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Abstract

In the context of climate change response, sustainable urban infrastructure needs to deliver deep cuts in greenhouse gas (GHG) emissions, of the order of 80-90% by 2050. This paper examines how various GHG reduction strategies applied to urban infrastructure open up or foreclose the potential for deeper cuts in the long-term. It uses case studies of a major precinct-scale urban redevelopment site and a city-wide planning process in Sydney to illustrate how developers and planners are balancing short to medium-term GHG reduction actions with the need to achieve much deeper cuts in the long-term. There is a particular focus on the implications of strategies that prioritise gas-fired cogeneration. The paper argues that too little attention is being given to the long-term implications of short-term GHG reduction strategies and proposes infrastructure design principles for long-term GHG reduction.

1 Introduction

An effective response to the threat of dangerous climate change is one of the great challenges of the 21st Century. As noted by Beinhocker et al (2008, p. 7):

> The debate on climate change has shifted dramatically over the past five years. The strong evidence presented by the scientific community through the Intergovernmental Panel on Climate Change (IPCC) process has largely settled the discussion about whether the world needs to respond. The question now is what shape such a response should take.

The risk of dangerous climate change increases substantially if global average temperatures rise by more than 2.0-2.5°C above pre-industrial global temperatures (United Nations-Sigma XI Scientific Expert Group on Climate Change, 2007). According to the IPCC (2007, p. 67), global average temperature rise could be limited to 2.0-2.4°C by stabilising atmospheric concentrations of greenhouse gases (GHGs) at levels of between 445-490ppm CO_2-e. This would require global GHG emissions to peak by 2015 at the latest and fall to 50-85% of 2000 levels by 2050. Further, an equitable response to climate change requires developed countries like Australia and New Zealand to reduce GHG emissions to 25-40% below 1990 levels by 2020 and to 80-95% below 1990 levels by 2050 to allow some room for growth in emissions from developing countries (Gupta et al., 2007, p. 776). This is a massive task, which has been likened to achieving an economic transformation on the scale of the Industrial Revolution but in one-third of the time (Beinhocker et al., 2008).

Intelligent design of new urban infrastructure, including buildings and their supporting energy, water and transport networks, can make a huge contribution to achieving GHG emission reductions of the necessary scale. An important question for infrastructure design is how to strike a balance between achieving emission reductions upfront and providing the flexibility and adaptability to achieve deeper emission cuts in the future. This question arises for several reasons. First, the cost of achieving GHG emission reductions is likely to fall in the future as a result of experience and economies of scale. This means that the least cost pathway to achieving deep GHG cuts is not to achieve all of these reductions upfront but to allow for these reductions to be achieved at an accelerating pace over the next four decades. Second, many items of urban infrastructure have long lives and some will still be in place in 2050; at some point, they will need to be retrofitted to achieve the 2050 emission reduction targets. Finally, there is still uncertainty about the pace and severity of climate change. Recent climate science points to alarming signs that climate change is accelerating and '[g]reenhouse emissions are rising faster than the worst case IPCC scenarios' (CAPSI, 2007, p. 2). It is possible that emission reductions may need to be achieved even more rapidly than is currently thought. New urban infrastructure needs to take this into account and designers of urban infrastructure need to consider how short-term and medium-term options open up or foreclose long-term options.

This paper uses case studies of the Sustainable Sydney 2030 urban planning process and the Frasers Broadway urban precinct development to examine how successfully urban infrastructure planners and designers are balancing the objectives of short-term and long-term emission reduction. Before turning to these case studies, some consideration of the advantages and disadvantages of different strategies for emission reduction is necessary as background to the case studies.

2 Strategies for emission reduction

Strategies for reducing energy-related GHG emissions can be categorised as follows:

1. Energy conservation, which reduces demand for energy services, e.g. through changing patterns of consumption or reducing population.

2. Energy efficiency, which delivers the same energy services using less energy.

3. Decarbonisation of fuel sources, which reduces the greenhouse intensity of the energy used to supply energy services, e.g. shifting from coal to natural gas, or from natural gas to wind power.

4. Sequestration of emissions, e.g. carbon capture and storage at power stations or uptake of carbon by forest plantations.

It is likely that an effective response to climate change will need to include elements from each of these groups of strategies.

The first group includes diverse strategies, some of which are simple and ubiquitous (e.g. turning lights off when not using them) and some of which are rare and radical (e.g. voluntary simplicity or choosing to have fewer children). The simpler options are relatively straightforward to encourage through intelligent infrastructure design. For example, building designers can include intelligent lighting systems that turn lights off automatically when not in use. The more radical options in this group would require broader cultural transformation if they were to make a significant contribution to emission reduction. For example, over time, voluntary simplicity movements may start to challenge the prevalence of consumer culture and its tendency to promote the purchase of more energy-intensive products. Urban planners and developers could choose to contribute to this process of cultural transformation; a developer could conceivably choose to devote some or all of the retail space in its development to retailers that offer products with low greenhouse intensity. Although this may seem unlikely at present, significant cultural shifts are likely, indeed necessary, before 2050 to achieve emission reduction targets. Importantly, strategies in this group do not foreclose options for deeper reductions in GHG emissions. By reducing demand for energy services they reduce the scale of emission reduction while leaving open the option to achieve further reductions by pursuing energy efficiency, decarbonisation and sequestration.

The second set of strategies reduces demand for energy by avoiding losses of energy during delivery, installing efficient appliances and equipment, or pursuing passive building design. The potential for these strategies to close down options for future emission reduction varies. To avoid losses of electricity during delivery, energy sources can be located closer to the point of demand in a distributed energy system. This might mean installing cogeneration systems to power an urban precinct or solar photovoltaic panels to meet the demand of particular buildings. The potential for distributed energy to close down future options depends on the energy source, so it is considered in more detail in the discussion of decarbonisation below.

Appliances and equipment are typically replaced within a decade (EES, 2008), so installation of energy efficient appliances and equipment leaves open multiple opportunities to replace this equipment with more efficient versions by 2050. In contrast, buildings and supporting infrastructure may remain in place for 50-100 years (EES, 2008). Most buildings constructed now will still be in place in 2050, so attention to passive design principles at the time of construction is critical. While it is possible to retrofit a building to improve its adherence to passive design principles, there will always be greater control over orientation, cross-ventilation and thermal mass at the time of initial design and construction. An effective response to climate change requires building designers to maximise efficient design right now, while also considering the ways that the building could be retrofitted in the future to further improve its efficiency. Although the building design will close down some options, the option of decarbonising the energy used to meet remaining demand always remains open for strategies that pursue energy efficiency improvements.

Decarbonisation of energy supply can mean shifting from one fossil fuel to a less greenhouse-intensive fossil fuel, or it can mean shifting away from fossil fuels towards renewable energy sources. The extent to which a decarbonisation strategy will close down future emission reduction options depends on the carbon intensity of the final energy source and its lifespan. If switching to a renewable energy source with greenhouse intensity close to zero, then immediate emission reductions will be achieved that are consistent with the 2050 targets. Renewable energy implemented in the short-term is entirely consistent with long-term targets.

Switching to natural gas is more problematic. In NSW, the average greenhouse intensity of grid electricity at the end user is 1.06 kg CO_2-e/kWh (DCC, 2008). By comparison, a combined cycle natural gas power station can achieve greenhouse intensities in the range 0.49-0.66 kg CO_2-e/kWh (ISA, 2006). If located at the point of demand, a natural gas power station replacing grid electricity could achieve emission reductions of 38-54% relative to current emissions. In a typical natural gas-fired cogeneration application, emission reductions of 50% relative to grid electricity are common. However, this means that natural gas-fired cogeneration alone will fall well short of delivering the 80-95% emission reductions that are required. For natural gas-fired cogeneration to contribute to such reductions, a number of approaches could be adopted. First, cogeneration can be used as one of a suite of strategies, including energy efficiency and renewable energy. In this approach, there are limits on the amount of cogeneration that can be allowed if 2050 targets are to be achieved. As an example, if energy efficiency measures kept electricity use stable into the future, then a 90% reduction in electricity-related emissions in NSW could be achieved by sourcing 20% of our electricity from cogeneration and the remaining 80% from renewable energy. However, it is important to bear in mind that natural gas is a finite resource and will eventually need to be replaced by other energy sources. Second, cogeneration could be installed with the assumption that it will need to be replaced with less greenhouse intensive technologies before 2050. This is currently feasible, as lifetimes for natural gas power stations are typically around 25-35 years (ISA, 2006). However, it may be less than a decade (2015) before natural gas power stations start to be installed that would normally still be in place in 2050. Further pursuit of this strategy would involve early retirement of power stations and this should be considered in costing cogeneration options. Third, cogeneration facilities could be designed so that they can be easily retrofitted or upgraded to use less greenhouse intensive fuels, such as hydrogen or biofuel. Whatever strategy is adopted, it is clear that urban planners and designers will increasingly need to make transitional strategies explicit when pursuing decarbonisation using natural gas.

The final group of strategies – sequestration – would not normally be used directly to reduce emissions associated with urban infrastructure. Neither carbon capture and storage nor tree planting is likely to be feasible on a significant scale within an urban setting. However, these strategies could be employed outside urban areas to offset emissions from urban infrastructure. This paper focuses on the design of urban infrastructure and does not give further consideration to the role of sequestration in reducing emissions.

The next two sections provide case studies on how these different types of emission reduction strategy are being deployed on an urban precinct and a city-wide scale and the extent to which the need for deeper emission cuts in the long-term has been taken into account.

3 Case study: Frasers Broadway

The Frasers Broadway site occupies nearly six hectares on the western edge of Sydney's Central Business District. Formerly occupied by the old Kent Brewery, the site is in close proximity to Central Station, close to several universities and situated at the western gateway to the city. The scale and location of the site combine to make it an outstanding opportunity to deliver a leading example of sustainability in the building industry.

Frasers Property, the owner of the site, is planning a mixed use development including apartments, offices, shops, restaurants and open space. Frasers Property is aiming to achieve a six-star rating under the Green Star rating tool, on a precinct scale. Consistent with this aim, the developer has given specific attention to the "future-proofing" of the development in its internal strategy and design discussions. A Concept Plan for the site was approved in February 2007 and amendments to the Concept Plan were lodged with the NSW Department of Planning in May 2008. While the details of sustainability initiatives for the site will not be determined until Project Applications are lodged and approved for specific buildings, several key initiatives to reduce GHG emissions are already clear. These include:

- Energy efficient building design
- Smart metering
- A natural gas-fired trigeneration facility to be located on-site
- Use of solar photovoltaic power for lighting in public spaces
- The design of underground car parking areas to be retrofitted for other uses in the future if there is a shift away from motor vehicle use
- Integration with local public transport options and bicycle networks
- Provision of space for vehicles dedicated to car-sharing
- Investigation of technologies and techniques to achieve 100% carbon neutrality.

The remainder of this case study will consider the extent to which the Frasers Broadway development pursues each of the strategies discussed in Section 2 and considers long-term GHG emission reduction.

The Frasers Broadway development is pursuing reductions in demand for energy services through options such as automated lighting control and smart metering. Smart meters, in conjunction with appropriate tariff structures, can reduce peak electricity demand by altering consumption patterns. Further, there is some evidence that they can prompt reductions in discretionary energy demand and associated GHG emissions (Kemp, Whitfield, Quach, Hedynach, & D'Souza, 2008). The specific functionality of a smart meter determines its potential to facilitate future reductions in GHG emissions. Smart meters are more likely to support reductions in GHG emissions if they are equipped with in-home displays to provide direct feedback to customers (Riedy, 2006) and supported by energy conservation and efficiency education programs (Kemp et al., 2008). Until recently, smart meters installed in Australia have not always had the functionality to support in-home displays, which closed down future options for achieving GHG reductions. The Ministerial Council on Energy has now specified a minimum functionality for smart meters that includes the ability to interface with an in-home display (MCE, 2008). This has opened up future GHG reduction options. Frasers Property has also been discussing the use of interpretive signage, green leases and owners' manuals to provide education on sustainability but it remains to be seen whether this education will include a focus on reducing consumption levels. In general, even progressive property developers are driven by what the market demands and do not see cultural transformation as their role. Consequently, more challenging options such as dedication of retail space to retailers of low-emission products have not been considered.

Energy efficiency is a key strategy for the site. Building designers have been encouraged to achieve the highest feasible levels of energy efficiency through passive design, efficient appliances and equipment will be specified and reductions in motor vehicles use are being encouraged through provision of access to public transport, cycling networks and car-sharing facilities. In addition, the development will include on-site energy generation through a trigeneration facility and solar photovoltaic panels, which reduces electricity transmission and distribution losses.

The building design, which is still in conceptual stage, highlights some of the difficulties of designing for long-term GHG reductions. One of the most important design considerations for reducing space heating and cooling demand and lighting requirements is solar orientation. Ideally, the site would maximise solar access by having the lowest buildings to the north of the site and gradually increasing building height to the south. This ideal is not feasible at Frasers Broadway because it would result in serious overshadowing of the relatively low-rise development in the suburb of Chippendale to the south of the site, as well as abrupt differences in scale. Instead, the tallest buildings are on the northern edge of the site, reducing the available solar access for the buildings to the south. This non-ideal solar orientation will be fixed in place for decades once the development is complete. This is a very difficult issue for developers and planners to address; cityscapes were not designed with solar access in mind and the ideal of a city with the lowest buildings in the north and the tallest in the south will not be practical in many cases. Nevertheless, urban planners will increasingly need to grapple with issues like city-wide solar access as the urgency of GHG emission reduction grows. For example, Chippendale is bounded to the south by a major rail corridor, so in the long-term it might be a suitable area for allowing taller development, as there are no overshadowing concerns to the south.

Another illustration of how the approach to energy efficiency can open up or foreclose future options is provided by lighting. At present, fluorescent lighting represents best practice in residential and commercial office lighting and is the most likely technology to be specified at Frasers Broadway. However, light-emitting diode (LED) technologies are emerging as a possible future replacement with lower GHG emissions. While it may not be cost-effective for developers to specify LEDs at present, a forward-looking approach would be to investigate the status of LED technology and ensure that it can be readily installed when the lighting is next upgraded. LEDs are emerging that use the same light fittings as fluorescent and halogen lighting, so it is likely that little modification would be necessary to allow for future retrofitting. On sites like Frasers Broadway, there is also an opportunity to install some LEDs, even if they are not yet cost-effective, to provide experience with the technology.

One area where the developers have specifically sought to build in future flexibility is through consideration of future uses for parking spaces. The developers have recognised that demand for ownership of motor vehicles is likely to decline in the future, particularly in an inner city precinct. Frasers Broadway will have excellent public transport access, integration with local pedestrian and bicycle networks and on-site car sharing, which will further reduce motor vehicle demand. Consequently, the developers are intending to design some basement parking areas to be convertible for other uses as demand for parking spaces declines. This has been made possible by integrating basement areas across the precinct, so that parking facilities are shared across multiple buildings. As a result, conversion of parking spaces under a particular building would not mean that residents or workers in that building could not access parking space. Of course, the potential uses for these spaces will be limited given that they are underground with no direct access to natural light. The developer is investigating innovative ways of bringing natural light to these areas.

The main decarbonisation strategy at Frasers Broadway is the inclusion of an on-site trigeneration facility that will use natural gas to supply some of the power, heating and cooling that the site requires. As noted in Section 2, the role of gas-fired generation in delivering GHG emission reductions of the scale required by 2050 is limited. A trigeneration facility developed now would likely be due for retirement sometime between 2035 and 2045. From a long-term perspective, it is appropriate to plan for its replacement with a lower carbon option. Replacement options include retiring the facility and replacing it with grid electricity or other on-site energy sources, or upgrading it to use a lower carbon fuel. The latter option could be relatively straightforward, as the space for an on-site facility would already be set aside and the existing gas engines could simply be removed and replaced with an alternative technology, such as hydrogen fuel cells. The facility will be designed with sufficient access to allow this. Broader questions of fuel availability and supporting infrastructure are considered in Section 4.

Retirement and grid connection may also be straightforward, as long as the site maintains a connection to the electricity network, as is currently intended. For this option to deliver a lower carbon footprint, the GHG intensity of grid electricity would need to fall below that of electricity from the trigeneration facility. Based on current modelling, the trigeneration facility at Frasers Broadway can deliver electricity with a GHG intensity of 0.59 kg CO_2-e/kWh, compared to grid electricity with a GHG intensity of 1.06 kg CO_2-e/kWh. Thus the GHG intensity of grid electricity would need to fall by 44% before it would be more attractive than electricity from the trigeneration facility. Under current Australian policy settings, which target a 60% reduction in emissions by 2050, grid electricity would be unlikely to deliver a lower carbon footprint than the on-site facility before it would be due for retirement, between 2035 and 2045. However, if Australia were to seriously pursue the targets discussed in Section 1, it is entirely possible that grid electricity would become more attractive than the on-site facility before it is due for retirement. Under these circumstances, the adoption of trigeneration could inhibit long-term GHG reduction, as the owners would have a financial incentive to continue operating the plant despite its poor greenhouse performance. The outcome here is highly sensitive to policy settings that are beyond the control of the developer.

The above discussion raises the question of whether it is more desirable for society to invest in renewable energy, which can deliver long-term deep cuts, than gas-fired generation, which can only make a limited contribution to long-term deep cuts. While investment in natural gas is generally more cost-effective at present and can deliver substantial GHG reductions compared to current practice, the future potential of the natural gas industry to deliver deep cuts is limited by its greenhouse intensity and the finite nature of the resource. Further, rising gas prices mean that the cost advantage may not be maintained in the future. It would seem that the best use of resources, from a societal perspective, would be to invest in long-term renewable energy technologies even if a given investment does not deliver as much GHG reduction as natural gas in the short-term. Returning to the specific case of Frasers Broadway, Frasers Property intends to use photovoltaic cells to power public lighting but there are no current plans for additional on-site renewable energy. On-site options are relatively limited due to the urban setting and the high cost of solar panels. Solar thermal energy (i.e. solar hot water or solar thermal power generation) could be viable at the site but leads to excess heat generation when used in conjunction with trigeneration. Nevertheless, the developer could choose to invest in more cost-effective off-site renewable energy options, such as wind power, and assign the emission reductions to the development. The cost of such an approach would be comparable to that of developing an on-site trigeneration facility but would have the advantage of building experience with a technology that can deliver long-term GHG reductions.

4 Case study: Sustainable Sydney 2030 – Green Transformers

The second case study briefly examines the implications of adopting trigeneration on a city scale. As part of its Sustainable Sydney 2030 process, the City of Sydney has developed a vision for the development of 330MW of "Green Transformers" in urban areas. Green Transformers 'are central plants which produce low–carbon energy and recycled water, and convert waste to energy' (SGS Economics and Planning, 2008, p. 120). These Green Transformers would use natural gas-fired cogeneration to supply heating, cooling and power to urban areas and would deliver an estimated 20% reduction in Sydney's business as usual emissions by 2030 (SGS Economics and Planning, 2008). The facilities would be built progressively between 2010 and 2030. In addition to Green Transformers, the Sustainable Sydney 2030 vision includes a range of other GHG reduction measures; together, the measures deliver a 50% reduction from current emissions. While this is impressive, further reductions beyond 2030 could be hindered by the carbon footprint of the Green Transformers themselves.

More importantly from a city perspective, the development of a network of Green Transformers would require the simultaneous development of a supporting network of hot water, chilled water and natural gas pipes. While the Green Transformers may reach the end of their lifetime and be retired or upgraded before 2050, much of the supporting pipework may not have reached the end of its design lifetime by 2050. How well will this supporting infrastructure meet the needs of the technologies that will replace cogeneration? If, as many have argued (e.g. Rifkin, 2002), the response to climate change and peak oil requires a shift to a hydrogen economy, we could imagine a network of large hydrogen fuel cells replacing the cogeneration plants. The hot water and chilled water pipes will still be needed but natural gas pipes could become obsolete or would need to be retrofitted to carry hydrogen. Alternatively, the Green Transformer sites could be taken over by solar thermal generators, again with no need for the natural gas network. Whatever scenario develops, there is a sense that in the present rush to achieve short to medium-term GHG reduction targets, long-term options are being forgotten.

5 Conclusion: designing for long-term emission reductions

The case studies considered in this paper point to a real danger that short-term thinking on climate change response will limit future options and make it more difficult to achieve deep future cuts in GHG emissions. In particular, strategies that prioritise greater use of natural gas as a transitional fuel need to give specific attention to how and when the eventual transition away from natural gas will take place. There is a real risk of developing a substantial natural gas infrastructure that becomes largely obsolete when deeper GHG cuts than natural gas can deliver are needed. Investment in options that can deliver deeper cuts, such as energy efficiency and renewable energy, appears to be a more promising strategy even if those investments do not deliver short to medium term cuts on the same scale as natural gas. In other words, it is better for society to begin investment in development of the long-term response than to spend money on a transitional response that will become obsolete. This approach also retains flexibility to respond more rapidly to climate change if needed and avoids locking up capital in options that do not contribute to the long-term response.

Drawing on the earlier discussion, several design principles for long-term emission reduction become apparent:

- Prioritise strategies that do not foreclose future emission reduction options, including energy conservation, energy efficiency and renewable energy
- When a particular technology is selected for a development, consider the technology that is likely to replace it in the future and how the design might be revised to ease this replacement
- Understand new urban infrastructure as an opportunity to develop experience and familiarity with technologies that have the potential to deliver long-term deep cuts in GHG emissions, even if this results in lower short-term cuts
- Develop a deeper understanding of viable pathways to a low carbon future as a framework for assessing the contribution of alternative infrastructure options
- Revise urban planning strategies to maximise solar access and to consider future uses of supporting infrastructure
- It is better to begin investment in development of a long-term response to climate change than to spend money on a transitional response that will become obsolete.

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