# Assessment of options for reducing greenhouse gas emissions in the ACT transport sector

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Report prepared for the Conservation Council ACT Region

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# 1. Introduction

With the ACT set to source 100% of its electricity from renewable generators by 2020, the transport sector will become the region's largest source of greenhouse gas emissions after this time (ACT Government, 2012). Finding ways to reduce transport emissions will therefore need to be a major area of focus for the government in reaching its target of zero net emissions by 2050. This report aims to aid in this process by providing an assessment of some of the options for reducing transport emissions in the ACT, in terms of their technical viability, cost, and likely community acceptance. Whilst the analysis is by no means comprehensive, it provides an initial assessment that identifies some potential opportunities (and any associated challenges) for reducing transport emissions in the ACT, and indicates some areas where more detailed assessment and planning activities could be directed.

The assessment was segmented into the areas of private, public and active transport. Preliminary research involved examining a wide range of potential options for reducing transport emissions in each of these areas, with a limited number of promising options selected and investigated further for the report. The majority of the options examined could be classified as efforts to reduce the emissions intensity of the vehicle fleet (both private and public), or encourage mode shifting to more sustainable forms of transport (public and active transport).
In the private transport section, hydrogen fuel cell and battery electric cars are assessed for the possibility of their integration into the private vehicle fleet, options assessed for public transport include battery electric buses, electric trams and intelligent transport systems, and finally awareness campaigns and bicycle share stations are proposed as means of encouraging greater rates of active transport participation.

# 2. Private Transport

Reducing the emissions intensity of the private vehicle fleet is one important step in reducing greenhouse gas emissions from the transport sector in the ACT, and will be crucial if the territory is to be able to meet its target of zero net emissions by 2050 (ACT Parliamentary Counsel, 2016). Two emerging technologies that can provide 'emission free' transport options (Hydrogen fuel cell vehicles and battery electric vehicles) will be analysed for the feasibility of their integration into the ACT's private vehicle fleet in the following subsections.

## 2.1 Hydrogen Fuel Cell Electric Vehicles

### 2.1.1 Technical Viability

A hydrogen Fuel Cell Electric Vehicle (FCEV) essentially operates by converting the energy of a chemical reaction (between hydrogen and oxygen) to electricity, which is then used to drive an electric motor and power the vehicle (US Department of Energy, 2006). When electricity from renewable sources (such as wind and solar) is used to produce the hydrogen fuel via water electrolysis, hydrogen FCEV's can be operated without generating any greenhouse gas emissions. This method of transport can be considered viable from a general technological perspective, as both the cars and the required hydrogen production and refuelling infrastructure are well understood and have been demonstrated in practical situations overseas for some time, and recently in Sydney (Brown et al., 2012; Hyundai Motor Company, 2016).

There are however a number of technical considerations to be made when evaluating the suitability of developing hydrogen vehicle transport in the ACT. The first of which is the overall low electrical round trip efficiency of this energy system. Due to losses occurring in AC-DC conversion, electrolysis, hydrogen gas compression, and in the vehicle's fuel cell and electric motor, the overall round-trip efficiency (for commercially available systems) is currently around 30% with on-site hydrogen production, and less where the hydrogen is transported or liquefied (Stocks, 2016; Mazloomi et al., 2012). Using the stated capacity of the electrolyser to be installed in Canberra and the performance specifications of the Hyundai ix35 fuel cell model car (Hyundai Motor Company, 2016), it was estimated that around 6 MWh of electricity per year would be needed to produce sufficient hydrogen for each FCEV (assuming an average of 14,000 km travelled per car per year). Therefore any targets for increasing the uptake of hydrogen vehicles will have to be matched by increases in renewable electricity generating capacity. Systems or technologies with better electrical round trip efficiencies will clearly require lesser increases in electricity production, and lesser associated costs (from purchasing renewable energy certificates or funding more renewable projects).

Another important technical consideration is the increase in consumptive water use that will be associated with the utilisation of hydrogen cars (as a result of hydrogen production by electrolysis). With some simple stoichiometric calculations, we obtained a rough estimate of the annual water consumption of a hydrogen FCEV at 1,200 L (assuming the performance of a Hyundai fuel cell and a distance travelled of 14,000 km/year). In a scenario with high rates of hydrogen car use, this extra water consumption could pose challenges for the management of water resources in the ACT, especially as they are expected to become increasingly scarce in the region as a result of climate change (ACT Government, 2012).

#### 2.1.2 Cost

The main cost to consider when assessing the economic feasibility of encouraging hydrogen-fuelled transport is the cost to develop the required hydrogen infrastructure. A US model estimated the capital cost of an onsite electrolysis system, with a hydrogen production capacity of 600 kg per day, in the year 2025 would be around $2 million (Melaina and Penev, 2013; Quin and Brooker, 2014). This size system is similar to the hydrogen production capacity that can be calculated for the 1.25 MW electrolyser proposed for Canberra (which should be 660 kg/day). The same US model also estimated hydrogen fuel production costs of around $6/kg for this type of system (Melaina and Penev, 2013). It must be noted that these costs can only be treated as very approximate ball-park estimates, and the cost for a centralised hydrogen production and distribution system (which is more likely when there is large demand for hydrogen) will differ significantly.

#### 2.1.3 Community Acceptance

Since hydrogen vehicles provide comparable range and refuelling times to internal combustion engine (ICE) vehicles (Hyundai Motor Company, 2016), there is the potential for this transport option to receive a high rate of community acceptance (as it would require close to no change to the behaviour and routines of those who use private transport). However, perceived safety concerns with the technology will likely hamper its uptake, and most significantly, the much higher purchase price of hydrogen FCEV's (Dowling, 2016) will prevent widespread acceptance and uptake. External forces that govern the production costs of hydrogen vehicles will therefore have the largest impact on rates of community acceptance. What can be used to control or improve uptake is the availability of refuelling infrastructure in Canberra, as well as measures that can reduce the purchase price (such as the existing differential duty scheme). The amount of support given to developing hydrogen car transport in Canberra will have to be based on a cost-benefit comparison to other options for reducing transport emissions (which includes the secondary costs and impacts; such as those resulting from increased electricity demand and water security concerns).

## 2.2 Battery Electric cars

### 2.2.1 Technical Viability

Battery electric vehicles (EV) are another private transport option that will not produce greenhouse gas emissions during operation if they are charged using electricity from renewable sources. An advantage they possess over hydrogen vehicles is their significantly greater round-trip efficiency, which is approximately 70% (Stocks, 2016).

The required technical knowledge on charging infrastructure and electric vehicle supply equipment (EVSE) design (including standards to which they must adhere) is well developed and readily available (Yilmaz and Krein, 2013), so there is the ability to expand this charging infrastructure in the ACT. An important technical consideration when pursuing this private transport option is the potential for EV charging to significantly increase peak electricity loads, and cause grid stability and reliability issues (at high EV penetrations) (Yilmaz and Krein, 2013). The most cost effective approach to dealing with this problem is by controlling EV loading; shifting electricity demand away from peak times through a number of mechanisms (such as time-of-use incentives, demand response, real-time pricing with smart-grids, and vehicle to grid support) (Electric Transportation Engineering Corporation, 2009). Demand shifting can reduce the extent of grid infrastructure upgrades that would be required if EV loads were left uncoordinated, and also delay the time where grid upgrades are needed to cope with higher EV penetrations (Electric Transportation Engineering Corporation, 2009).

### 2.2.2 Cost

Determining the costs associated with load shifting or upgrading grid infrastructure for different EV penetrations in Canberra will require a much more comprehensive analysis than can be conducted for this report, but estimates for the capital costs of public charging infrastructure are more straightforward. Charging systems are categorised as level 1, 2 or 3; based on the voltage and power at which they operate (charging power increases and charging time reduces at higher levels). Mostly level 2, and some level 3, charging stations would be the focus for public charging infrastructure (as level 1 only requires a standard wall socket, and have slow charging times not suitable for public use). Level 2 charging stations (which require only EVSE equipment) have reported installed costs ranging from $1000 to $3000, whilst level 3 charging stations (which require a charger and EVSE equipment) are reported to cost between $30,000 and $160,000 (Yilmaz and Krein, 2013).

#### 2.2.3 Community Acceptance

Some significant barriers to community acceptance of electric cars as a transport option include the perceived inconvenience associated with their longer charging times and shorter range than ICE vehicles, and the significantly higher cost of EV vehicles. Whilst future technological improvements in battery storage capacity and production up-scaling will likely do most for increasing EV penetration, there are steps that government can take to improve uptake. Developing public charging infrastructure (and perhaps offering early-adopter incentives such as free parking and electric vehicle charging in the city) could alleviate ‘range anxiety’ and help increase the uptake of EV’s (Yilmaz and Krein, 2013). Similarly, planning and establishing load controlling systems (such as those mentioned previously) that can accommodate EV uptake targets would demonstrate the readiness of the region for EV transport, and could also improve uptake.

In future work it would be also be useful to conduct a cost-benefit analysis of various incentive schemes that lower the purchase price of EV’s to consumers - to assess the likely increase in EV uptake (and associated decrease in emissions) that is estimated to result from certain spending on incentives, and compare this cost-benefit to other options for reducing transport emissions.

## 3. Public Transport

### 3.1 Battery Electric Buses (BEB’s)

#### 3.1.1 Technical Viability

The aim is to get the technology at a point where convenience and practicality of BEB’s meet that of fuel powered vehicles. This means reducing the required charge time down to minutes or a charge frequency of once nightly. (Brooker, et al, 2016) This has presented two options; frequent but small recharges (opportunity charging) or one large recharge (overnight charging). (El-Taweel, et al, 2017) Both options ensure large distances, have low maintenance, provide acceleration equivalent to diesel buses and emission reductions. (Arora, et al, 2016) Taking the best-case scenario (that Action will purchase 100% renewable energy – cost factored into table 2) and 2014 bus emissions, BEB’s will provide a reduction of 29.66 million kg $CO_2$-e each year or 68,657 kg $CO_2$-e each year per BEB. Although 29.2 g $CO_2$-e/passenger-km will remain from manufacturing and infrastructure. (Arundell, 2012) Future research will need to focus on emission reductions during manufacturing and infrastructure.

Table 1 – Operational Comparison of Opportunity and Overnight Charging - Lithium Ion Phosphate

| Bus Type | Approx. Cycles (per-day)/(per lifetime) | Approximate Battery-Life Span (Years) | Required Infrastructure | Stress on Electricity Grid |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Opp.<br>(≥18 kwh) | 11.7/120,000 | 28.1 | Extensive | Low |
| Night.<br>(≥211 kwh) | 1/120,000 | 328.8 | Minimal | High |

(Charest, et al, 2011)

Battery lifespan for operations below 1800 amps over two 2 minutes. This allows for fast charging (<10 minutes) and discharging during the route. (Brooker, et al, 2016)

### 3.1.2 Cost

Over a 14 to 16-year basis diesel investments will become economically inefficient. Opportunity charging will show economic benefit during the 14th year. Overnight charging during the 16th year. After these periods BEB's will truly begin to shine due to low operating cost. Opportunity charging is seen to be the most economically feasible alternative during a 22-year period due to lower unit price, however, after the 22nd year overnight charging will become most economically feasible due to lower operating cost. When purchasing overnight BEB's this report highlights that these buses will need to run over 22 years as this is how long it will it will take before a net benefit is seen over opportunity charging.

Table 2 – Cost Comparison of Opportunity and Overnight Charging (1 USD = 1.34987 AUD)

| **Bus Type (12m)** | **Average Unit Price Bus/Battery Replacement (AUS$)** | **Operating cost (AUS$/km)/ $-Replace Existing Action Bus Network ($M)** | **Unit-Operating Cost/Entire fleet Operating Cost ($M/year)** | **Cost-of Emission Reduction ($/kg $CO_2$-e)** | **Invest. payback period (years)** | **Invest. Benefit Period (years)** |
|---|---|---|---|---|---|---|
| Opp.<br>(≥18kwh) | 595,835/<br>≥$2,430 | 0.735/257.4 | .04/18.56 | 7.33 | 14.3 | >14.3<br><22 |
| Night.<br>(≥211kwh) | 647,940/<br>≥28,500 | 0.695/279.9 | .04/17.25 | 10.02 | 16.2 | >22 |
| Diesel | 269,975 | 1.46/116.6 | .08/36.24 | N/A | N/A | <14.3 |

(Ferguson, et al 2016), (McCormack & Noel, 2014), (Grütter, 2015), (MRCagney, 2015), (Wesoff , 2016).

Operating cost includes maintenance, fuel and infrastructure cost. Investment period does not include carbon credit benefits equalling approximately $303,400 for every 29,660 tonnes of $CO_2$-e per year avoided - maximum crediting period of seven years. (RepuTex, 2016) Canberra 100% renewable electricity cost has been used – overnight charging has included savings for utilising the Electric Vehicle Tariff. (ActewAGL, 2016) Cost of battery replacement includes projected price reduction ($135/kwh by 2022). Other costs associated within Action including administration, labour, training, registration and insurance are assumed to even out following the introduction of BEB's, thus these were excluded. Analysis of solar electric buses has not been included due to lack of information regarding cost, however, it is assumed that their likely higher cost per unit will be offset by their economically efficient operating cost with investment periods alike overnight charging buses.

#### 3.1.3 Community Acceptance

BEB's present further benefits than primarily energy efficiency and emission reductions of which include: noise reduction, increased local air quality, decreased vibration and increased ride quality. Commuters will experience comfortability and health benefits from BEB's compared to diesel. With acceleration and range features matching that of diesel commuters are likely to favour BEB's. (Bjerkan, et al, 2016)

### 3.2 The Capital Metro Light Rail (CMLR)

The primary requirement of light rail is the ability to provide large scale relief during peak periods. (Birdsall, 2015.) At best an Action bus can carry 107 passengers, where a CMLR vehicle is projected to carry over 220. (ACT Light Rail, 2015) Light rail uses ten times less energy than a car per passenger kilometre. (NSW Government, 2016)

Table 3 - Displaying Cost Break Down of Gungahlin to Civic Route (Stage 1)

| Net Cost Over 20 Year Project | Operation Cost ($)/Year | $CO_2$-e From Construction (kt) | Projected Emission Reduction (kt$CO_2$-e/year) | Time-Net Emission Saving (years) | Cost ($) / kg $CO_2$-e | Projected Cost Benefit |
|---|---|---|---|---|---|---|
| 939 M | 22M | 60.9 | 15.698 | 3.88 | 3 | $1.20 per $1 Invest. |

(Lawson, 2016), (ACT Light Rail, 2015), (Flannery, et al, 2015), (Arundell, 2016)

#### 3.2.1 Community acceptance

The vehicles are environmentally friendly, quieter than car traffic, safe, spacious and convenient. Light rail is beneficial to add service and image to public transport including the Canberra city landscape in which Lassen & Olesen, describe to be necessary to win commuters over to public transport.

### 3.3 Intelligent Transport System (Smart Traffic Lights)

Integration of complex computer systems which can predict and manage traffic flows to keep a consistent flow. For fast and reliable operation of light rail, light rail vehicles should have priority at highway junctions. (Maunsell Australia, 2007) Adaptive controls can improve traffic flow at intersections by between five and 25 per cent. At $21,000 - $81,000 per intersection, installing adaptive controls can be seen to be more economically efficient than building more road capacity. (O'Leary, 2016) Adaptive controls benefit everyone on the road – extending priority to buses is also an option. (Cheng, et al, 2014)

## 4. Active Transport

Active transport is primarily concerned with the attitudes and behaviours of the public towards sustainable transport, but in particular their ability and willingness to seek out alternative forms of transport. For the purposes of this report, 'Active Transport' encompasses cycling and walking as modes of transport, and cultural awareness programs as aids to motivating a population. Because these modes of transport are inherently localised, active transport as a research area acts as a support for private and public transport, either providing easier access to public transport, or being an alternative to private transport for commuters.

In most instances of active transport initiatives, the motivation is primarily to reduce congestion and improve the general health of the public. While obviously commendable, the focus of the recommended initiatives are primarily to aid in the reduction of carbon emissions, and so will aim for convenience rather than health, though these will be by-products of most recommendations.

The following recommendations and accompanying references are well documented and all work toward a more carbon-neutral transport system, as well as encouraging carbon-neutral awareness among local communities and businesses. The final recommendation, bike-share stations around Canberra's city centre, is the most technical of the solutions and so is the main focus of the research into the active transport sector.

**Take2Pledge**

The Take2Pledge is a Victorian initiative that encourages businesses, families and communities to be aware of the climatic consequences of their actions. It encourages them to pledge to reduce carbon emissions by committing to a series of activities, such as energy assessments for businesses and travel efficiency for individuals. (https://www.take2.vic.gov.au/actions/)

Applying this to the Canberra context would require very little modification and would be another step towards developing a healthy community awareness of the kind of initiatives available to reduce carbon emissions.

**Cycling Tracks**

Continued investment in a cycling network to roughly match access to Canberra's local road networks. Canberra already does a commendable job on this, but it needs to remain a focus of developing infrastructure if a carbon-neutral cycling culture is to be maintained and encouraged within the city

**'Cycling Capital' marketing scheme**

In order to encourage a culture of cycling, both for commuting and tourism, a targeted marketing approach to advertise Canberra as the Cycling Capital, with co-operation from local cycling clubs and communities, would highlight the current cycling opportunities in Canberra. This could be paired with continued investment in cycling tracks (mentioned above) and information boards etc. to move transport use from vehicles such as taxis to a more active, local tourism transport system. This could be especially effective with the newly introduced international flights coming into Canberra.

**Bike Integration with Public Transport**

A big part of making public commuting more accessible is allowing easy access for cyclists. For example, increasing the capacity of long-route buses (such as Gungahlin and Watson routes) to carry bikes would encourage commuters to use public transport rather than private. Parallel vertical storage for bikes on the new light rail system would be another improvement to encouraging easy cyclist access to the city centre.

**Cycling Stations**

Finally, the largest-scale initiative recommended is establishing cycling stations around key inner city areas, with possible future expansion to outlying areas and tourist attractions. The major benefits of such an initiative would be an increased change over of commuters from private to public/active transport, especially if the cycling stations were well integrated with the already existing public transport infrastructure. This initiative, more so than any of the above, would have a lasting impact on the emission reduction goals of Canberra, as it would provide the necessary system and infrastructure for a behavioural shift in commuters, with bussing/cycling becoming more convenient and cost effective than driving.

The following discussion serves to highlight and provide some structural recommendations about how implementing cycling stations might be done.

**Bike Share in a Canberran Context**

The essential elements of a bike share system are as follows: a 'fleet' of bikes that can be electronically locked and unlocked from a public station, with payment being either in advance, or at the station itself. There is a form of identification (either credit card or transport/ID card) that is processed before a bike is checked out, so that while a bike is out, there is a record of who is responsible for it. There is also the option of having small GPS trackers etc. to find lost bikes.

Bike shares have been used in Australia to varying degrees of success. For example, the establishment of a bike-share system in Melbourne is an example of how such an initiative can fail if thought is not put into the public framework of convenience. The Melbourne scheme cost around $5.5 million dollars, involved establishing 52 stations around the city and was aimed at people who were currently driving or using public transport for their commutes. However, problems arose due to the inconvenient payment system (payment was made through a relatively long credit card transaction process), a lack of supporting infrastructure (namely safe bicycle lanes) and the requirement for personal helmets.

For Canberra, the best ways to overcome these obstacles have already been suggested above. Canberra's bike network is already fairly advanced, at least around the central parts of Northern Canberra, which is where the most commuter traffic passes through. It should also be noted that the average Canberra commute is around 10km, compared to Melbourne's 14km, meaning that a private commute has slightly less convenience to be overcome than in more populated cities. MyWay is already established, and so integrating the 'Tap On, Tap Off' payment system would do away with the inconvenience of long transactions, as well as providing a form of ID for bike users. An alternative form of payment, though more expensive to set up, is used at Monash

University, with students being allocated codes to identify themselves and unlock bikes, making the process far more secure.

The necessity of helmets is harder to work around, and can partly be addressed through targeted marketing/safety campaigns, as long as the appeal of a bike commute is good in other areas such as accessibility. Canberra is in a unique position, compared to cities such as Melbourne and Brisbane, which have struggled with compulsory helmet laws, in that cycling is already a popular activity, so personal helmets are not such an inconvenience to the general public. An additional future development, at least in the inner city, could be to construct covered or protected bike routes, so that short commutes (for example, between government department buildings) could be done without requiring a personal helmet.

The technology required for the most basic of bike shares is already well established, even in Australia, and there are a number of equal options to choose from. The primary concerns are ease of use and security. MyWay has already been discussed as the ideal payment method, especially as it makes use of users spontaneity; users are less likely to choose to ride if they know it involves a relatively lengthy transaction process, compared to 'tapping onto' a bus or grabbing a taxi. Security is important to avoid prolific theft, but most bike share technologies have now developed to be impervious to forced theft.

Finally, the cost for Canberra will be similar to that of Melbourne in terms of price per station (around $100,000), but it is assumed that there are some irreducible set-up and maintenance cost involved, especially as Canberra is a smaller city and so requires less stations. The upper limit is put at $200,000 per station, though this is a generous estimate and expected to decrease as more stations are built.

## 5. Conclusion

In conducting this investigation, a number of options for reducing transport emissions in the ACT have been analysed, with consideration given to their technical viability, cost and potential for community acceptance. Hydrogen FCEV and battery electric cars are technologies that are both sufficiently developed to be included in the ACT's private vehicle fleet, however the significantly higher round-trip efficiency of battery electrics makes them more advantageous for minimising increases in total electricity demand. The extent to which load shifting can be used to control electricity demand from EV charging will need to be assessed in future work, and beyond this the grid infrastructure upgrades that may be needed will have to be identified. Additionally, the potential impact of consumptive water use in hydrogen production should be considered when deciding appropriate hydrogen capacity. Costs of $2 million for on-site hydrogen electrolysis were reported in the literature (for 600 kg/day hydrogen production), and for electric vehicle charging level 2 stations costs were reported between $1000 and $3000 and between $30,000 and $160,000 for level 3 infrastructure. Improving the availability of these infrastructure was discussed as a key way for the government to increase community acceptance and uptake of hydrogen cars and EV's, as were any incentive schemes that could bring the purchase price of clean vehicles into cost competitiveness with ICE vehicles.

In the public transport sector, potential emissions reductions from battery electric buses were discussed. Cost analysis showed that opportunity charging and overnight charging become more economically viable than diesel options after 14 and 16 year payback periods respectively, and it was concluded that significant community support could be expected for the integration of electric buses into the system. The cost and emissions savings provided by the light rail system were discussed, with community acceptance expected. The possibility for a smart traffic management system to cut emissions by reducing idling times was mentioned, along with the potential for its favouring of the public transport system, and it was found that this approach would be a more cost effective way of improving traffic flow.

The final recommendation for reducing transport emissions within active transport is to ideally pursue all the minor recommendations to some degree, but to especially consider introducing several bike share stations to central Canberra, at a cost of up to $200,000 a station, with care taken to address and encourage positive public perception, namely highlighting the benefits (both environmental and convenience) of an integrated public transport and active transport system. Extensive use should be made of technologies and processes proven successful in Melbourne.

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