

Where are they grown?

The harvesting of macroalgae for use in commercial applications dates back as far as the 17th century although large-scale cultivation has only occurred since the 1950s. The algae are typically grown on long-line systems out at sea. Around 15 million wet tonnes are produced each year with activity largely limited to Eastern Asia. Within Europe, commercial production of macroalgae is restricted to France and Spain although experimental research is being performed in the UK, Norway, Ireland and Portugal.

five times
chemical energy
terrestrial plant

How do they compare to other renewable resources?

As well as being capable of producing a wide range of valuable products, many species, such as giant kelp, can grow very quickly when compared to plants. Their main benefit, however, is that they like to be grown out at sea. Not only does this mean that macroalgae do not compete for land but they also do not need to be supplemented with other valuable resources such as fresh water and inorganic nutrients (e.g. nitrates and phosphates).

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EnAlgae is a four-year Strategic Initiative of the INTERREG IVB North West Europe programme. It brings together 19 partners and 14 observers across 7 EU Member States with the aim of developing sustainable technologies for algal biomass production.

What?

The **EnAlgae** project will assess the potential for producing energy and fuels from both microalgae and macroalgae in NWE in accordance with three specific objectives:

- To develop a network of pilot and demonstration sites and identify strategic factors for optimising the algae cultivation environment
- To undertake a technical and economical feasibility analysis to determine if algae use can be of added value in NWE
- To perform a SWOT Analysis to identify the political, economic, social and technological opportunites and barriers for producing energy from algae

How?

A transnational network of research institutes and algae project operators has been coordinated to deliver data for development of a tool that will facilitate stakeholder decision making.

Project partners will also share knowledge and best practice to establish the most promising algal species for commercial exploitation in NWE and to understand cultivation requirements and optimal conditions.

Why?

The potential of using algae for harvesting energy is huge. Yet in Europe, its potential has long been overlooked. Only now is interest starting to grow.

Just like for agriculture, successful large scale algae cultivation requires selection of the most suitable species for the intended purpose, an understanding of the optimal environmental conditions for growth, and consideration of nutritional requirements. For arable farming these factors have been developed and optimised over the course of many centuries. However, algae aquaculture is in its infancy and knowledge of best practice is comparatively sparse. Due to the immediate need for fossil fuel alternatives, intensive coordinated studies are therefore required to quickly understand the best means for commercialising energy and fuel production from algae.

We also live in an era where climate change, food shortages and droughts are becoming of increasing concern. There is therefore a need to understand the sustainability impacts of algae cultivation at scale to prevent any unfavourable outcomes occurring from its commercial exploitation.

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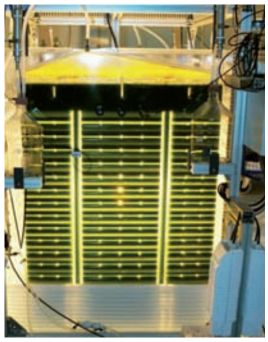
EnAlgae Pilot Facilities

One of the most important outputs for the **EnAlgae** project is the development of an integrated network of algal pilot plants across North West Europe. Information from these facilities is being used to consider technology requirements, economics and environmental aspects of growing algal biomass and converting it to bioenergy in the region. In total there are nine facilities; six of these are dedicated to microalgae cultivation and three dedicated to macroalgae cultivation.




Microalgae facilities

Swansea University (United Kingdom) has upgraded and expanded its tubular photobioreactor facilities which are operated using nutrients from aquacultural, agricultural and municipal wastes. A mobile photobioreactor laboratory has also been developed to extract CO_2 from heavy industry flue gases.

Hochschule Für Technik und Wirtschaft des Saarlandes (Germany) works in the field of closed loop aquatic production. Its facilities include several recirculation aquaculture systems (RAS) for marine fish and crustacean that are coupled with photobioreactors for the production of microalgae.

University College West-Flanders (Belgium) has built a mobile pilot installation; a heated open pond with microalgal bacterial flocs and flue gas injection. It will operate on three different company sites, treating parts of real waste water streams. Biomass will be harvested and then tested for its biogas potential.

Wageningen UR / ACRRES (Netherlands) has built two open pond systems and two open LED light assisted pre-culture basins which provide vital data about how algae grows under different conditions.

Plymouth Marine Laboratory (United Kingdom) has upgraded a large-scale microalgae facility at the Boots company site in Nottingham. It consists of a photobioreactor system which is directly coupled to the emission stack of a gas power station. The aim of the facility is to provide data on cultivation and maintenance of microalgae.

InCrops Enterprise Hub (United Kingdom) is building a pilot facility to investigate how by-products of water purification can be used to grow algae. The information collected will be shared across the partnership to develop understanding of the financial and environmental aspects of growing algae in North West Europe.

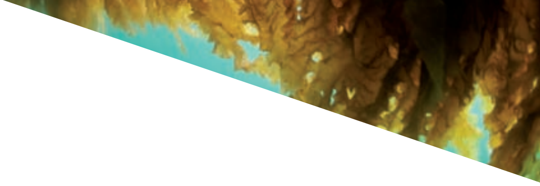
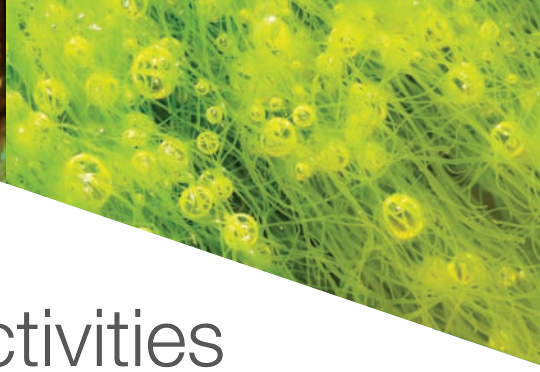
Macroalgae facilities

National University of Ireland, Galway (Ireland) has developed a large-scale hatchery which is being used to grow kelps. This facility aims to standardise and increase the production of macroalgae at sea.

Queen's University Belfast (United Kingdom) is evaluating offshore cultivation methods that will allow sustainable kelp biomass production. QUB is collecting biological, ecological, and socio-economic data to assess the suitability of various seaweed strains for large-scale cultivation.

Centre d'Etude et de Valorisation des Algues (France) is helping to develop and exchange best practice methods for the exploitation of seaweeds. CEVA has set up three sea sites in France for the large-scale cultivation of kelp species.




EnAlgae Activities

EnAlgae Project Launch

1st Dec 2011; Brussels, Belgium

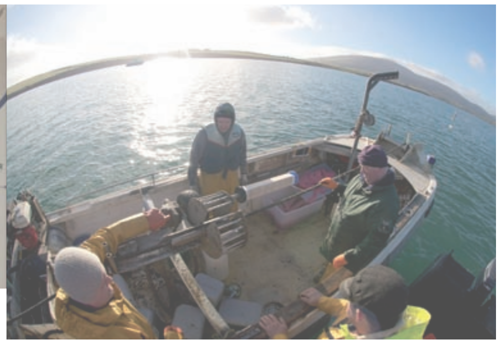
The project was introduced to a broad audience representing the European Commission, government, industry, NGOs and academia. The event involved a moderated discussion on sustainable pathways for algal bioenergy and biotechnology in NW Europe.

InCrops Explore Algae AD

18th Jul 2012; Bury-St-Edmunds, UK

EnAlgae partner InCrops Enterprise Hub brought together a mixture of entrepreneurs, farmers, plant designers and regional government officials to discuss the synergies of emerging algae growth technology with anaerobic digestion (AD).





Seaweed Cultivation Workshop

16th Oct 2012; Galway, Ireland

The National University Ireland, Galway held its first **EnAlgae** seaweed cultivation workshop with the aim of standardising methodologies. It also gave attendees the opportunity to explore the entire seaweed cultivation process.

Hochschule für Technik und Wirtschaft des Saarlandes Photobioreactor Workshop

19th Oct 2012; Völklingen, Germany

EnAlgae partner Hochschule für Technik und Wirtschaft des Saarlandes held a workshop to coincide with an open day at Marine Fishfarm Völklingen. Attendees were shown how photobioreactor advanced recirculation aquaculture systems minimise the impact of the cultivation system on the environment and allow production to remain close to consumers.



EnAlgae Strasbourg Reception

11th Dec 2012; Strasbourg, France

This two-day event was an opportunity to brief Members of the European Parliament (MEPs) and other stakeholders on the progress of the **EnAlgae** project in developing sustainable technologies for algal biomass production, bioenergy, and for mitigating climate change.

Maritime Festival

1st Jun 2013; Ards Peninsula, Northern Ireland

EnAlgae partner Queen's University Belfast treated visitors to a host of activities, which included boat trips and a 'seashore safari', at the Strangford Lough Maritime Festival.

Pilot Reactor Launch

26th Mar 2013; Roeselare, Belgium

Howest, University College West Flanders, launched its mobile algal facility in Roeselare, Belgium. More than 70 people attended the launch event, including members of the local community and industry representatives. Guests were able to tour the new facilities whilst finding out why the development of such technologies is so important.

Upcoming Events

Bioeconomy Seminar

10th Oct 2013, Brussels

EnAlgae is organising a seminar as part of the Committee of the Regions 'Open Days' event to discuss the issues facing Europe in its transition to a bio-based economy. Four relevant INTERREG IVB projects including **EnAlgae** will highlight key issues across the bio-economy supply chain.

Reception at Committee of Regions

Dec 2013, Brussels, Belgium

EnAlgae partners will be showcasing the project to a meeting of the ENVE Committee of the Committee of the Regions in December 2013.

European Biomass Conference and Exhibition

23rd-26th June 2014, Hamburg, Germany

EnAlgae will host a session at the conference to provide a forum for discussion of the latest algal technologies and market trends.

Stakeholder meetings and **EnAlgae** pilot site open days will also be arranged throughout 2014.

Countries **all over the world** are working on **algae**

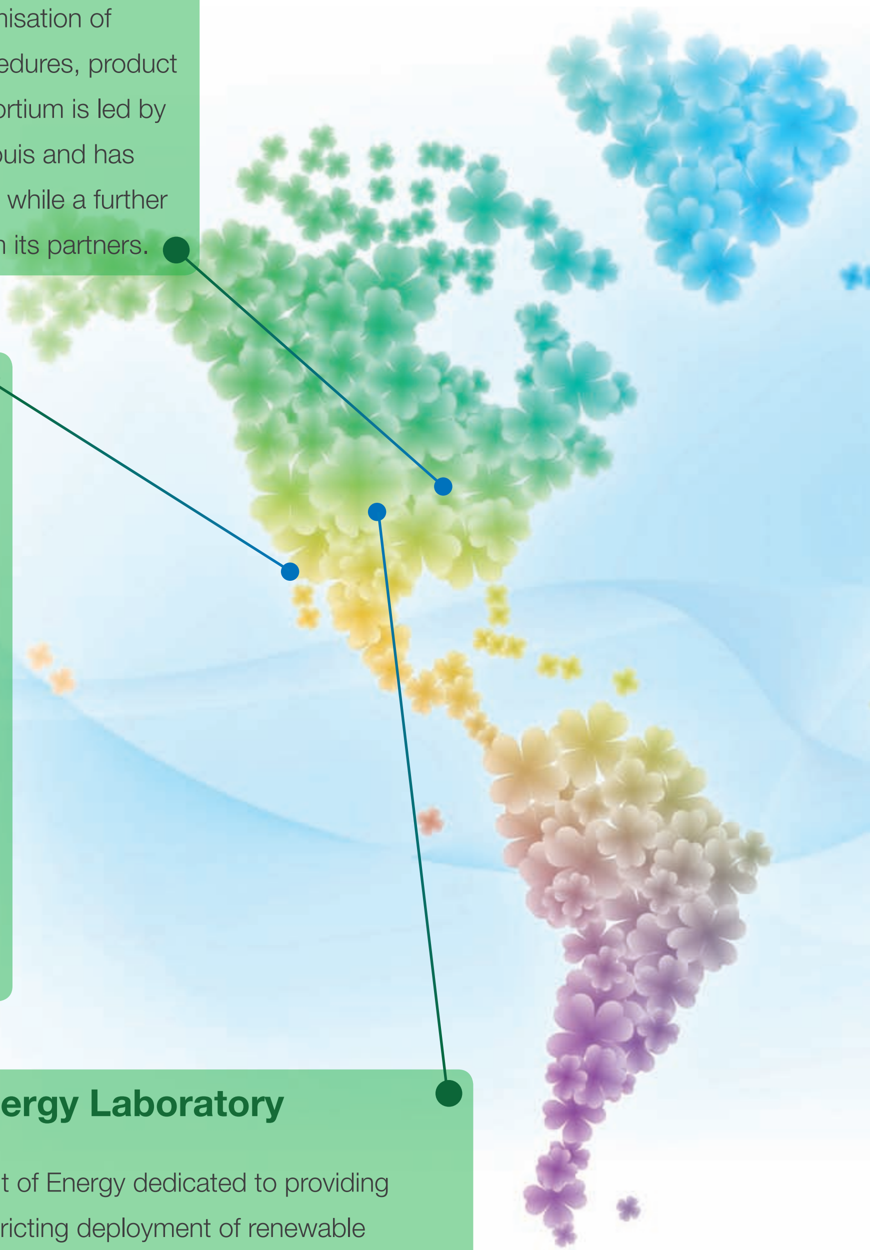
Here are some of the big projects from across the globe...

National Alliance for Advanced Biofuels and Bioproducts

NAABB is a collaboration between 10 different US academic institutions and 15 industrial partners that was initiated to develop new technologies for driving forward the algal biofuels industry. The program has several objectives including optimisation of algae cultivation environments and extraction procedures, product development and sustainability analysis. The consortium is led by the Donald Danforth Plant Science Centre in St. Louis and has been granted $49 million from the US Government while a further $20 million has been committed to the project from its partners.

San Diego Centre for Algal Biotechnology

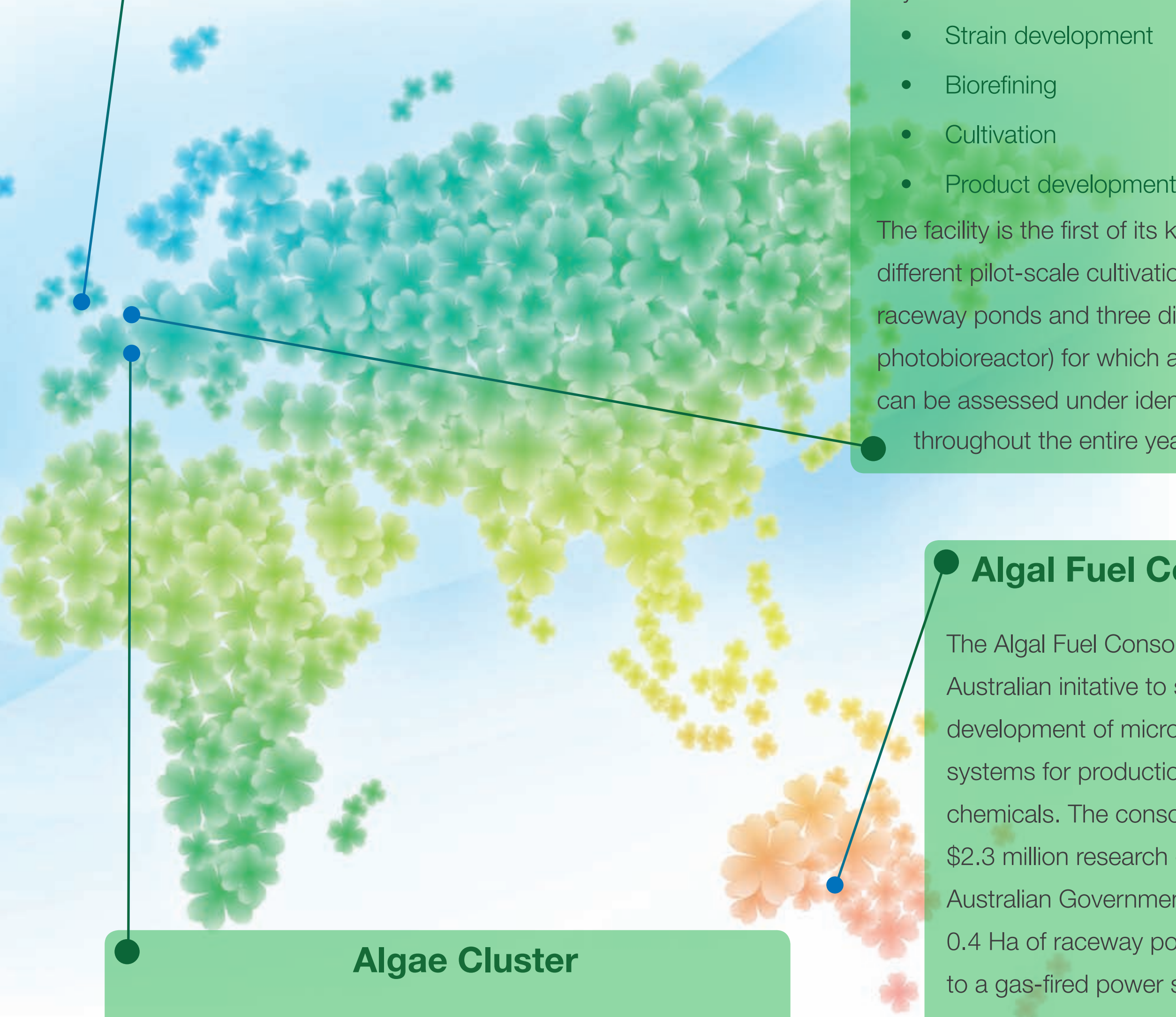
The San Diego Centre for Algal Biotechnology has 10 different research programmes, falling under a number of different themes including biofuel development, CO_2 sequestration, co-product development and strain development. The facility has eight 800 litre circular ponds and two full-sized greenhouses for cultivation of microalgae. In addition to having several sponsors, the centre has also been awarded a $9 million grant from the US Department of Energy to develop a Consortium for Algal Biofuels Commercialisation.



National Renewable Energy Laboratory

NREL is a national laboratory of the US Department of Energy dedicated to providing innovative solutions to the challenges currently restricting deployment of renewable energy technologies. One of the laboratory's key research programmes is focused on the development of microalgal biofuels. The programme has many ongoing projects, several of which are being performed in collaboration with institutional and industrial partners such as the US Air Force Office of Scientific Research, the National Research Council of Canada and Chevron Corp. These projects include the development of a 400+ bioenergy-focused strain collection and techno-economic assessment of algal biofuels.

EnAlgae



AlgaePARC - Wageningen University

AlgaePARC, is a research facility located at the University of Wageningen. The centre was designed to facilitate the commercialisation of algal biotechnological processes and has four key research themes:

- Strain development
- Biorefining
- Cultivation
- Product development

The facility is the first of its kind to have four different pilot-scale cultivation systems (open raceway ponds and three different types of photobioreactor) for which algae productivity can be assessed under identical conditions throughout the entire year.

Algal Fuel Consortium

The Algal Fuel Consortium is an Australian initative to support the development of microalgal cultivation systems for production of fuels and chemicals. The consortium won a $2.3 million research grant from the Australian Government to construct 0.4 Ha of raceway ponds adjacent to a gas-fired power station. The microalgae will be used to absorb CO_2 from the waste flue gases of the plant and use it to produce oils to be refined into biodiesel and high-value products. Sancon Resources Recovery are coordinating the project but will be supported by industry, institutional and government partners.

Algae Cluster

Algae Cluster is an EU seventh framework programme (FP7) that consists of three large-scale industry led projects: **BIOFAT**, **InteSusAl** and **All-gas**.

The programme is aimed at demonstrating the production of biofuels from algae across the entire value chain. Focus areas include strain selection, cultivation, oil production and extraction and biofuel testing.

Growing the **future**

the companies commercialising algae...

While there is much commercial interest in using algae to produce energy, fuels and bio-based products (e.g. chemicals and materials), large-scale production is still currently restricted to a handful of predominantly US-based companies. For most of these, operations are largely focused on the manufacture of microalgal biofuels.

However, full-scale facilities are under construction in the likes of Brazil and Australia and companies such as chemical giant DuPont are now attempting to use macroalgae for developing fuels. Moreover, businesses in Europe, such as BFS Biofuel Systems and Abengoa, are now also beginning to cultivate algae at scale.

Here are some of the main players in the industry

Solazyme

Solazyme is a US-based biotechnology company that produces algal oils for a variety of end products including fuels, chemicals, cosmetics and nutrition supplements. The company has a semi-commercial facility in Illinois capable of producing up to 2 million litres of oil per year and is in the process of developing a commercial facility in Brazil, in partnership with Bunge, that will have an initial operating capacity of over 90 million litres, increasing to 280 million litres by 2016. Solazyme has many commercial partners including Chevron, Dow Chemical Company and Unilever.

Algenol

Algenol is focused on producing ethanol from microalgae. The Florida-based company claims their patented 'Direct to Ethanol' technology enables the production of ethanol for around $1.00 per gallon. In early 2013, Algenol confirmed that it had exceeded production rates of 9,000 gallons of ethanol per acre per year and announced that it expects to achieve sustained production rates above 10,000 gallons per acre per year by the end of 2013. The company intends to complete its first biorefinery in 2013. At full scale, the facility will consist of 17 acres filled with photobioreactors, and will produce 100,000 gallons of ethanol per year.

Sapphire Energy

Sapphire energy is concentrating its efforts on using microalgae for energy applications and are developing 'drop-in' gasoline, diesel and jet fuels. The US company has four facilities spanning California and New Mexico and have developed the world's first commercial demonstration scale algae-to-energy farm. The demonstration plant will produce up to 4 million litres of 'Green Crude' every year once fully operational. By 2018, Sapphire hopes to increase its production capacity to upwards of 250 million litres.

Grown in the **dark**

Algae are incredibly adaptable organisms. While they are renowned for using photosynthesis to create chemical products from sunlight, they can also be grown in the dark using an entirely different metabolic process known as ‘heterotrophic fermentation’. In this process, the algae are given sugars and convert these to a range of valuable oils and biomass.

Solazyme (see page 14) have pioneered the commercialisation of heterotrophically grown algae and are currently using the technique in their manufacturing facilities. The process offers a means to grow the algae in a strictly regulated environment at large scale without the need of developing a system which allows maximum exposure to sunlight.

Aurora

Aurora algae has recently opened its first demonstration biorefinery in Western Australia. The facility was built on a 5,000 acre plot and has the potential to expand to as much as 15,000 acres. The biorefinery could provide as much as 100 million litres of algal oil each year once operating at full capacity. The oils will be used for a variety of applications including biofuels.

Exxon Mobil/Synthetic Genomics

Synthetic Genomics, led by the distinguished geneticist Craig Venter, signed an agreement with Exxon Mobil in June 2009 to optimise scale-up operations in a deal worth more than $300 million. The two companies signed a further development contract in Spring 2013 with an aim to develop enhanced algae strains using advanced molecular techniques.

Du Pont/Bioarchitecture Lab

In 2010, DuPont and BioArchitecture Lab were awarded an $8.8 million dollar fund from the US Department of Energy to develop efficient processes for converting sugars from macroalgae into isobutanol to be used as a biofuel. The programme is being conducted in Southern California and involves more than 60 research scientists.

Abengoa

Abengoa is a Spanish multinational company that develops new technologies for the bio-renewable fuels and chemicals markets. In 2012, the company completed commissioning of its ‘EcoAlga’ plant - a 5,000 m^2 experimental microalgae facility with a direct, industrially-sourced, CO_2 supply. The primary objective of the facility is to demonstrate the techno-economic viability of the industrial cultivation of microalgae for the manufacture of biofuels and animal feed.

BFS Biofuel Systems

BFS Biofuel Systems has developed a proprietary technology that uses cyanobacteria (a form of bacteria closely related to algae) to convert CO_2 into an artificial crude oil it calls ‘Blue Petroleum’. The company’s 50 km^2 ‘Blue Petroleum ONE’ plant in Alicante, Spain, uses CO_2 from a nearby cement works to feed the algae, which are grown in long bioreactors. BFS claim that for every acre of bioreactors installed, five barrels of Blue Petroleum is produced.

To find out more information about the **EnAlgae** project contact the team at info@enalgae.eu.

To join the **EnAlgae** mailing list and receive project and industry updates please register at:

www.enalgae.eu

You can also find us online at www.facebook.com/enalgae and www.twitter.com/enalgae_nwe.

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INTERREG IVB

INTERREG IVB NWE is a financial instrument of the European Union's Cohesion Policy that funds projects which support transnational cooperation. The programme will invest €355 million from the European Regional Development Fund (ERDF) into the economic, environmental, social and territorial future of North West Europe.