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Exploring the feasibility of algae building technology in NSW

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Abstract

For some time, Biochemists have been exploring the potential to produce biofuels as an alternative to fossil fuel energy. Biofuels can be derived from crops such as corn, soybean and sugarcane however these crops can contribute to water scarcity and deforestation. Furthermore, large areas of land are used that could otherwise be used for food production. Another possibility is to use microalgae, which does not have the disadvantages associated with crop-based biofuels. Depending on conditions, microalgae can produce bio compounds that are converted into biofuels.

The built environment is responsible for around 40 to 50% of total greenhouse gas emissions through fossil fuel consumption. Not only is it necessary to design and to retrofit our built environment to be more energy efficient, but it is also necessary to consider alternative fuel sources. To date, this has mostly focused on solar, wind and geothermal sources, however one residential building in Hamburg Germany has adopted algae building technology in the form of façade panels which act as a source of energy for heating the apartments and for hot water. The climate in northern Germany is very different to Australia, and the question arises; *what is the feasibility to adopt algae building technology in New South Wales?* There are issues around the physical and technical aspects of the technology, the social and environmental aspects, the regulatory and planning aspects, as well as the economic considerations. This paper reports on a study with key stakeholders in New South Wales to explore barriers and drivers associated with the adoption of algae building technology.

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1.0 Introduction

The environmental impact of humans on the natural world manifests in various ways, for example, greenhouse gas emissions (GHG) contribute to the greenhouse effect where temperatures increase and the Earth warms. Buildings and energy used therein contributes around 40% of total GHG emissions [1]. Reducing building-related GHG emissions could impact substantially efforts to mitigate global warming. Increasing the energy efficiency is one way to reduce GHG emissions; another option is to use renewable energy, which will dominate energy production in the 21st century [2].

In 1839, Becquerel discovered the photovoltaic (PV) effect however energy generated by PV was inefficient and prohibitively expensive until 1941, when Ohl invented the solar cell. Further developments in battery storage, smart electricity grid management, and greatly reduced costs, transitioned PV from expensive and inefficient to a viable alternative to fossil fuels. In the 1950s, the price of PV was exorbitant, costing AS$2723.32 per watt in today's money. Slowly, and then swiftly the price of building a solar cell fell and today it is less than AS$1.14 per watt [3]. Sudden, disruptive and largely unpredictable technology shifts occur, making technologies viable and attractive [4], this occurred with solar; the same thing could happen for other 'new' renewable energy technologies. Global biomass energy production reached 88 GW in 2014 [2]; as such bio-energy is no longer a transition energy source. This paper explores the feasibility of algae building technology in NSW.

2.0 Existing Algae Building Technology

In 2013, the BIQ House was constructed in Hamburg, which has a cool temperature Northern European climate. The building comprises 15 apartments, over four floors plus penthouse level, with approximately 50 to 120 metres squared space and a gross floor area of approximately 1600m² [5]. 200m² of integrated photo-bioreactors in 120 panels, mounted on the façade, generate algal biomass and heat as renewable energy resources in a low-energy residential building. The algae façade panel system provides a thermally controlled microclimate around the building, noise abatement and dynamic shading [6]. The construction costs were approximately five million euros [5]. The BIQ is shown in figure 1.

Fig. 1. BIQ Building Hamburg [7].

Microalgae are cultivated in flat panel glass bioreactors, sited on the south-west and south-east elevations and are the main point of all energy processes and converting and distributing different types of energy deliver the building heat and electricity needs. Sunlight and a constant turbulence to avoid algae aggregation, causes the microalgae to grow inside the PBRs producing heat. This heat has 38% of efficiency compared to 60-65% to a conventional solar thermal source and the biomass has 10% of efficiency compared to 12-15% with a conventional PV [5]. The biomass and heat generated in the façade panels are transported to an energy management centre. Here biomass is harvested and heat is recovered from the water-algae solution by a heat exchanger. The bioreactor façade competes well in comparison to other technologies, as the façade provides a similar efficiency level and removes up to six tonnes annually of carbon dioxide by using flue gas delivered in the gas burner to produce biomass in the PBRs**.** The system is integrated with the building services, and excess heat from the photo-bioreactors (PBRs) pre-heats domestic hot water, warms the building interiors, or is stored in an aquifer under the building. The biomass, resulting from the growth (30KWh/m2 year), is harvested through an algae separator and collected in a temperature-controlled container [5]. Up to 80% of the biomass is converted into methane at an offsite outdoor biogas plant, after which it is returned to the building where it generates electricity and heat for the building.

The associated heat production of about 40ºC (150KWh/m2y) is reintroduced to the system via a heat exchanger in the heating network or stored in below ground geothermal boreholes. The boreholes store heat from 16 to 35 degrees depending on the season. When a higher temperature is required for heating and/or hot water, a heat pump is used to pump the water back into the system. A unit is operated to provide the carbon dioxide nutrient (flue gas) required by the microalgae in the bioreactor façade and, to cover the supply of hot water at 70ºC or heating in the energy network [5]. A building management system (BMS) manages the processes to operate the bioreactor façade and to integrate it with the building energy management system. This includes the control of the algae cell density and the temperature in the culture medium.

Algal biomass can be combusted for power and heat generation, and stored with virtually no energy loss [6]. 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 [6].

As microalgae absorb sunlight, the bioreactors act as dynamic shading devices for the building. The amount of sunlight absorbed and shading provided, depends on the density of algae, which relies on the algal species, the harvesting regime and available carbon dioxide (CO_2); conditions which can be adjusted. Algae density 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, the algae grow faster providing more shading for the building [6].

According to Arup [6], the flat PBRs used on the Hamburg building are highly efficient for algal growth and require minimal maintenance. The PBRs have four glass layers: a pair of double-glazing units creating a cavity, which is 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 growing medium is pumped into the PBR from below and flows out of the top of the panel and back to the central energy plant.

At set time intervals compressed air is introduced to the base of each PBR. The gas emerges as large air bubbles and generates an upstream water flow and turbulence to help the algae to take up CO_2 and move the cells in the cavity. Simultaneously, water, air and small plastic scrubbers wash the inner surfaces of the panels [6].

Water temperature in the PBRs is controlled by the speed of the fluid flow through the panel, with lower flow rates allowing greater time for sunlight 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 within the PBRs is around 40 degrees Celsius, as higher levels harm the microalgae. These temperature constraints pose 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 species, which can tolerate higher temperatures.

The efficiency of the conversion of light to biomass was measured at around 10% and available light to heat is roughly 38% [6]. Including additional energy captured from biogas generated by the algae, total solar energy conversion efficiency of the system is 56%. 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. PV systems yield an efficiency of 12-15% and solar thermal systems 60-65%, when placed optimally to capture the total available solar radiation. 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 [6]. As a new technology it benefits from strong interdisciplinary collaboration, combining skills in environmental design, façades, materials, simulations, services, structural engineering and control systems [6]. It is 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.

2.1 Built environment stakeholders and perspectives

Within the built environment numerous 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 knowledge, expertise and skills, which they exert at different times during the project lifecycle.

These practitioners belong to various 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 ongoing continuing professional development (CPD). Membership is a mark of the expertise and quality of these professionals for 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 and involve interpretation of legislation. 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. They sometime advise on measures or features that deliver additional 'value' to a development. 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 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. They may advise on procurement options. Depending on the scope of the project it may be managed by a Project Manager. Fire engineers assess compliance with fire regulations. Environmental and sustainability consultants advise with regards to design, maintenance and operation of buildings and with regards to sustainability rating tools such as Green Star. Together with the design team they affect the types and extent of sustainable and environmental technologies and specifications adopted.

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 is endeavouring to reduce carbon emissions by 70% by 2030.

3.0 Research question and aims

Given that the technology is so innovative and that no building exists outside of Germany stakeholders are able to apply their prior knowledge and experience to the question of how algae building technology might work elsewhere. Moreover the many types of built environment professionals as well as the different interests of the stakeholders mean that they have different knowledge, views and ideas in respect of the technical, regulatory, economic, environmental and social feasibility of algae building technology in NSW. Furthermore stakeholders have different drivers and will perceive different challenges based on their role, area of expertise and level of experience. The research question is therefore; *what is the feasibility of algae building technology in NSW?*

4.0 Research methodology

The research is qualitative, sharing the three basic assumptions identified by Patton [8] of being naturalistic, holistic and inductive. Naturalism involves seeing the phenomenon in its natural occurring state, in this case by interviewing practitioners and stakeholders to ascertain their perceptions and concerns about this technology. The holistic aspect involves looking at the whole problem to develop a more complete understanding of the influencing factors and variables, which determine what the drivers and barriers for algae building technology in NSW would be. The inductive approach is derived from the literature review whereby a picture of the problems and issues emerge as the researchers become more familiar with the topic area. The literature review identified which areas needed to be investigated.

To research the drivers and barriers of algae building technology in NSW, 23 semi structured interviews were conducted with a broad range of stakeholders (see table 1). An advantage of semi-structured interviews is that it is a flexible method which can be adapted during the research [9]. A limitation is that the researcher does not sample widely enough and that responses may not be representative [9]. However Yin [10] noted that the data is concerned with analytical, and not statistical, generalisation. Care was taken to ensure conclusions drawn are noted as being analytically general rather than statistically representative. Bias was eliminated because the researchers had no personal or professional contact with any of the interviewees, companies or practices involved [9].

Table 1: Stakeholders

Discipline	Private sector (number of stakeholders interviewed)	Public sector (number of stakeholders interviewed)
Engineering	7	
Architecture	1	
Building Contractor	1	
Facility Manager	1	
QS	1	
Project Manager	1	
Valuer	1	
Property Manager	1	
Planner / local government		3

Developer	1
Certifier (Building Surveyor)	1
Research	2
Industry advocacy group	3

(Source: Authors).

Data was collected via semi-structured interviews as it allowed the researchers to collect identical data from each interviewee, in a relaxed atmosphere [11][13]. A formal structured interview was too restrictive and would not allow the interviewer to investigate interesting areas which arose during the interview. The unstructured interview was rejected as they can generate data which does not relate to other cases and is impossible to analyse [9]. The interviewers started with factual questions to put interviewees at ease. The interviewer recorded the interview to allow continuity and flow. Interviews were conducted after obtaining consents from participants and showing a brief two-minute video showing the technology. Interviews were analysed based on five key areas as follows:

i. Technological drivers and barriers
ii. Economic drivers and barriers
iii. Social drivers and barriers
iv. Environmental drivers and barriers
v. Regulatory drivers and barriers.

The feasibility of transferring the algae building technology were explored through participants' previous experiences. Each was asked about their professional background, experience and educational qualification. The interviewees expressed their personal ideas based on their education, qualifications and experience to generate 'richer' deeper information [11]. Each interview took an hour, the optimum time for useful data collection without over tiring participants. Following Moser and Kalton [11]long multiple confusing questions were avoided and jargon was eliminated because of the international aspect of the study. There were no leading or biased questions in the interview and the interviewers expressed no views during the interviews to lead or encourage interviewees in any way.

5.0 Data collection and analysis

The environmental drivers and barriers were focussed on carbon abatement, innovation, bio building technology, environmental rating tools, competing renewables and potential contamination. All interviewees noted the reduction in carbon, where algae absorbs CO_2 during photosynthesis [12]. Adoption of this technology would lead to lower operational greenhouse gas emissions; however concerns were raised about the total carbon footprint associated with the whole life cycle. Innovation and development of a new energy source was seen positively. If implemented on a larger scale some saw potential to contribution to mitigate the Urban Heat Island effect. The planner and property manager saw potential for reduced loading on existing energy infrastructure. The bio-engineer noted the need to adopt biology in buildings. The microalgae academic raised the possibility of selling biomass to other industries, e.g. pharmaceutical companies. Potential food production was raised however, numerous health and safety regulations affect food production, and may inhibit this option. Possible revenue from biomass sales may offset energy costs. Another driver might be to attain innovation points in the Green Star building-rating tool, although it does need to perform as designed. Many noted with new technologies the risks are the innovation fails to perform as anticipated and some piloting or proof-of-concept, and performance was seen as a good way to minimise risk.

A frequently expressed view was other renewables such as solar, PV and wind power produce more energy than algae. Production rates in Australia for algae may be higher than Hamburg because there is more sunlight, over longer periods of the year. The Hamburg building shuts down in winter, due to lack of sunlight for photosynthesis and maintenance [7], would not be an issue in NSW, however overheating may be a problem. The costs of new technologies compared to established technologies are expensive. Many were concerned about contamination and leaks as some algae contain hepatotoxins and neurotoxins, which are deleterious to human health to some extent [13]. Furthermore damage or leakage could cause odours. So whilst there are many environmental benefits arising from the technology, there are valid, but not insurmountable concerns which will need to be addressed. Table 1 summarises the environmental issues raised by participants.

Given the technical professional background of many participants, technological issues were raised. The NSW climate was noted as different from Hamburg and there were questions about what that would mean for production rates. The amount and intensity of sunlight in NSW was expected to lead to higher rates of biomass production and there may be different maintenance issues regarding cleaning. The anticipated lifespan and durability of the technology is unknown, for example, there are glazing panels and pipes with valves that require cleaning and periodic replacement and these are known unknowns with this technology. Maintenance would require training and education in the trades and professions to ensure continued optimum performance. There was a view that maintenance will be onerous, which may be heightened because no one has direct experience with such technology. A structural issue raised 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. Building adaptation occurs often, quite soon after occupation and drivers can be technological, economic, social, environmental, locational or regulatory [14]. This can be unpredictable in many instances. Alterations to building facades are less common because of the costs, but it is an issue to consider [15]. 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. One consideration was resistance to accidental and intentional damage because of resulting potential for odour and contamination. 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. Another technology related issue is the manufacture of the components for the façades may occur overseas and lead-in times for projects will be affected.

Green washing is the practice of making an unsubstantiated or misleading claim about the environmental benefits of a product, service, technology or company practice. There is a danger that algae technology, because of its' novelty, is perceived as 'green wash' by industry. Reliability of the installations was raised and algae technology would need to approach the reliability of static systems, performing consistently to succeed. Many participants summed up the technological issues as 'complex'. This is because the technology is new and unknown; no one has direct experience of the technology on which to draw.

Within Australia, according to participants, the power and political influence of the coal and gas industries makes it hard for new renewable to emerge compared to European and other countries. 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. Another planning aspect is the loss of net lettable area within buildings as a result of the façade area and plant room requirements and incentives may be needed. This technology would require an alternate solution approach to building code compliance, which is expensive and time consuming. 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. Participants noted a need for guidelines for planners, building certifiers and other bodies such as Sydney Water, Department of Health NSW to reassure officers give appropriate advice to applicants. A retrofit issue occurs where the original structure is built to boundary line, because the façade would overhang boundary line. It is possible to negotiate for permission to overhang the boundary for a fixed period, however, it adds time and cost to projects. Some developers and owners would avoid additional unnecessary legal arrangements if the technology did not add substantially to capital or rental values.

There were many economic issues raised that often reflected the background of the participant. The Quantity Surveyors and Project Manager focussed on design and construction, whereas the Property Manager focussed on the operational phase. A question arose about the value of the end product which needs further investigation. The cost of the panels and plant is very expensive compared to other renewables. Another 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 larger installations make living algae technology more economically viable, for example at precinct level. The relative costs of the centralised and shared system elements influence scalability.

For most participants cost is the main barrier to algae system development and adoption. The façade cost on the BIQ building was US $2,200-2,300 m^2 or approximately ten times more expensive than many conventional facades. This is a substantial barrier, even with offsets through energy savings. However this technology will position NSW in a low-carbon economy. Additional costs would be incurred in the design, construction, operation and maintenance. There is only one complete building to inform 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. The valuer stated that capital value of algae buildings could be high as it is a unique technology. However, if it is perceived as too complex, too expensive, or green wash capital value will be affected negatively. The valuer thought the Sydney market would be sceptical, and wondered who would fund it. The problem is there are no local precedents, so valuers cannot determine reliably system whole of life costs. Some noted there are long-term cost savings through on-site energy production and increasing energy costs over time. The economic loss of NLA from the additional thickness of the façade and the plant room makes the technology less economically attractive. The economic payback period is unknown and needs to be reasonable and within the lifecycle of the building of 25 years. 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.

Table 2 Issues raised

Environmental	Carbon abatement, Innovation, Bio building technology, Environmental rating tools, Competing renewables Potential contamination.
Technological	Climate Lifespan and durability Maintenance Competition with other renewables Structural issues and façade design Building Adaptation Algal Production rates Heat transfer and shading Blueprints and guidelines Performance Clauses In Green Leases Intentional and accidental damage Cleaning (exterior and interior surfaces) Education of stakeholders Green wash Reliability Complexity

Regulatory and political	Power of vested interests Incentivising technology Building certification Health and safety Retrofit issues
Economic	Value Of The End Product The cost of production Scalability Costs Capital value
Social	Slime Innovation

(Source: Authors).

Social factors concerned participants the least. Some mentioned the negative perception of algae as 'slime', which would be associated with odours. Most were concerned about potential health impacts caused by leakage or damage and this risk needs to be managed. Most viewed the innovation as exciting, 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.

6.0 Conclusions

This paper posed the question; *what is the feasibility to adopt algae building technology in New South Wales?* The conclusions from the interviews are that renewable energy will dominate energy production in the 21st Century, and Australia lags in terms of innovation and adoption. 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. The BIQ building in Hamburg is the first iteration of a fully functioning algae façade.

This study canvassed the views of a highly experienced and well-educated group of professional stakeholders in the Australian built environment sector. Considerable discussion focused on drivers and challenges for the technology. Their views were summarised in terms of technological, economic, environmental, social and regulatory factors in relation to algae building technology.

Technological factors include the need to develop technology suited to the NSW climate. Further considerations are the mechanics of the systems, cleaning and maintenance and a suitably trained workforce. Accidental leakage and potential contamination needs to be addressed. A further unknown is the amount of production that can be derived in NSW. 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.

Economic factors weighed heavily and there was consensus that early adopters will face high costs of research and development, production and manufacture. Operating and maintenance costs also need to be quantified and analysed. There may be savings in operational energy costs due to on-site energy generation from the panels to building users

Environmental factors were strong drivers for adoption, 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 favourably. Negative environmental issues related to potential for odours and contamination, which would have to be managed through

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. Some felt there might be a negative perception if people associated algae with slime, and if the panels were not maintained and algae biofilms appeared.

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 blueprint to ensure all requisite guidance and information is provided for regulators.

Underpinning the above, there is insufficient system performance and cost information about algae building technology. This information is needed to complete 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 lessons learned from this study for NSW are that there is 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, the drivers and challenges for innovation and development of this technology are now known. Acknowledging the challenges ensures the innovation is more likely to result in viable outcomes. Undoubtedly, it is complex and costly technology, but so too was development of other innovations and technologies and on this basis prototype development is warranted. The main limitation of the research is that only one building exists with the technology in the northern hemisphere, and participants, although knowledgeable and experienced could only apply their knowledge to this one example and speculate on the issues and performance levels that might be achieved in other locations. The next step is to develop prototypes and to test performance in NSW.

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