Feasibility of Algae Building Technology in Sydney

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Cover image: Conceptual rendering of algae panel installation on Alumni Green. Image courtesy of Atelier Ten.

Table of Contents

Introduction

1.Introduction

1.1 Rationale for the study

The environmental impact of humans on the natural world manifests in various ways. Greenhouse gas emissions (GHG) contribute to the greenhouse effect where temperatures increase and the Earth warms. The total stock of buildings globally and the energy used therein adds significantly to GHG emissions; and it estimated to be around 30% to 40% of total GHG emissions. Historically the majority of emissions emanated from developed countries, however it is predicted in the near future that the level of emissions from buildings in rapidly industrialising countries will surpass emission levels from buildings in developed countries (UNEP, 2009). As such reduction of building-related GHG emissions could have a substantial impact on efforts to mitigate the effects of global warming. Space heating is the main end-use in buildings in developed countries, however appliances are driving the growth of energy consumption with the most common types of end-uses being: heating, ventilation and air conditioning (HVAC) systems; water heating; lighting; personal computers, data centres and electronic appliances; cooking; and refrigerators, freezers, washing machines, dryers and dishwashers (UNEP, 2009).

There are many ways to reduce building-related greenhouse gas emissions; such as increasing the energy efficiency so less energy is used through efficient design of the fabric and orientation. Another option is to convert buildings to use renewable forms of energy such as solar or wind energy. According to Goldenberg in Rosillo *et al.* (2016) renewable energy will dominate energy production in the 21st century.

Renewable technologies have been around for over 175 years. In 1839, Alexandre Becquerel discovered the photovoltaic (PV) effect and described how electricity can be generated from sunlight, when he found that shining light on an electrode submerged in a conductive solution would create an electric current. However, even after much research and development, energy generated by PV continued to be inefficient and prohibitively expensive. Until, in 1941, Russell Ohl invented the solar cell, shortly after the invention of the transistor. Further developments in PV and supporting technologies such as battery storage and smart electricity grid management, and greatly reduced costs through commercialisation, have transitioned PV technology from prohibitively expensive and inefficient to a viable alternative to fossil fuels. In Europe, not only are PV farms common outside of urban settlements generating energy but they are also found on building facades and rooftops providing on-site power.

In the 1950s, the price of solar panels was exorbitant, costing AS$2723.32 (£1,350) per watt in today's money, the only practical use for them was in space on the US Vanguard 1 satellite launched in 1958. Slowly, and then swiftly the price of building a solar cell fell and today it is less than AS$1.14 (£0.55) per watt (The Guardian, 2016). Proliferation of PV panels in Europe, China, US and India has followed the same curve that lead to the market domination of technologies including the car, mobile phones and electricity (The Guardian, 2016). A Deloitte report (2015) noted that sudden, disruptive and largely unpredictable technology shifts occur, making technologies viable and attractive where previously this was not the case. This shift has occurred with solar; inevitably the same thing could happen in time for other 'new' renewable energy technologies.

Globally renewables represented 22% of total energy production in 2013 (Rosillo *et al.*, 2016) although distribution of adoption is very unequal, with the European Union having a 72% share of renewable energy. Australia is lagging currently in adoption innovation with just 13.5% renewables in 2014 (Clean Energy Council, 2014.). Of the various renewable energy technologies, hydro contributes generation (6.2 per cent) to total Australian energy, followed by wind (4.2 per cent), solar (2.1 per cent) and bioenergy (1 per cent) (Clean Energy Council, 2014).

Bioenergy in Australia has had a tumultuous history with support waxing and waning between Governments and consumers. Bioenergy encompasses biogas (methane) from landfill, covered anaerobic ponds, and in vessel waste treatment; and liquid fuels (predominantly biodiesel and ethanol) from a range of sources. Ho *et al.* (2014) provide a good overview of the sustainability issues of a number of these biofuels.

Methane (CH_4) as a component of biogas represents only between 50-70% of the gas volume with most of the remainder being carbon dioxide (30-45% CO_2). Biogas also has only half the energy of natural gas (91% methane; <1% CO_2) (http://www.biogas-renewable-energy.info/biogas_composition.html).

Ethanol has been produced largely via the fermentation of sugars from cane, beets, wheat and more recently cellulosic sources, whilst biodiesel has been produced from tallow, waste cooking oil, canola and other oil seeds / plants using a traditional alkali treatment process. Several more recent developments have included the application of pyrolysis to produce biocrude oil from various sources – such as mallee timber, food waste and effluent.

Almost with out exception the raw biomass material for liquid fuels have been derived from arable land or use precious fresh water that could otherwise be used for crop or animal production. Algae is another form of biomass that has been investigated heavily (particularly in the US and Europe) for its ability to produce large amounts of biomass with very few inputs. The resultant oil or sugar components can then be converted into energy. The challenge has been finding the right organisms, and the right production, processing and extraction processes (Brennan and Owende, 2010).

Global biomass energy production in 2014 reached 88 GW, including 116.1 billion litres of biofuels (Rosillo *et al.*, 2016); as such bio-energy is no longer a transition energy source. The Clean Energy Council's Bioenergy Roadmap (Clean Energy Council 2013) proposes that by 2020 the contribution from Australian biomass for electricity generation could be 10,624 GWh per year which is six times the 2013 generation. Long-term potential for electricity from biomass in 2050 could be 72,629 GWh/year, approximately 40 times the 2013 level (Clean Energy Council 2013). CSIRO noted the potential for second-generation biofuels to replace between 10% and 140% of current petrol only usage over time (Bio fuels in Australia, RIRDC 2007).

This study explores the potential for algae biomass to provide a renewable source of energy for buildings in NSW Australia. While energy production is the centre of much of this paper's discussion, biomass also can serve many other end uses. Those multiple uses for biomass have been presented as the 6 Fs:

1. Food
2. Feed
3. Fuel
4. Feedstock
5. Fibre
6. Fertiliser

Biomass has the potential to meet numerous human needs and globally attention is turning towards different types of biomass. This study explores the potential for algae to provide a renewable source of energy for buildings in NSW Australia.

In addition to being able to produce biofuel and heat energy, algae also sequesters carbon (Subhadra and Grinson-George, 2010). Biomass for energy has an important role to play in climate change mitigation (Rosillo *et al.*, 2016), with the Worldwatch Institute (2006) noting that algae could be grown as a biofuel although there are concerns about long-term stock availability (Rosillo *et al.*, 2016:186). The range of algal products can be used in cosmetics, pharmaceutical products and food supplements particularly where those algae have high levels of protein (Spolaore *et al.*, 2006. Subhadra and Grinson-George, 2010).

It is possible that algae building technology may make the intensive culture of algae viable within urban and industrial environments. To date, one building powered by algae has been designed and built in 2013 in Hamburg, Germany (Arup, 2013). This is in the northern hemisphere in a cool climate, whereas Australia (generally warmer climate) has eight climate zones within its borders making the selection of materials, organisms and products possibly more challenging. The question arises; *is algae building technology feasible in NSW? And if so, what form could it take? And what benefits may it provide?*

1.2 Scope of project and limitations

This report adopted a desktop study of secondary sources to explore the technological, economic, environmental, social, and regulatory drivers and challenges to algae building technology. This was followed with some primary research consisting of a series of semi-structured interviews with key stakeholders to ascertain their perceptions of the potential drivers and challenges with regards to algae building technology.

The limitations of the study are that this is a very new technology, with only one building designed and built in 2013 in Hamburg Germany. Participants have no direct experience with the technology and their perceptions are based on limited impressions of algae buildings in the media and their experience of applying other newly emerging technologies to the built environment. A further limitation is that project outputs are based on the empirical evidence from the only one building in Germany, in a cool temperate climate zone, which may be very different for a number of reasons highlighted in the report. A demonstration (prototype) algal building panel operated in Australia would provide additional empirical evidence of production rates from an alternate climate.

Algae Buildings

2. Algae Technology in the Built Environment

2.1 Algae explained to non-specialists

Algae are either single-celled microbes (microalgae) or multi-celled organisms (macroalgae or seaweeds) that photosynthesise. Algae grow from the tropics to the poles, in freshwater, saltwater and in the soil. For the most part, we are only describing microalgae in this report. Algae need light, nutrients and CO_2 to grow and produce new biomass. The biochemical diversity of cellular products produced by algae is immense and therefore the products that can be "grown" in these cells can also be used across a wide range of industries. Algal biomass can be used in biofuels, human food supplements, functional foods, feedstock for livestock, fishmeal for aquaculture, bioplastics, industrial enzymes, pharmaceuticals, nutraceuticals, the list of applications is virtually endless.

2.1.1 Algae as a biofuel

To convert algae from cells growing in water to a final product requires some process engineering. Firstly, the cultured cells need to be filtered, flocculated or centrifuged (de-watering) once the cells are more concentrated, usually they need to be ruptured to access the compounds of interest such as omega-3 oils or proteins. The product must be chemically separated from the cell debris and purified to the level required for the specific product. To convert the oils (lipids) into a biofuel requires additional chemical processing such as hydrothermal liquefaction (high temperature and high pressure conversion of oil to hydrocarbon).

2.1.2 Existing Algae Building Technology – BIQ Hamburg

In 2013, a team of designers including building engineers Arup, Strategic Science Consult of Germany, and Colt International designed the BIQ House for an International Building Exhibition (IBA) in Hamburg. 200m² of integrated photo-bioreactors in 120 façade-mounted panels, generate algal biomass and heat as renewable energy resources in this low-energy multifamily residential building (see Plate 1). The algae façade panel system also provides additional benefits such as thermally controlled microclimate around the building, noise abatement and dynamic shading to deliver the full potential of the technology (Arup, 2013). Arup claim the system is suitable for new and existing buildings (Arup, 2013).

Plate 1 BIQ House Hamburg Elevation
Source: Colt 2013

Plate 2 BIQ House Hamburg Elevation
Source: Colt 2013

The microalgae in the facades are cultivated in flat panel glass bioreactors, measuring 2,500mm x 700mm x 90mm. The bioreactors are mounted on the south-west and south-east elevations of the four-storey residential building (as shown in Plates 2 and 3). The biomass and heat generated by the façade are transported by a closed loop system to the energy management centre in the basement, where the biomass is harvested through floatation and heat is recovered from the water-algae solution by a heat exchanger (See Plate 4). As the system is integrated with the building services, the excess heat from the photo-bioreactors (PBRs) can be used to pre-heat domestic hot water, warm the building interiors, or may be stored seasonally in an aquifer under the building for later use. The algae biomass is taken off-site, converted to biogas, and the biogas is returned to the building where it helps power a small-scale combined heat and power micro-turbine, generating electricity and more heat for the building.

Known as "SolarLeaf", the façade system is the result of three years of research and development by Colt International based on a bio-reactor concept developed by SSC Ltd and design work led by the international design consultant and engineering firm, Arup (Arup 2013). The German Government's "ZukunftBau" research initiative provided funding for the innovation. SolarLeaf provides around one third of the total heat demand of the 15 residential units in the BIQ house.

The advantage of algal biomass is that it can be combusted for power and heat generation, and it can also be stored with virtually no energy loss (Arup, 2013). Moreover, cultivating microalgae in flat panel PBRs requires no additional land-use and is not unduly affected by weather conditions. In addition, the carbon required to feed the algae can be taken from any nearby combustion process, for example from a boiler in a nearby building. The result is a zero net carbon emission with no carbon emissions entering the atmosphere and therefore helping to mitigate climate change (Arup, 2013).

Plate 3
BIQ House Hamburg Elevation
Source: Colt 2013

Microalgae absorb sunlight, and therefore the bioreactors act as dynamic shading devices for the BIQ (as shown in Plate 2). The amount of sunlight absorbed, and thus shading delivered to the building, depends on the density of algae inside the bioreactors. The algae density in turn relies on the algal species, the harvesting regime and available carbon dioxide. These conditions can be adjusted to suit any installation. Algae density also depends on available sunlight and on the temperature of the growing solution inside the bioreactors, both factors of the bioreactor's specific site and its location in a broader geography and climate. When there is more sunlight available, the algae grows more rapidly – providing more shading for the building (Arup, 2013) and this could make algae building technology more productive in a sunny country such as Australia.

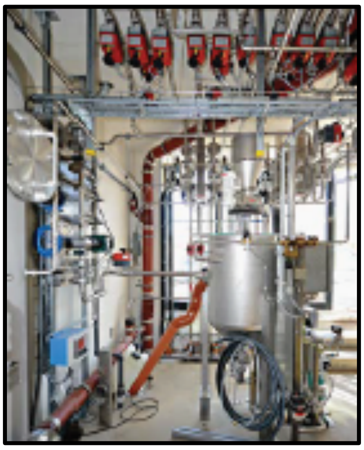

Plate 4 BIQ plant room
Source: Colt 2013

According to Arup (2013), the flat photo-bioreactors (PBRs) used on the Hamburg building are highly efficient for algal growth and need minimal maintenance. The PBRs have four glass layers: a pair of double glazing units (DGUs) creating between them a 24-litre capacity cavity for circulating the growing medium. The cavities within each double glazing unit are filled with argon gas to minimise heat loss. The outer glazing pane comprises white anti-reflective glass, while the glazing on the inner face can integrate decorative glass treatments. The PBR assembly is held together by steel U-section frames that resist the significant outward static pressure from the water within the cavity. See Figures 1 and 2.

The growing medium is pumped into the PBR from below, via tubing that runs along the supporting frame structure, and similarly it flows out of the top of the panel and back to the central energy plant. See Figure 2, section diagram.

At set time intervals compressed air is introduced to the bottom of each bioreactor. The gas emerges as large air bubbles and generates an upstream water flow and turbulence to assist the algae to take up carbon dioxide (CO_2) and move the cells into less bright parts of the cavity. Simultaneously, water, air and small plastic scrubbers wash the inner surfaces of the panels (Arup, 2013). All servicing pipes for the inflow and outflow of the culture medium and the air are integrated into the panel frames.

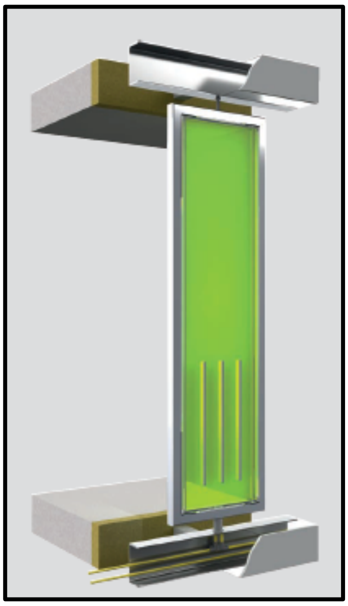

Figure 1 PBR diagrammatic view
Source: Colt 2013

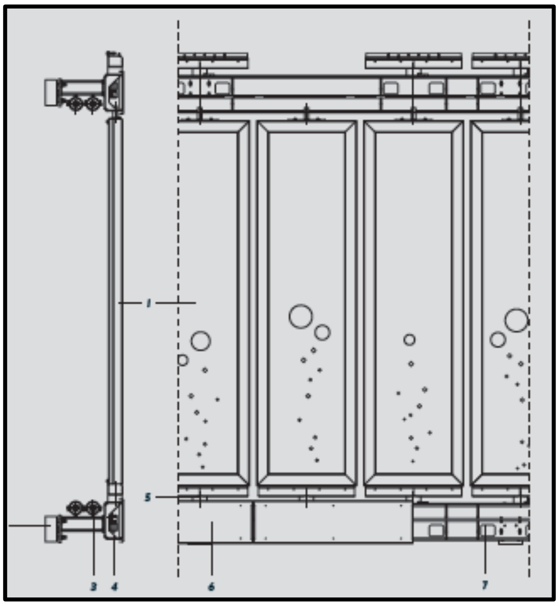

Figure 2 Section and elevation of the photo-bioreactor in the BIQ building
Source: Colt 2013

1. SolarLeaf external louvers
2. Brackets with thermal breaks for the transfer of loads to the primary structure
3. Pipework for the medium to enter and leave
4. Sub-frame and rolled steel U section
5. Pivot fixing allowing rotation
6. Metal cladding
7. Supply of pressurised air controlled by magnetic valves.

The temperature of the water within the PBRs can be controlled somewhat by the speed of the fluid flow through the panel, with lower flow rates allowing greater time for the sun to warm the water as it passes through, and by the amount of heat extracted via heat exchangers in the central plant. The maximum temperature allowed within the BIQ bioreactors is around 40 degrees Celsius, as higher levels would harm the microalgae. The system can be operated all year round, although we have been informed that the system in Hamburg has been shut down over this past winter for maintenance (Arup Schepers, 2016).

Note that these temperature constraints pose several challenges to applying directly the BIQ system in Australia. First, the relatively low maximum PBR temperature limits the practical use of the extracted heat to mainly a pre-heating function for other building systems. Furthermore, the maximum growing temperature for the kind of algae used in the German panel may limit panel use to cooler regions of Australia as air temperatures can exceed 40 degrees Celsius in much of the country. However it is possible also to use other algae types which are able to tolerate higher temperatures.

According to Arup (2013) the efficiency of the conversion of light to biomass is currently around 10% and available light to heat is roughly 38%. Including additional energy captured from the biogas generated by the algae, the total solar energy conversion efficiency of the system is 56%. Note that these figures are all relative to the length of the daylight period and the time that sunlight is incident on the building facades. The total energy system conversion efficiency is 27% relative to the full available solar radiation incident on an unobstructed building roof. By comparison, PV systems yield an efficiency of 12-15% and solar thermal systems 60-65%, when placed optimally to capture the total available solar radiation. Figures 3 and 4 show estimated yield and conversion for an algae building façade located in Munich Germany.

Figure 3 shows that where global radiation energy in Munich measures 1250 kWh/m^2 p.a half (550 kWh/m^2 p.a) this energy is lost due to reflection, exposure and orientation of the algae panel. 220 kWh/m^2 p.a. of energy (40%) is produced as heat energy which is distributed for use in a building, via hydronic heating systems. The biomass component is 50 kWh/m^2 p.a (10%) which can be converted to biogas where 40 kWh/m^2 p.a energy is produced. Each component; heat, biomass and biogas results in CO_2 reductions of 0.04 t/m^2 p.a, 0.015 t/m^2 p.a and 0.014 t/m^2 p.a respectively.

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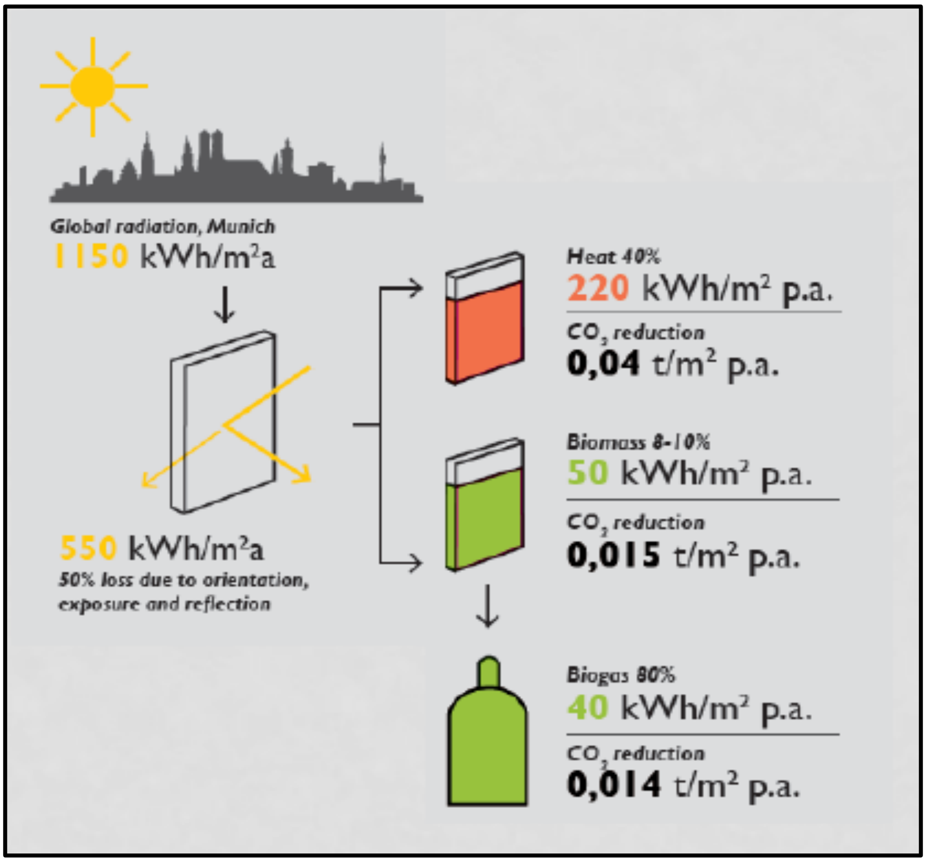
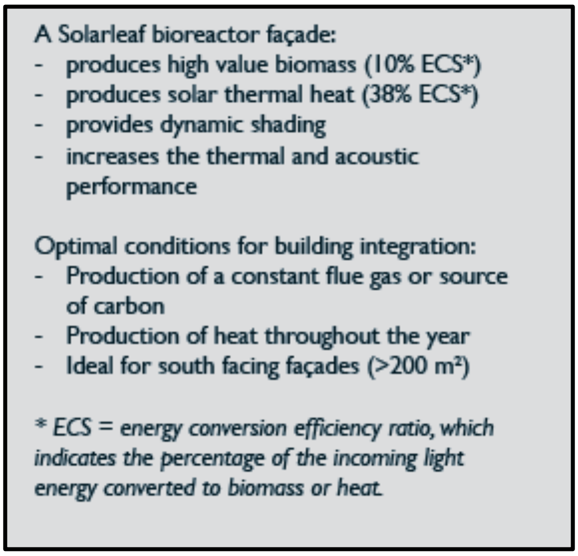


Figure 3 Estimated calculated energy yield of bioreactor sited in Munich
Source: Colt, 2013

Given that the total energy conversion of the BIQ algae system is notably lower than that of conventional solar hot water panels, the BIQ building's bio-responsive façade necessarily aims to provide energy directly to several building services systems, to provide additional energy benefits through summertime shading, and by providing a biomass stock for additional use.

The BIQ team claim a key to a successful implementation of PBRs on a wider scale will be cooperation between stakeholders and designers (Arup, 2013). It is a new technology that benefits from strong interdisciplinary collaboration, combining skills in environmental design, façades, materials, simulations, services, structural engineering and control systems (Arup 2013). It is also argued that take up and acceptance of the technology requires an understanding and view of the systems' benefits for owners, users, and built environment professional such as planners, surveyors, project managers, contractors, quantity surveyors, certifiers property managers and facility managers.



A Solarleaf bioreactor façade:
- produces high value biomass (10% ECS*)
- produces solar thermal heat (38% ECS*)
- provides dynamic shading
- increases the thermal and acoustic performance

Optimal conditions for building integration:
- Production of a constant flue gas or source of carbon
- Production of heat throughout the year
- Ideal for south facing façades (>200 m²)

** ECS = energy conversion efficiency ratio, which indicates the percentage of the incoming light energy converted to biomass or heat.*

Figure 4 Energy efficiencies and conversion rates
Source: Colt 2013

2.2 Built environment professionals and other stakeholders

Within the built environment various professional practitioners and stakeholders possess knowledge and skills which they exercise in respect of design, engineering (including structural, mechanical, electrical, and façade), valuation, property management, cost management and control, planning, building certification and regulations. Each professional and stakeholder possesses different expertise and skills, which they exert at different times during the project.

They belong to a variety of professional bodies for example, the Royal Institution of Chartered Surveyors (RICS), Australian Property Institute (API), Australian Institute of Architects (AIA), Australian Institute of Quantity Surveyors (AIQS), Australian Institute of Building Surveyors (AIBS), Chartered Institute of Building Services Engineers (CIBSE) and the Association of Refrigeration and Heating Engineers (AIRAH). Each professional body sets minimum standards and educational requirements of members as well as requirements in respect of on going continuing professional development (CPD). Membership is a mark of the expertise and quality of these professionals for the clients. Industry bodies represent specific manufacturers and installers; such as the Australian Window Association (AWA).

Projects commence with inception, which comprises initial plans and ideas to assess economic, social and environmental feasibility. Planning approvals are sought for permission to develop the land or site for permitted uses. Valuation surveyors ensure the proposed development will be economically profitable, and during later phases of a building lifecycle they may be involved in the sale or leasing of property. Initial designs are explored and viable options worked up in further details. Depending on the scale of the project structural, façade, electrical and mechanical engineers will propose and evaluate solutions in respect of the building form and structure, facades, lighting, heating, ventilation and air conditioning, whilst Architects engage in the overall design and space planning aspects. Quantity surveyors prepare procurement and tender documents and manage costs during the construction phase. Fire engineers assess compliance with fire regulations. Depending on the scope of the project it may be managed by a Project Manager. Within the last decade or so environmental and sustainability consultants have emerged with regards to design, maintenance and operation of buildings. These professionals also advise with regards to sustainability rating tools such as Green Star in Australia. Together with the design team they will affect the types and extent of sustainable and environmental technologies and specifications adopted in developments.

Some stakeholders work for local authorities and advise at the city scale on regeneration and planning matters. These stakeholders can influence the types, densities and scale of permissible developments, which occur in our urban environments. Many city level stakeholders are committed to sustainability in the built environment and actively encourage new initiatives and ideas. For example, the City of Sydney target is to reduce emissions from the local government area by 70 per cent by 2030 based on 2006 levels.

Given the different expertise and educational backgrounds of the many built environment professionals and the different interests of the various stakeholders, they all have different knowledge, views and ideas in respect of the technical, regulatory, economic, environmental and social feasibility of algae building technology in Sydney and NSW.

Research Methodology

3. Research methodology

This was a qualitative research study adopting the characteristics of an inductive, holistic and naturalistic approach as advocated by Silverman (2010) seeking to establish the opinions of the research population, here experienced professional practitioners and stakeholders in the built environment (Naoum, 2003: 38-43). The researchers wanted to gain an in-depth overview of the different issues perceived by various built environment stakeholders with regards to algae building technology. Time, finance and physical distance allowed the use of data collection via semi-structured interviews.

The semi-structured interview questions were designed using best practice methods (Moser and Kalton, 2002; Robson, 2002) and comprised seven sections and lasted up to an hour (see Appendix 3). Questions were generated through a combination of information derived from the desk-top study, direct consultation with research panels and expert advice. Given the novel nature of the technology an information sheet (Appendix 1) was sent to potential interviewees to give them some understanding and background on which to base a reasonable interview. The semi-structured interview allowed the researcher and interviewee to explore the issues particular to that professional area covered by the interviewee. For example, the regulatory aspects featured more with the certifiers and cost aspects more so with quantity surveyors. The semi-structured interview asked about participant's background and experience in order to gain an understanding of the participant's strengths and practical experience with sustainable technologies both in Australia and overseas. Interviews were conducted in NSW and Victoria from January and April 2016. The data was analysed using a content analysis approach (Silverman, 2010). Similarities and differences between the various stakeholders were identified and grouped.

Results & Interpretation

4. Results and interpretation

In total, 23 interviews were conducted with built environment professionals working in NSW and Victoria from the following professional disciplines:

Architecture
Civil engineering
Structural engineering
Chemical engineering
Façade engineering
Services Engineering
Mechanical Engineering
Planning
Building construction
Building certification
Project Management
Building Surveying
Property Development
Sustainability Manager
Valuer
Quantity surveying

Given the breadth of professional expertise covered by these participants, they were able to reflect on most aspects of the technology from costs and value, to technology, design, construction and installation, to maintenance and operation, and to the regulatory and health and safety aspects.

The participants were largely very experienced professionals, who are highly qualified in respect of vocational educational and professional qualifications. The majority belong to professional bodies including:

1. The Royal Institute of British Architects (RIBA)
2. The Royal Institution of Chartered Surveyors (RICS)
3. The Planning Institute of Australia (PIA)
4. The Australian Property Institute (API)
5. The Chartered Institute of Building Services Engineers (CIBSE)
6. Association for Project Management (APM)

They also have considerable professional experience ranging from 6 to 40 years, with the median experience being 29 years. This experience has been gained in Australia as well as overseas. Most participants have worked overseas particularly in the UK, Middle East and Asia. Significantly, most have senior management roles in their workplaces. Furthermore, most have had direct experience of dealing with complex projects and sustainability technologies. In summary, the participants have the requisite levels of experience that allowed them to reflect on algae building technology and the possibility of changes that have occurred over time based on their experiences.

4.1 The drivers and barriers to adoption

Each of the professional groups was asked to consider the technology from their area of professional practice. In this respect some emphasised technical and engineering aspects, whereas others focussed on regulation and value aspects. Some were concerned with design, others with construction and others with the operational phase of the building lifecycle. In this regard the interviews have managed to capture a broad range of issues from the professional disciplines /stakeholder groups across the whole lifecycle of buildings.

4.1.1 Environmental issues

The environmental issues can be broadly grouped into positive aspects and concerns.

Carbon abatement

On a positive note all participants commented on the reduction in carbon, which results from algae absorbing carbon dioxide during photosynthesis. Subhadra and Grinson-George (2010) state that algae capture '2 pounds [0.907 kg] for each pound [0.453 kg] of algae produced'. Adoption of this technology would lead to lower building related emissions; however some concerns were expressed about the total carbon associated with design, construction and occupation or the whole life cycle. There were concerns expressed about the embodied energy of the technology, which would vary depending on the materials used as well as the life expectancy of the technology.

Innovation

Innovation and development of a new energy source for buildings was seen as a positive. If implemented on a larger scale some interviewees saw potential for a contribution to the reduction of the Urban Heat Island (UHI) effect. The planner and property manager also saw potential for reduced loading of the existing energy infrastructure. As urban settlements increase in density the pressures on the existing infrastructure will mount.

Bio Building Technology

Not surprisingly the bio-engineer noted the need to adopt biology in buildings, which has been advocated by many in the sustainable building community. The microalgae academic also raised the possibility of using the biomass for sale to other industries, for example the pharmaceutical companies or for the manufacture of sustainable fabrics. The issue of food production was raised by a number of interviewees, however discounted by the microalgae academic because of the amount of health and safety regulations, which surround food production, although this could change in future. It is possible that revenue from sales of product could offset energy costs for occupiers and owners.

Green Building Rating Tools

Another driver for some developers and owners might be to attain innovation points in the Green Star building-rating tool. However, as a Valuer noted, *'it's only green when it's installed and operating – if not it's a white elephant'*. A number of interviewees spoke about other new sustainable technologies adopted in various Australian buildings, and awarded green star points, that had either not performed as designed or had not performed at all. There are issues about the sustainability of such innovations. Furthermore, it is a very public statement by an owner to adopt new technologies and no one wishes to be associated with something that fails to perform as anticipated. This is a risk that many will consider very carefully. Therefore, some piloting or proof-of-concept, and performance in NSW was seen as a good way of minimising risk. Another option is to design part of a building to accommodate the technology as a trial, and which could be easily removed and replaced with an alternate façade if required.

Other renewables

A frequently expressed view was that other renewables such as solar, PV and wind power all produce more energy than algae. The engineers stated that solar produced about 1400 kwh/m^2/yr. in Australia, which is *'about forty times more than the Hamburg building does currently'*. However, a counter to this argument is that production rates in Australia for algae may be higher because we have more sun, over longer periods of the year. The Hamburg building is shut down during the winter periods due to lack of sufficient sunlight for photosynthesis and maintenance, that would not be an issue here, whereas overheating could be (Colt, 2013). Furthermore, when other renewables were first introduced, and their costs compared to established technologies such as coal, gas and oil they were found to be prohibitively expensive (Guardian, 2016). Additionally, as the technology evolves and greater market penetration occurs over time, economies of scale are realised.

Contamination

Many expressed concerns about contamination and leaks and the technological aspects are covered below. The issue is that some algae (such as cyanobacteria) contain hepatotoxins and neurotoxins, which are all deleterious to human health to some extent (Bell and Codd, 1994). Furthermore any damage or leakage could also cause odours. So whilst there are many environmental benefits arising from the technology, there are also valid, but not insurmountable concerns which will need to be addressed. Table 1 summarises the environmental issues raised by participants.

Table 1 Environmental issues raised by participants (Source: Authors)

1. Biomass and biofuel are good for the environment
2. Develops another fuel source
3. Sequesters carbon
4. Reduces carbon footprint
5. Lower greenhouse gas emissions
6. Mass adoption could help lower urban heat island effect in urban settlements
7. Reduces loads on existing infrastructure
8. Need to adopt biology in built environment
9. Could produce sustainable fabrics as a by product
10. Can claim innovation points in green building rating tools
11. Potential protein source for food production
12. Other renewables produce more energy
13. Leaks and potential contamination
14. Food not viable as many regulations governing production
15. Complexity of biological systems
16. Current environmental benefit is negative within the building lifecycle

4.1.2 Technological issues

Not surprisingly given the technical professional background of the majority of the participants, a broad range of technological issues and many questions were raised repeatedly.

Climate

Climate was raised as an issue in terms of being different from the Hamburg location and what that would mean for production rates. Secondly the amount of, and intensity of, the sunlight in NSW was also expected to result in higher rates of biomass production. This might also result in different maintenance issues with regards to cleaning, for example, do higher rates of production require more frequent cleaning of the pipes and glass panels?

Lifespan and durability

There were numerous discussions with regards to the anticipated lifespan and durability of the technology. For example, there are glazing panels semi-filled with fluid connected by inlets and outlets. There are also pipes distributing the growth media to the panels and for removing the growth media (with algae) to the plant room for processing. Within these pipes there will be valves.

It will be necessary to pump the fluid at certain rates and at certain temperatures to assure optimum production and to keep the algae alive and to avoid putrification or rotting of the algae. There were various views expressed in respect of traditional glazing technology lasting for 10 years (engineer) as an algae-panel and a consensus that a minimum design life should be around 20-25 years. Many thought that reference to domestic aquarium-based technology would be useful for designers as there is a history of designing, constructing and maintaining installations filled with water. The engineer from Arup did note that problems had been experienced with the seals in the Hamburg building and this, too, is an area requiring further investigation.

Maintenance

Maintenance was raised as an issue and it was noted that as an unknown technology, this would require a programme of training and education in the trades and professions to ensure maintenance was undertaken in a timely way to ensure continued optimum performance. There is a perception that maintenance is going to be fairly onerous, along the lines of maintaining cooling towers where *Legionella* bacteria are a health issue for building occupants. This concern may be heightened because no one yet has direct experience with such technology and installations. The 'unknown' tends to heighten risk awareness. Furthermore, training and education is also needed for Building or Facility Managers, Property Managers, as well as the production of manuals for these professionals. In particular, and importantly, there is a need to educate and train Australians with this technology rather than reliance of overseas professionals.

Competition with other renewables

Many participants raised the issue of unfavourable comparisons in terms of performance and costs with existing renewable technologies, and this is true at this point in time. However, looking at the history of the evolution of renewables such as PV, there have been 'technology shifts' which move developments forward at a fast rate, the Tesla battery announced in 2015 is one such example. Whereby the storage of solar power has been greatly enhanced and has become more viable as are result. These 'technology shifts' result in lower costs and greater efficiency. Furthermore, there is also a tipping point in terms of adoption where, economies of scale are achieved and this results in lower costs. There was a view that the technology is so innovative, it would attract much interest from built environment stakeholders.

Structural issues and façade design

A structural issue raised by participants was that the weight of the algae façade would require support for dead and live loads, for example, the weight of the panels with their growth media and for wind loads. The additional weight of the façade may require additional strength and incur additional costs, in the structural frame or structural wall. One approach to minimising this would be to explore using lightweight structural materials, where possible, in the façade design.

Building adaptation

The issue of building adaptation came up. In many buildings, adaptation occurs often quite shortly after construction and occupation. The drivers of adaptation can be technological, economic, social, environmental, locational or regulatory (Wilkinson, 2014). This is known as obsolescence and the drivers can be unpredictable in many instances. Alterations to building facades are less common because of the costs involved, but it is an issue to bear in mind (Remoy & Wilkinson, 2015). One way to reduce the consequence of obsolescence and the need for adaptation is to design components so that they can be disassembled and relocated when no longer needed. The notion of reuse is familiar to the industry though not adopted as often as it could be. There is an opportunity here to demonstrate leadership in this aspect of design.

Algal production rates

With production rates, participants generally felt that because NSW has a sunnier warmer climate than Hamburg algal production should be higher. However, a few also raised concerns about over production or heat gain into the building. The Services Engineer noted that the panels might cause radiating heat to pass into the building causing internal temperatures to increase, if the panels were designed to grow algae in a solution temperature higher than normal peak ambient temperatures. A potential solution suggested to address the issue of excess heat gain from sunlight might be to introduce a louvre or shading system outside the panels, or an additional glass layer; this approach could have the additional consequence of slowing down production rates. This solution would also add costs and time to construction and costs to maintenance budgets, although benefits may outweigh these issues, and; this is another aspect requiring further investigation and trialling. Another solution proposed may be to use the triple glazing approach and an air barrier (on the innermost layer) as both a limiter on heat and noise transfer.

The shading issue may also be addressed by looking at double skin façade technology, such as that applied to 1 Bligh St, Sydney. This is a 6 Star (the highest score possible) Green Star building completed in 2009. It is the first building in Sydney to adopt a double skin technology. The double-skin façade is a system of building comprising two skins positioned in such a way that air flows in the intermediate cavity. The ventilation of the cavity can be natural, fan supported or mechanical. Double skin façade design is predicated on the idea that external walls respond dynamically to varying ambient conditions, and can incorporate a range of integrated sun-shading, natural ventilation, and thermal insulation devices or strategies. Early solar passive design is perceived as a precursor to modern double skin systems and the technology is acclaimed as environmentally responsible design.

Another variation in façade design is where the internal spaces are designed in such a way that one side of the building is given over to vertical transportation, such as lifts and stairs and rooms which do not require window openings. 88 Phillip Street in Sydney, a Renzo Piano award winning building, has such a façade. This design might offer a large wall area for panels where radiant heat gain may not impact immediately on occupants. Or a light coloured wall surface would diminish heat gain into the building.

Blueprints and guidelines

All stakeholders noted the absence of a 'blueprint' to follow. Therefore algae panel information and design guidelines are needed by the industry at all stages of the building development process: inception, feasibility, construction, commissioning, occupation, adaptation, decommissioning and demolition. This will give stakeholders and professionals a framework to adopt, reducing their exposure to risk. To be adopted widely, awareness will need to be raised and design information will have to be disseminated widely across all property stakeholders, from owners to designers to installers to site staff.

Performance Clauses In Green Leases

The Valuer made a good point regarding performance clauses in green leases. There is a move across the industry in Australia and internationally through work led by the Sydney Better Buildings, to formalise and adopt so called green leases. These green leases focus on collaborative goal-setting, management and upgrade of the building to improve performance. This focus can include performance requirements for building owners and tenants alike in terms of carbon emissions and water and energy consumption (Bright et al., 2015). They are in the early stages of development and often include voluntary actions rather than binding requirements. Research conducted by the Better Buildings Partnership shows that take up is focused mostly in the top tier of the commercial office market, though 62% of leases include some form of green lease clause (Dawson, Bailey and Thomas, 2014). Green leases have been adopted also in other sectors such as retail. If the living algae building technology is adopted in sectors with green leases, then owners and Facility Managers may be tied into meeting performance standards. If there is any likelihood that algae system performance may vary significantly due to weather or other variables, this may deter these owners from adopting algae technologies. Although another option is to pro-rata production to incoming sunlight, so the Green Lease performance targets are rated on the performance of the algae system not the changes in weather.

Intentional and accidental damage

One design technology consideration that was mentioned universally was resistance to accidental and intentional damage. This could be achieved by using impact resistant glazing at ground floor level or by using metal screening that allows vision of the panels but also protects it.

Cleaning (exterior and interior surfaces)

Cleaning of the glazing panels and pipes was another technical consideration. This could be achieved by looking at measures taken in aquarium design for example, where magnetic scrubbers are used to clean the inner face of the glass. The microalgae scientist suggested this is best undertaken manually as a visual check on the panels can take place at the same time, and it will be possible to check whether there is any excessive accumulation of algae in corners or areas where insufficient water flow is occurring. Such manual cleaning on the upper floors of a multi-storey building would add to maintenance costs. One suggestion to reduce cleaning liability is to specify special glazing with low a friction coefficient, which will reduce algae biofilm formation. In addition, regular and possibly computer monitoring of the system should ensure optimum operating environments are maintained. There may be opportunities for innovation in glazing technology as a result.

Education of stakeholders

Another technology related issue is the availability of sufficiently educated professionals in Australia to design, build and maintain algae buildings. Furthermore, manufacture of the components for the façades may occur overseas and therefore lead-in times for construction projects will be affected. Such circumstances may deter some owners or developers from adopting the technology, if time and delivery of the finished building or replacement panels is a key issue.

Green wash

There is in the built environment a phenomenon referred to as ‘green wash’. Green washing is the practice of making an unsubstantiated or misleading claim about the environmental benefits of a product, service, technology or company practice. Green washing can make a company appear to be more environmentally friendly than it really is. There is a danger that algae system technology, because of its’ novelty, is perceived as ‘green wash’ by the community and wider industry. A program of awareness raising and transparency regarding performance would address this aspect.

Therefore, if a building were to adopt this technology, a commitment to research and dissemination of results may overcome suspicions in this respect. Many participants recollected instances of a number of Sydney buildings that had adopted new sustainable technology, along with much promotion and marketing, only to find performance had fallen way below expectations. In some cases, the technologies had been decommissioned as a result of non-performance. Such practices reduce peoples' belief in sustainability in buildings and this aspect needs to be managed so that expectations are realistic.

Reliability

Reliability of the installations was raised by the bio-engineer, for example what happens if there a number of cloudy days in a row, controls are inaccurately calibrated and fail, or a unit fails? He stated that 'there are inherent problems with biological systems and that's reliability'. Following this logic, algae technology would need to approach the reliability of static systems, performing consistently, for the technology as a whole to succeed.

The services engineer discussed the different properties of water in different regions, whereby some have hard or soft water. Where hard water exists, scale or calcium is deposited and builds up in pipes reducing flow and possibly production rates, although these are considered mostly manageable problems. This may be an issue in some locations, or water may require treatment before introduction to the system.

Complexity

A number of the participants summed up the combination of technological issues as that of 'complexity'. This is largely because the technology is new and unknown; no one has direct experience of the technology on which to draw. There is no similar technology that can be used as a reference point at present. Table 2 summarises the technological issues raised by participants.

Table 2 Technological issues raised by participants

1. Climate – Hamburg is different to Sydney
2. Lifespan of the technology such as glazing units and seals
3. Seals and sealants
4. Maintenance
5. Technology shifts
6. Structural capacity
7. Building adaptation
8. Production rates
9. No blueprints to follow
10. Knowledge of industry
11. Performance clauses in leases
12. Double skin façade technology
13. Dead façade technology
14. Durability
15. Cleaning
16. Access to façade
17. Glazing technology
18. Lead in times for getting materials / units to Australia or capacity to build in Australia
19. Perception of ‘green wash’
20. Reliability
21. Accidental or intentional damage to panels resulting in gas or seepage of algae
22. Inadequate maintenance leading to rotting algae
23. Complexity
24. Water quality affecting algae production rates and scaling pipes

4.1.3 Regulatory and political issues

Power of vested interests

The overarching political issue within the Australian context according to the participants is the power and political influence of the coal and gas industries. Politically, these groups make donations to political parties and lobby government to maintain their vested interests. This power is significant and evidenced by the inconsistent support for and thus take-up of solar and other renewable technologies in Australia, compared to European and other countries.

Incentivising technology

In terms of planning regulation it was suggested that the market could be incentivised to develop renewable on-site energy technology, including biomass, by making it a requirement of certain types of development. For example, large residential developments on existing brownfield sites create a considerable extra energy loads through the new buildings for existing infrastructure to accommodate; requiring these developments to be partially energy self-sufficient would encourage adoption of renewables in urban settlements. A further aspect related to planning which arises, is the loss of net lettable area (NLA) within buildings as a result of the façade area and plant room requirements. For example a 1000m^2 floor plate might lose 60m^2 per floor, and developers would want to 'recover' this area with additional height allowances to make the development meet 'highest and best use' objectives. A directive from the Department of Planning NSW would be useful in this respect to encourage adoption of the technology initially.

Building certification

With regards to building certification this technology would require an alternate solution approach to building code compliance, which is expensive and time consuming. In this paradigm, the designers are required to demonstrate the alternate design meets all requirements of the Building Code of Australia. This is usually achieved through calculations and professional reports providing evidence of compliance. An alternative approach might be to consider exemptions for any one new technology incorporated into a building. In this paradigm, the owner/ developer would also conduct research and disseminate performance data to the broader community to maintain that exemption. This would be one way to gather real data on new technologies for the building industry.

Health and safety

In terms of maintenance, commissioning, and operation, directives and guidelines in respect of Health and Safety would be required to ensure the safety of building operators, occupants, and people passing by. There may also be a requirement for certification of the installation from Health and Safety officers. The bio-engineer noted that robust regulations and maintenance were needed to cover health and safety to ensure systems do not fail.

Participants noted a need for guidelines for planners, building certifiers and other bodies such as Sydney Water, Department of Health NSW to reassure their officers that they are giving appropriate advice to applicants.

Retrofit issues

The Valuer and Property Manager raised the legal issue with retrofitting buildings where the original structure is built to boundary line because the retrofit façade would overhang boundary line. It is possible to negotiate with the authorities for permission to overhang the boundary for a fixed period. However, this process adds time and cost to projects, and some developers and owners would seek to avoid additional unnecessary legal arrangements with third parties if the resulting technology did not add substantially to capital or rental values.

Public Relations

One way of overcoming reticence in respect of being the first in the market to adopt the technology might be through grass roots promotion to the public to help with acceptance of technology – possibly through the adoption of the technology on public buildings as a starting point. Table 3 summarises the regulatory and political issues highlighted in the interviews.

Table 3 Regulatory and political issues raised by participants (Source: Authors)

1. Politics around protection of existing coal and oil industries keeping renewables as fringe.
2. Health and safety certification.
3. Could incentivise by making some proportion of on-site renewable energy (including biomass) a requirement of planning permission for some developments, possibly at precinct level.
4. Requires alternate solution approach to building code compliance, which is expensive and time consuming.
5. Need guidelines for planners, building certifiers and other bodies such as Sydney Water, Department of Health NSW.
6. Requires robust regulations and maintenance to ensure systems do not fail.
7. Top down directive from Department of Planning would be useful.
8. Grass roots promotion to public would help with acceptance of technology – possibly adoption on public buildings is a good starting point.
9. Planning gain, where developers are able to obtain additional floor area in a building, would be required to compensate owners for loss of Net Lettable Area caused by accommodating thickness of façade and plant room within the curtilage of the site.
10. Legal issue with retrofit where built to boundary line as façade would overhang boundary line.

4.1.4 Economic issues

There were many economic issues raised by all participants, and they often reflected the background of the participant. For example, the Quantity Surveyors and Project Manager focussed on the design and construction, whereas the Property Manager and Valuer focussed on the operational phase and the points of leasing or sale.

Value Of The End Product

One question arose about the value of the end product. This would vary depending on whether the end product (algae biomass) was sold to a third party, an industrial chemical company for example, or used for energy production on site. Further research is required to evaluate the economic case for a number of end-product options.

The cost of production

The cost of the algae panels and associated plant is very expensive compared to other renewables such as PV and this point came up frequently. This is acknowledged and inevitable in the early stages of innovation and development. As discussed above with innovation, incentivisation, evolution of design and technology, and with economies of scale, the costs of production will fall. A comparison with the PV market shows those products 20 years ago were very expensive compared to alternative technologies available at the time and also less efficient.

Scalability

One unknown is the scale or size of installation needed to make living algae building economically viable. Currently it is not clear whether an installation covering 100 metres squared or 500 metres squared is viable? Would a larger installation generally make living algae technology more economically viable, for example applying across a precinct rather than a single building, was another regularly asked question that needs an answer. The relative costs of the centralised and shared system elements (energy recovery plant room and algae harvesting systems) will influence scalability.

Costs

For most participants cost is the main barrier to algae system development and adoption. The Quantity Surveyor stated that goal for hospital façades in Australia is around AS \$350 m^2. The cost of the façade on the German building was US \$2,200-2,300 m^2 or approximately AS\$ 3,300, nearly ten times more expensive. This is a substantial barrier to overcome, even with offsets through sales of product to third parties and energy savings. However this technology will position NSW and Australia in a low-carbon economy. It is clear that ways need to be found to reduce overall construction costs by standardising the product and developing and adopting a viable business model.

Additional costs would be incurred in the design phase, researching developing and communicating the technology to the design team. Further costs would be incurred during construction, appointing contractors able to construct and install the technology. Contractors are likely to add a premium to their tenders to cover unforeseen costs associated with a new and unknown technology. Finally, additional costs arise during operation with the maintenance contract. Sourcing replacement components may be a challenge and result in higher costs, especially if required at short notice, although the use of standardised and easily replaceable components would help keep costs down.

A related cost issue is that there is only one complete building to inform the industry or probable costs for this technology. Only after several buildings are completed using this technology will there be sufficient cost data to draw reliable conclusions about costs. Without reliable data, cost management risks are significantly higher, a factor that is a barrier to adoption all by itself.

Capital value

On a positive note, the Valuer stated that capital value of algae buildings could be higher as it is a unique technology. However, if it is perceived by the market as too complex, too expensive, an example of green wash or a white elephant then capital value will be affected negatively. A Valuer takes into account three key factors when conducting a valuation: income, expenditure and risk. For all of those factors, some benchmarks are needed as valuation is backward looking rather than forward-looking. For income, the Valuer looks for rental comparisons to other similar buildings in the area, which may be tenanted or owner occupied. If they're rented, then the income stream is rental income. They look at what rental income is achieved and how it compares to other nearby similar buildings; if income is lower, the sustainability technology is at risk of being understood to be the cause of this problem. If income is higher, and there is evidence that this is due to the sustainability features, then the sustainability premium feature can be considered to add value. For example, if there were evidence that tenants leased a building specifically because they wanted to be involved in a living algae scheme and pay a 10% premium relative to comparable properties nearby, the algae systems would be linked to the asset value. However, the Valuer needs to try to get to the bottom of why there is that 10% premium to make sure it is related to the sustainability features and not something else. They look at things like average floor areas between the apartments that can be compared on a like-for-like basis. The same process applies to commercial buildings when valuing, rents on a per square metre basis, the Valuer looks at the technology and fit-out, similar standards of accommodation, as they want to be confident as Valuers that any premium relates to technology rather than to anything else.

When asked how the Sydney market would react to something like a living algae building, the Valuer said he thought the market would be sceptical, and wondered who would fund something like this. It is likely to be a major developer, but would that developer hold the building and manage it, or sell it? Either way, the developer would be nervous as holding the building means they are responsible for the longevity of the technology and the expenditure of maintaining it. If they sell the building, they would be nervous about the same factors, as buyers will be thinking about these issues and have the same concerns. The problem is there are no local precedents, so the Valuer cannot determine reliably system whole of life costs. Accordingly, developers would want guarantees from the installer and designer of the technology that it would last for a certain number of years and also that the companies are going to be around in 20 years' time (for maintenance and upgrade).

Some participants noted that there are long-term cost savings as the technology produces on-site energy and energy costs will increase over time. Another view was it would be more attractive to the market in terms of value, if the technology can provide power, light, heat and cool buildings.

As noted in the regulatory section, energy cost variability - including the possibility of a reintroduced carbon tax - make it difficult to assess definitively the financial attractiveness of this kind of system.

The economic loss of Net Lettable Area (NLA) from the additional thickness of the façade and the plant room also makes the technology less economically attractive; and, compensation in respect of additional height allowances or development ratios is needed to redress this loss.

The economic payback period, the term in which the technology pays for itself, in years is unknown. The payback period needs to be reasonable and within the lifecycle of the building and a term of 25 years was suggested by a number of participants, while others suggest that a shorter payback would be required to be commercially viable.

There are some clients who may pay more to show their green credentials and that they are market leaders and innovators. However, they will want proof-of-concept and innovation to be first into the market with the technology. Possibly a small-scale installation on part of a building or development may reduce risk and encourage adoption.

Finally, the issue of warranty arose in respect of whether one exists and if so, how long does it last? A warranty would reassure owners and developers that their exposure to risk was reduced somewhat. Table 4 summarises the economic issues raised.

Table 4 Economic issues raised by participants (Source: Authors)

1. What is the value of end product?
2. Production is very expensive compared to other renewables such as PV.
3. What scale is needed to make it viable? 10 metres square or 100 metres square? What is the return on energy production?
4. Cost was the main barrier to development and adoption.
5. Potential revenue from other industries – e.g. industrial chemicals or sustainable materials.
6. Façade cost of German building was US \$2,200-2,300 m^2 compared to Australian hospital facades which are around AS \$350 m^2.
7. Cost of PV 20-25 years ago was prohibitive.
8. Additional Costs – design.
9. Additional Costs – construction.
10. Additional Costs – maintenance and operation.
11. Capital value could be higher as unique technology or, lower if perceived as too complex, expensive, green wash or a white elephant.
12. Long-term cost savings as it produces on site energy and energy costs will increase.
13. Would be more attractive to market (in value) if technology can power, light, heat and cool buildings.
14. Valuer assesses income, maintenance and capital expenditure (Cap Ex); needs benchmarks.
15. This technology assists NSW towards a low carbon economy.
16. Loss of Net Lettable Area (NLA) from additional thickness of the façade and plant room makes it less economically attractive.
17. Payback period is unknown and needs to be reasonable within lifecycle of building i.e. 25 years.
18. Some clients may pay more to show green credentials, proof of concept and innovation to be first into the market.
19. Warranty – Is there one, and how long does it last?

4.1.5 Social

Surprisingly the social factors concerned participants the least in the interviews.

Slime

Inevitably some mentioned the negative perception of algae as 'slime', which would be associated with odours. Most were concerned about potential impacts to health caused by leakage or damage; however many are familiar with the designing, building and operating of buildings with cooling tower where *Legionella* bacteria can potentially cause fatalities. This risk has been managed successfully in the majority of buildings over time, and on this basis most were reassured that algae building technology would adopt similar approaches to risk management.

Innovation

In respect of positive perceptions most were of the view the innovation was exciting and should be explored to its fullest extent. Global problems and climate change has reached such a stage that all options should be investigated. They particularly liked the aesthetic and the potential for red, purple or blue green algae facades. Only one participant commented that the green light from the panels is unattractive for occupants. Importantly they felt this technology would engage people's minds about biomass and renewable energy – although large scale production may be better in peri-urban locations it is important to educate and to remind the wider community about these technologies. The algae façade is a very visual statement of sustainability in the built environment. Table 5 summarised the social aspects raised by participants.

Table 5 Social issues raised by participants (Source: Authors)
1. Negative perception of algae as slime.
2. Interesting and new and innovative.
3. Aesthetically different – potential for red, purple or blue green algae façades.
4. Engage people's minds about biomass and renewable energy.
5. Very visual statement of sustainability in the built environment.
6. Concerns about health and safety and contamination through leaks.
7. Green light from panels is unattractive.
8. This is attractive technology

1.6 Options for other land uses

Throughout the interviews, the potential for diverse locations of the technology was discussed, both on and off of buildings. Though the German developers had used the technology on a residential building, participants explored other land use types that might be better options in Australia. The issues driving these suggestions were availability of façade space, value of property, scale district or building, access and maintenance. Table 6 illustrates the ideas proposed, which professional or stakeholder made the suggestion and they reason they thought it was worthy of consideration.

Table 6 Other potential land use options (Source: Authors)

Other potential land use options	Suggested by	Reason
Motorway	Quantity Surveyor	Unused space
Outback land open space	Quantity Surveyor	Large areas of low value land could provide power
Precinct or district level	Architect Property Management Surveyor Valuer	Utilise economies of scale
Shopping Centre/ Big box retail	Quantity Surveyor Valuer	Large areas of blank walls
Airports	Quantity Surveyor	Large areas of blank walls on hangers and land adjoining runways have no other uses currently.
Residential (large precinct scale)	Valuer	Utilise economies of scale
Hospitals	Quantity Surveyor Services Engineer	Can have large number of buildings with wall/roof area available
Car parks	Quantity Surveyor	Large areas of wall unused currently
Industrial	Property Management Surveyor Valuer Bio Engineer	Large areas of blank walls, lower value land.
Brewery	Micro-algae specialist	Net emitters of CO_2 due to yeast fermentation may allow environmental brewers to offset emissions
Abbatoirs	Services Engineer	Large areas of blank walls, lower value land.
Dry cleaners	Services Engineer	Associated with contamination due to chemicals used in cleaning process may offset environmental harm caused.

Another question arose around which group was most likely to adopt this technology, most participants believed that public bodies and major developers were deemed most likely to explore algae building initially in Australia.

4.1.7 Potential locations in Australia

All participants commented that the building in Hamburg is located in a very different climate region to that of Sydney. Hamburg has a cool temperate climate zone with a predominant need for heat energy, whereas Sydney is located in warm temperate zone with a predominant need for cooling energy for most of the year (BOM, 2016). Australia has eight climate zones in all ranging from the coolest, alpine, to the hottest, tropical, which has a high humidity summer and warm winter. Depending on the building type and location, only some buildings in some locations require heating during winter, and often for only short periods of time. Broadly within buildings, heating energy needs are found in Victoria, Tasmania and the ACT, whereas cooling power is required in Sydney, SA, WA, NT and Queensland. See figure 6.

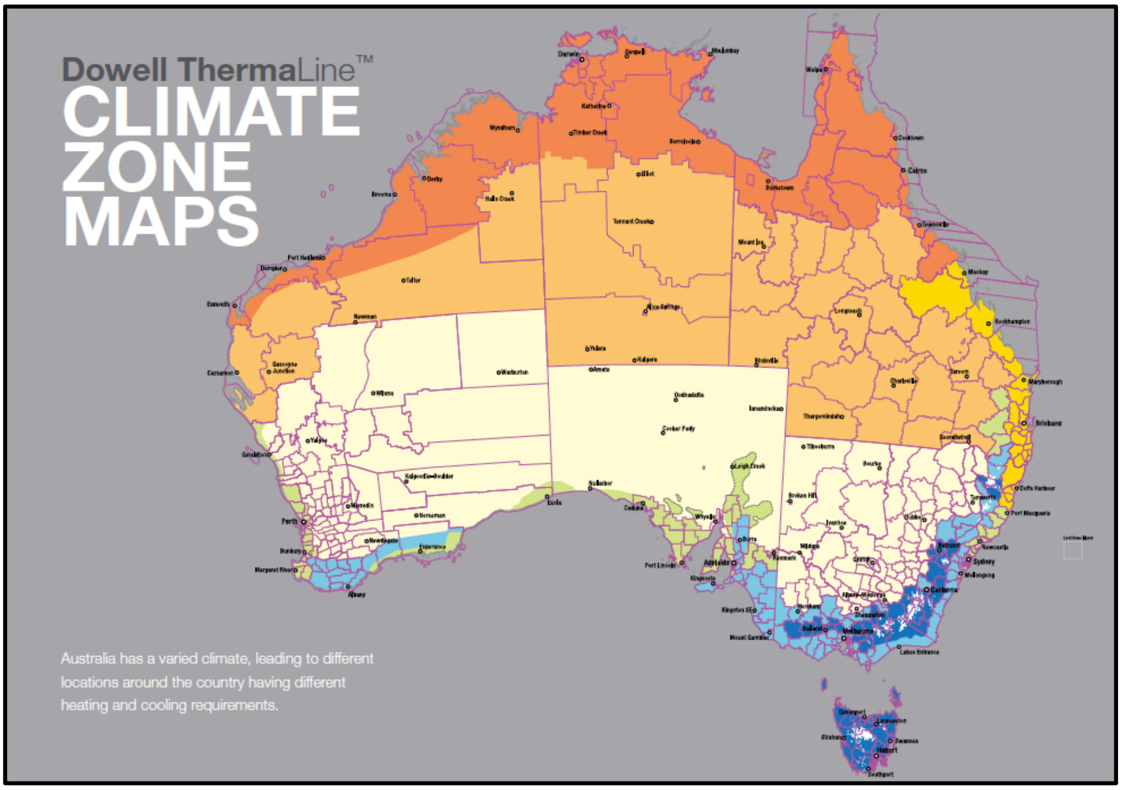


Figure 5 Climate zone map Australia
Source: Dowell ThermaLine

Although climates vary between the States and Territories in Australia, it also varies within States and Figure 7 shows the climate map for NSW.

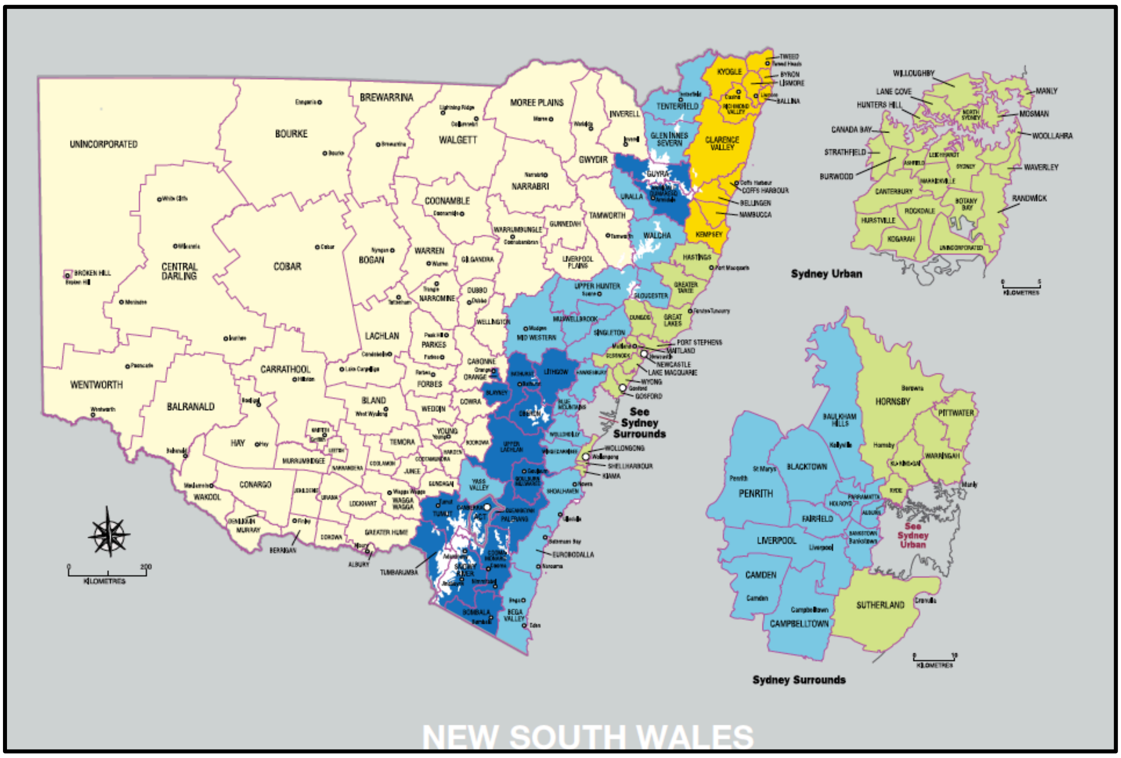


Figure 6 Climate zone map NSW

Source: Dowell ThermaLine

4.1.8 Challenges to Algae Building Technology – The Six Cs

Overall six themes emerged from the 24 interviews undertaken in respect of challenges to adoption of the technology in Australia. These are, not in order of importance; contamination, cleaning, cost, conversion, complexity and competition. The challenges are summarised in Table 7.

Table 7 Summary of the six challenges for algae building technology (Source: Authors)

Challenge and nature of issue	Means of resolution
Contamination caused by leakage of algae (accidental and deliberate)	Can be overcome by specifying less toxic alga, protection of glazing at lower levels from impact – via screens, and/or toughened glass.
Cleaning (and maintenance)	Overcome by having clear instructions and training regarding cleaning and maintenance. Also panel and system design should optimise ease of cleaning and maintenance.
Costs (construction, operation and payback)	Overcome by training and education, development of specialist installers and commissioning engineers. Economies of scale and shifts in technology will reduce construction and operating costs over time – thereby reducing payback periods. In the short-term technology is not cost effective, with payback likely to exceed lifecycle. Lessons to be learned from aquarium technology regarding seals.
Conversion (how much energy is produced especially compared to other renewables)	Overcome by innovation. PV initially was not as efficient as it is now, however technology shifts and innovation occurred to improve efficiency. Same is likely in long term with algae technology too.
Complexity (makes it more difficult to build and install, commission and more likely to break down)	Overcome by innovation and design. As more actors enter the market technology shifts and innovations will occur to reduce complexity.
Competition (from other technologies)	Overcome by innovation and through trail and pilot schemes being supported in the sector by stakeholders. Eventually economies of scale may make this technology competitive with other renewables.

4.2 Potential application of algae technology in property in NSW

During the interviews participants were asked what they thought might be potential applications of the technology in property in NSW. Participants were asked to consider the commercial, industrial, residential, retail and other property sectors in their considerations. The following sections indicate the drivers and challenges for the adoption of algae building technology in each of the sectors.

4.2.1 Application of algae technology in the commercial property sector

Table 7 Commercial Building/Land Uses - Drivers and Challenges (Source: Authors)

Building / Land use type	Drivers	Challenges
Commercial	High-end tenants often want to showcase new technology as part of sustainability commitment. Outside CBD located office towers, many workplace buildings have large flat and easily accessible facades and roofs for locating the technology. Significant share potential of algae panels suits programme need for diffuse, controlled daylight. Potential of algae panels to reduce urban heat island effect due to office buildings.	CBD commercial buildings are often high-rise, with facades largely located too high for easy system inspection and maintenance. Building owners are often different than tenants and typically do not have a business model that involves running specialised energy or industrial production systems. Commercial buildings typically have little use for heat produced by living algae systems.

4.2.2 Application of algae technology in the industrial property sector

Table 8 Industrial Building/Land Uses – Drivers and Challenges (Source: Authors)

Building/ Land use type	Drivers	Challenges
Industrial/ warehousing	Buildings often have large, flat and easily accessible facades and roofs for cost-effective installation and scaling of the technology. Some warehouse or industrial facility owners, such as micro-breweries, have experience running complex technical systems.	Often industrial buildings have no additional structural capacity to support rooftop or façade algae systems. Typical business model for industrial buildings does not allow for design innovation. Typically industrial buildings have no use for heat produced by algae panel system.

4.2.3 Application of algae technology in the residential property sector

Table 9 Residential Building/Land Uses –Drivers and Challenges (Source: Authors)

Building/ Land use type	Drivers	Challenges
Medium/high density units, including hotels	Residential buildings can use much of the heat produced by algae panel system for pre-heating domestic hot water. Residential buildings in mixed-use settings often support restaurants in their ground stories, which can use algae as a food product.	Residential strata laws deeply complicate ownership of centralized building energy systems.
Low density housing	Residential buildings can use much of the heat produced by algae panel system for pre-heating domestic hot water. For a technologically minded homeowner, algae system can provide energy, food, and product to sell.	Most homeowners are incapable of operating a system as complex as a living algae building façade. Residential property valuation -- more than any other property type -- fails to account for sustainability features and energy efficiency.

4.2.4 Application of algae technology in the retail property sector

Table 10 Retail Building/Land Uses – Drivers and Challenges (Source: Authors)

Building / Land use type	Drivers	Challenges
Retail – regional centres/big box retail	Major retail centre owners, especially those in urban centres, increasingly have ambitious sustainability commitments that will make them more interested in adopting innovative technology, particular visible technology, that reduced environmental footprint. Retail centres increasingly are featuring food and beverage tenancies that can make direct use of algae as locally grown food for consumption on-premises. Retail centres with food and beverage component have a high demand for heat produced by algae systems.	Retail centres are typically an amalgamation of building and system types and vintages, making wholesale adoption of a new energy or other technology very difficult. Retail centres other than those managed by leading brands often have minimally trained and resourced operations staff, living algae systems would be beyond their operational ability.

4.2.5 Application of algae technology in the airport property sector

Table 11 Airport Building/Land Uses – Drivers and Challenges (Source: Authors)

Building / Land use type	Drivers	Challenges
Airport aircraft hangers	While airport hangers have little demand for heat produced by algae systems, airport terminals with food & beverage tenants have a high demand for heat. Airports typically are owned and operated by sophisticated organisations with capability for managing complex systems.	Airport business models would need to be revamped to accommodate selling algae products. Airports have stringent glare criteria that may limit placement or orientation of reflective glass algae panels.

4.2.6 Application of algae technology in property in the public sector

Table 12 Public Sector Building/Land Uses – Drivers and Challenges (Source: Authors)

Building / Land use type	Drivers	Challenges
Public sector	Major public sector clients, especially those in urban centres, increasingly have ambitious sustainability commitments that will make them more interested in adopting innovative technology, particular visible technology, that reduced environmental footprint. Public realm increasingly features food and beverage tenancies to activate places. These can make direct use of algae as locally grown food for consumption on-premises. Other public place types (swimming pools, botanic gardens with greenhouses) have a high demand for heat captured by living algae systems. Food and beverage outlets have a high demand for heat produced by algae systems.	Public sector building operations range from very good, and capable of managing a living algae system, to appalling, and unable to manage complex systems. Operational capability must be carefully considered before applying this technology. Some public sector organizations are risk averse, so would not be well-suited for trial application of new technologies like Living Algae Systems.

4.2.7 Application of algae technology in property in other categories

Table 13 'Other' Building/Land Uses – Drivers and Challenges (Source: Authors)

Building / Land use type	Drivers	Challenges
Kiosks, small scale public pavilions	Small-scale public building accessible by the wider community might be a good pilot of the technology. With information panel, this would raise awareness among wider society. The hot water needs can be met through the algae technology. Also energy needs for lighting are likely to be low so may be supplied with algae technology too.	Could be vulnerable to impact damage or vandalism if not protected.

Conclusions & Next Steps

5. Conclusions

The overall conclusions and recommendations from the study are reported here. Renewable energy will dominate energy production in the 21st Century, and Australia currently lags in terms of innovation and adoption. As such there are opportunities to engage in renewable innovations and to explore ways of once again leading in the adoption of renewable technologies, or at least the adoption of energy efficient technologies. Looking at other renewables, initial high costs of production and low levels of performance transform over time as the technology shifts and economies of scale are realised.

This feasibility study has canvassed the opinions and perceptions of a substantial group of highly experienced and well-educated professional stakeholders in the Australian built environment sector on the prospects of living algae building systems. Considerable discussion was undertaken in respect of a broad range of drivers and challenges for the technologies. Their views are summarised in terms of technological, economic, environmental, social and regulatory factors in relation to algae building technology.

Technological factors include the need to develop panels and bioreactors suited to the Australian climate, which vary from cool to tropical. Thus the mix of heating energy and cooling energy loads will vary. Further considerations are the mechanics of the systems, the cleaning and maintenance requirements, along with a suitably trained workforce. Accidental leakage and potential contamination needs to be addressed; however experience with *Legionella* bacteria in cooling towers demonstrates that it is possible to successfully manage microorganisms that are deleterious to human health. A further unknown is the amount of production that can be derived from algae panels in an Australian location; given that there are more sunlight hours over a longer period of time per year compared to Hamburg, it could be higher. Piloting and testing of different algae and panel types is recommended to ascertain production levels. From this it would be possible to model whether precinct-scale adoption is preferred over single building technologies. Other suggestions included algae towers or roof mounted panels rather than façade technology, as well as designing panels so that they can be easily detached for cleaning, maintenance, repair or replacement. The potential with a modular system is also that different sized systems can be set up according to client needs. Furthermore standardisation will dramatically reduce per unit costs.

Economic factors weighed heavily in all cases and there was consensus that early adopters will be faced with high costs of development and research, as well as high costs of production and manufacture. However, there is an opportunity to develop expertise in both areas that may become an exportable expertise and commodity in future years. The operating and maintenance costs also need to be quantified and analysed. Again, until prototypes are developed this analysis cannot be undertaken. Demolition costs will also be higher given the need to dispose of the algae safely and to engage people with this expertise. There may be cost savings in operational energy costs as a result of the on-site energy generation from the panels to building users but this will largely depend on the type and scale of co-generation equipment being utilised. An anaerobic digester can utilise algal biomass to produce biogas (methane), which can then be used to generate power and heat for the building, but all have operational costs, which may or may not make the system commercially or sustainably viable. To the wider community, there are savings and benefits in respect of the total costs of providing energy infrastructure; as energy and heating from algae, its digestion or electricity cogeneration that can take a precinct level development partially off grid. An anaerobic digester could also treat putrescible food wastes, so there are additional benefits to the installation of such a system, beyond just treating or utilising algal biomass.

Environmental factors were strong drivers for adoption and development of the technology amongst the participants, especially the argument for carbon sequestration and the opportunity to reduce the high levels of greenhouse gas emissions from the built environment. The opportunity for solar heat and hot water production, biofuel production and sewerage treatment were perceived very favourably. Opportunities for acoustic insulation featured less, though the potential in some areas for additional thermal performance of the building skin was commented on. Negative environmental issues related to potential for odours and contamination, which would have to be managed through design and operation and best practices in maintenance management.

Social considerations included the aesthetics; most participants thought the panels looked very different and attractive. A few felt the green colour was not particularly attractive, especially if the sun behind it created a green shadow internally and there are ways to design facades to ensure this does not occur. Some felt there might be a negative perception if people associated algae with slime, and if the panels were not maintained properly and algae biofilms appeared. Again maintenance and cleaning is paramount to ensure this does not happen.

Regulatory issues were discussed in respect of the need to for guidelines to be produced to help planners, certifiers and health and safety officials to ensure they are satisfied that they have undertaken thorough due diligence. Again the introduction of other technologies previously 'new' provides a blue print in respect of ensuring all the requisite guidance and information is provided for the regulators. This is paramount and, of course, relates ultimately to insurance premium levels for buildings.

Underpinning all of these factors, there remains insufficient system performance and cost information about algae building technology. This information is needed by the property and construction industries to complete the business case feasibility studies, which enable technology adoption. Similarly, there is very little design guidance available to help design teams work through the complexities of developing this system technology. The compilation of this basic business case information through further research will help industry assess the value of this technology and guide the appropriate and successful uptake by the property industry.

This study has resulted in some 'lessons learned for Australia' which include we have year-round growing temperatures and year-round growing sunlight. There are possibilities of overheating of water, and the algae choice is critical in this respect. Depending on geographical location, shade and daylight control benefits more valuable in most of the country compared to heating benefits.

Overall, there are clear drivers and challenges for innovation and development of this technology. Acknowledging the challenges will ensure the innovation is more likely to result in viable outcomes. Undoubtedly, it is complex and costly, but so too was development of photovoltaic technologies and; as the old Chinese proverb goes, 'the journey of a thousand miles starts with a single step'.

6. The next steps

The next logical step and main recommendation is to design and fabricate a demonstration prototype panel in Sydney to gather empirical data on algae panel performance when operated in the city. A number of participants expressed interest and have expertise to offer in this respect. The Algae Manifesto is as follows:

1. Develop a prototype panel to demonstrate proof-of-concept and production rates for NSW.
2. Design and develop education programmes for various trades' people, professionals in TAFEs and Universities in engineering, construction, planning, design, architecture and property disciplines.
3. Develop series of guidelines for regulators and certifiers.
4. Answer industry need for basic information on:
    a. Potential for on-site energy source and carbon sink in Australia.
    b. Potential for on-site agriculture.
    c. Potential on-site industrial product generation.
    d. Experiential, aesthetic potential.
    e. Quantify costs and value.
    f. Identify development or application scenarios for algae systems most likely to succeed.
    g. Gain maintenance and operation experience necessary to assess whole of life costs.

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Appendices

Appendix 1 BIQ Building Technology Information Sheet

How it works

- Biomass is grown in reactors located on the façade.
- Renewable energy sources include generation of biomass and collection of solar heat for on-site use.

Project Data

- Project Data 61 S-Bahn Wilhelmsburg Exhibition Wilhelmsburg Central
- Project partner Otto Wulff Bauunternehmung, Strategic Science Consult
- Project costs approx. 3.4 million Euro
- Size of site approx. 839 m2 Gross floor area approx. 1,600 m2
- Size of the utilisation units approx. 50 to 120 m2
- Architecture SPLITTERWERK, Arup GmbH, B+G Engineers, Immosolar
- Beginning of construction December 2011 Completion March 2013
- Energy standard Passive house
- Energy supply Integrated Energy Network Wilhelmsburg Central
- Building is a four-storey residential apartment block.
- The engineers were Arup, panel fabricators were Colt International.

Technology/physical attributes

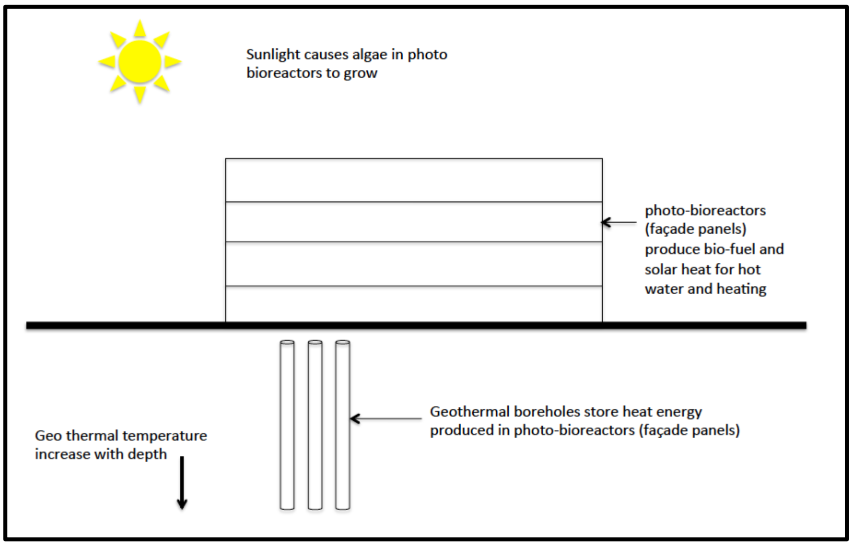
Bio fuel production

- A bio-adaptive facade comprises flat panel photo-bioreactors filled with water in which algae grow.
- A fast-growing algae, Chlorella, was selected to maximise production rates.
- The alga responds to certain conditions, i.e. more biomass is produced on sunny days. No production occurs during the winter as there is insufficient sunlight and so maintenance is undertaken.
- Nutrients and carbon dioxide are also adding to grow the algae.
- The algae biomass is harvested and used to produce energy.
- Algae is removed from the photo bioreactors automatically by means of flotation. In an off-site facility biomass is transformed into methane.
- The facade panels move to provide shade for occupants when required.
- Façade panels or photo-bioreactors are also known as solar conversion louvers.
- 129 photo bioreactors, 2600 mm high x 700 mm wide x 90 mm deep, are fixed to the building facades.

- The photo-bioreactors are sited on the south-west and south-east facing sides of the buildings for access to full northern hemisphere sunlight. (In the southern hemisphere, these panels would be sited on north-east and north-west facing elevations.)
- Thickness of panels is important with respect to production rates (exposure to sunlight) and cleaning.
- Externally laminated safety glass is provided to protect against damage and breakage of the panels.
- Three cavities, 17 mm wide are filled with water. Glazing is 6.5mm thick.
- Panels were manufactured by Colt International, Hampshire, UK.

Solar heat production

- Some solar energy not absorbed by the algae in photosynthesis is absorbed on the surface of the algae, increasing the temperature in the water.
- The heat from the photobioreactor water is captured for use on site.
- Heat exchangers remove heat from the photo bioreactors and move it into a separate heating water loop that provides space heating for the building and pre-heating for domestic hot water.
- Surplus heat is stored in geo thermal boreholes and recovered when demand for heat increases.
- Heat pumps supplement the heating needs not supplied by algae technology, including regular top-up of domestic hot water to safe storage and supply temperature.



- Solar thermal heat is 150kWh/m^2/yr
- Photo bioreactors can operate all year round, but the biochemical process requires certain levels of sunlight. Therefor it is more effective in summer.
- In Sydney it is likely that sufficient energy could be produced year round.

Table 15 Summary of Environmental, economic and social attributes of algae building technology

Attributes	Positive	Negative
Environmental	Very low carbon energy is possible through short cycling of carbon dioxide: CO2 is cycled between energy generation, when it is released, and algae growth, when it is captured.	Potential contamination and algae eutrophication if growing conditions (temperature and water flow) not maintained.
	Thermal insulation is also provided by the panels when panel temperatures are closer to internal conditions than ambient extremes –winter nights and hot summer days, in Sydney	Some algae produce toxins which are potentially harmful to humans and animals. Mainly occur in slow moving bodies of water where algae is present. Not all algae have toxins though.
	Acoustic buffering from ambient noise is provided by the mass of liquid in the external panels, although the panels themselves make a quiet noise as air bubbles through the water.	Can smell malodorous – when the cells die (maintenance issue)
		Exposure to health risks can occur through ingestion, inhalation and engaging in activities where toxic algae are present.
Economic	Price will drop as more manufactured and adoption rates increase.	Operational complexity
	Industrial properties and hotels are thought to be ideal because they generate a lot of carbon dioxide.	Requires new business model for some application scenario
		High first costs, US$2,300 – 3,300 / m^2 currently, and dependant on size of the project and economies of scale.
Social		Can pollute water – affects taste, smell / odour, toxic (possibly carcinogenic and possibly causing neurological disease. Has killed humans exposed to harmful algal blooms. Some algae contain cytotoxins, hepatotoxins or neurotoxins.

Appendix 2 Algae sewage treatment plants

- Increased urbanisation creates increased need for wastewater or sewage treatment plants.
- Include on-site wastewater treatment using algae, some algae taxa are known to purify water bodies
- Over the last 50 years, they have been used in biological purification of wastewater; algae accumulate plant nutrients, heavy metals, pesticides, organic and inorganic toxic substances and radioactive matters in their cells.
- They are an effective and low cost alternative to chemical and other treatments.
- The question is *can algae treatment work effectively as an on-site form of waste water treatment, recycling the wastewater from the building for distribution to the mains system or for re-use in toilet flushing and other non-potable uses?*
- Algae harvested from treatment ponds can be used as a nitrogen and phosphorous supplement for agriculture purposes;
    - *is there potential to either close the loop further with on-site food production possibly at rooftop level?*
    - *and/or; to sell the nitrogen and phosphorous supplement to local growers?*
- Finally the algae can be fermented to produce methane for energy use in the building as described for the façade panels above.

See Figure 2 schematic.

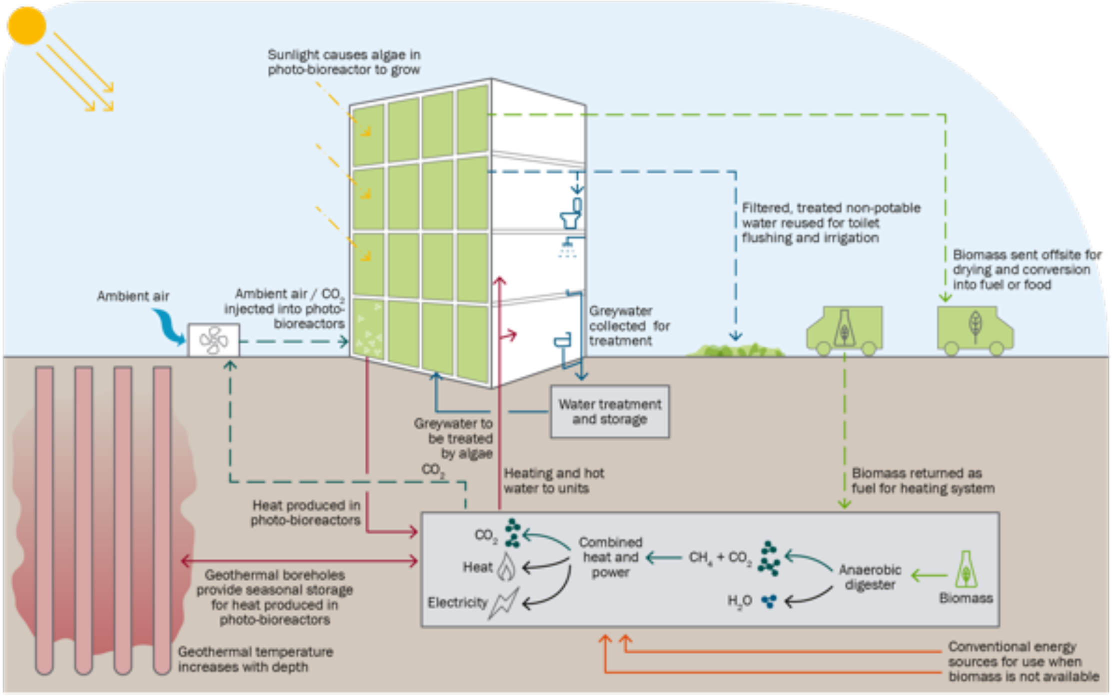


Image courtesy of Atelierten.

Appendix 3 Semi-structured interview questions

Algae Building Technology Feasibility Study – Semi-structured Interviews

Introduce self and project: This project explores the technical, economic, environmental, social and regulatory feasibility of introducing algae building technology into Australia.

Refer to consent form and information sheet details

Ask if comfortable and ready to begin

FACTUAL INFORMATION

1. Name of interviewee
2. Name of employer
3. Background and qualifications
4. Experience
5. Experience of sustainable built environment technology (direct/indirect).

Explanation of the technology – you tube video of the Hamburg building.

Part 1 Technological drivers and barriers to adoption.

In your view, what are the technological drivers to adopting technology?
In your view, what are the technological barriers to adopting technology?

Part 2 Economic drivers and barriers to adoption.

In your view, what are the economic drivers to adopting this algae technology?
In your view, what are the economic barriers to adopting this algae technology?

Part 3 Social drivers and barriers to adoption.

In your view, what are the social drivers to adopting this algae technology?
In your view, what are the social barriers to adopting this algae technology?

Part 4 Environmental drivers and barriers to adoption.

In your view, what are the environmental drivers to adopting this algae technology?
In your view, what are the environmental barriers to adopting this algae technology?

Part 5 Regulatory drivers and barriers to adoption.

In your view, what are the regulatory drivers to adopting this algae technology?
In your view, what are the regulatory barriers to adopting this algae technology?
Do you think mandation would be an option?

Part 6a Overall – thinking of the economic, environmental, social, regulatory and technological drivers – please rank in order which you think is the strongest reason to adopt algae building technology:

Drivers for algae building technology	Rank order 1 = strongest reason/driver for ABT
Economic	
Environmental	
Social	
Regulatory	
Technological	

Part 6b Overall – thinking of the economic, environmental, social, regulatory and technological barriers – please rank in and is order which you think is the strongest reason **not** to adopt algae building technology

Barriers for algae building technology	Rank order 1 = strongest reason not to adopt/or a barrier for ABT
Economic	
Environmental	
Social	
Regulatory	
Technological	

Thank you for your time.

Appendix 4 - Participant Information Sheet

INFORMATION SHEET

Feasibility of Algae Building Technology in Sydney

(UTS APPROVAL NUMBER 2014000598)

WHO IS DOING THE RESEARCH?

My name is Dr Sara J Wilkinson and I am an academic at UTS.

WHAT IS THIS RESEARCH ABOUT?

This research is to evaluate feasibility of adopting Algae building technology in Australia. The study explores *the technological, economic, environmental, social, legal and political aspects of algae building technology in Australia* and investigates the drivers and barriers to adoption amongst key stakeholders.

IF I SAY YES, WHAT WILL IT INVOLVE?

I will ask you to participate in a one hour semi structured interview at a place of your choice, typically your office which may be audio recorded.

ARE THERE ANY RISKS/INCONVENIENCE?

Yes, there are some risks/inconvenience. They are that the research will take up 60 minutes of your time.

WHY HAVE I BEEN ASKED?

You are able to give me the information I need to find out about sustainable conversion adaptations.

DO I HAVE TO SAY YES?

No you don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I can help you with, please feel free to contact me on 02 9514 8631 or 0432 357 213.

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this number *(give UTS HREC Approval Number)*

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