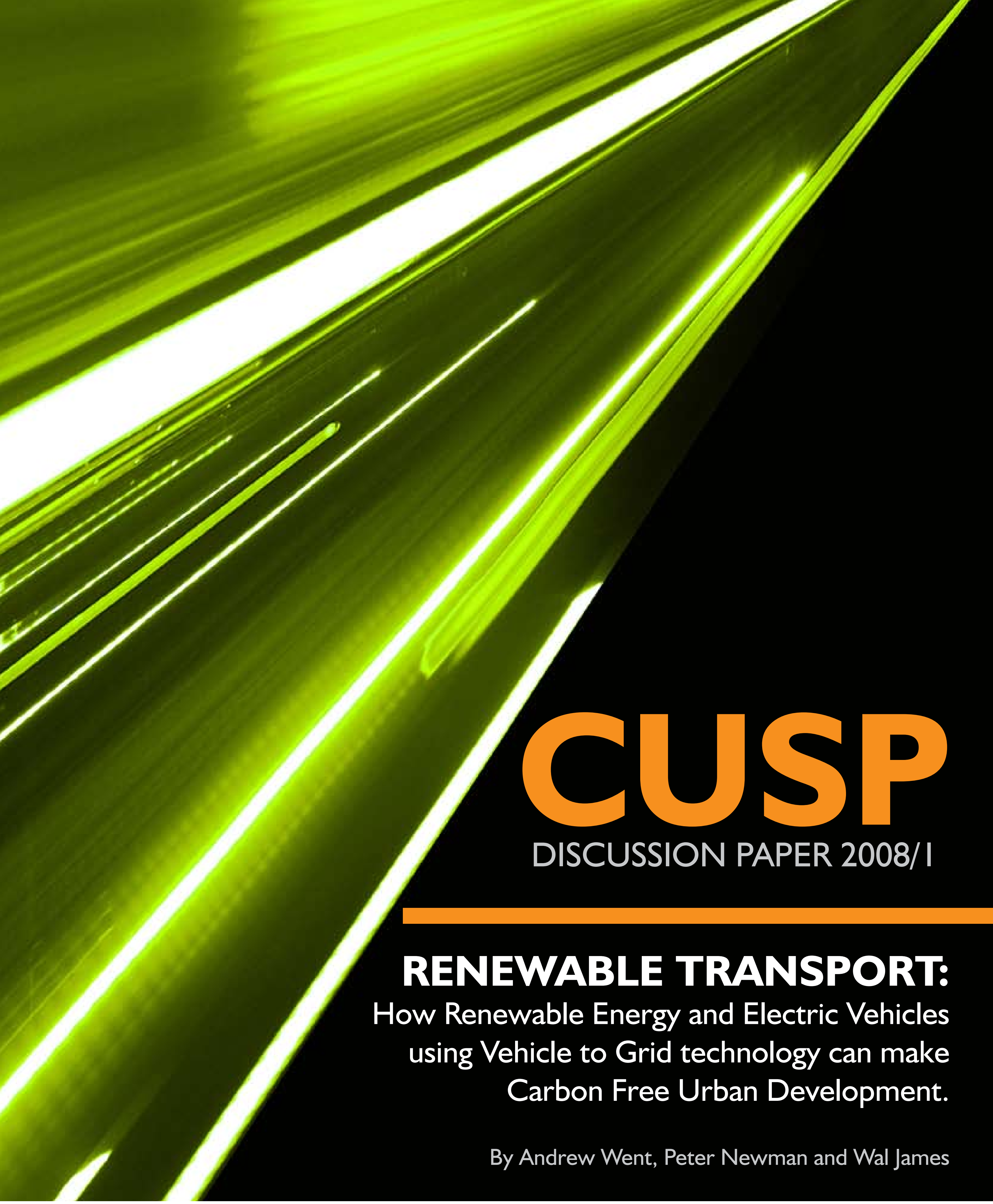

CUSP

DISCUSSION PAPER 2008/1

RENEWABLE TRANSPORT:

How Renewable Energy and Electric Vehicles using Vehicle to Grid technology can make Carbon Free Urban Development.

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Abstract

Renewable Transport is proposed as the phrase to describe a new collection of technologies based on V2G, PHEVs and Smart Grids. Vehicle to Grid (V2G) is the idea that the combined electrical storage capacity in a fleet of Plug-in Hybrid Electric Vehicles (PHEVs), linked through a smart grid, can allow the introduction of a large amount of renewable energy into the electricity network. This paper discusses the individual benefits of each of the technologies required for Renewable Transport, then how their combination can lead to even greater reductions in fossil fuel consumption and greenhouse gas emissions. The payback period for the electric vehicle's initial price premium is estimated from fuel savings and income generated by providing ancillary services to electric utilities. Further, the number of vehicles required for a given penetration of wind power providing baseload electricity is assessed. It also discusses the current advances in these technologies and makes suggestions on how it can be implemented in a carbon free development demonstration project from the perspective of the Western Australian electricity network.

Introduction

In light of the growing oil supply problem the need to diversify the fuel supply of our transportation industry is growing increasingly urgent. The most promising scalable, near-term solution is to switch to electric based propulsion. Electricity offers several key advantages over other alternative fuel sources such as bio-fuels, Hydrogen fuel cells, compressed air and CNG/LPG[1]. It is already ubiquitously accessible, requires no significant technological breakthrough, does not compete with land that can be used to grow food and can reduce mechanical complexity in the vehicle. Furthermore, urban air quality is greatly improved as electric propulsion emits no emissions from the vehicle's tailpipe and, if the electricity is supplied from renewable sources, no overall CO^2 emissions at all.

The new element in this discussion is that the use of electric vehicles can not only solve these oil and emissions issues, they also provide the chance to bring renewable energy into cities at a much higher proportion than was possible before. This paper will discuss the potential for electric vehicles to enable cities to be carbon free. The combination of technologies involved we have called Renewable Transport.

Vehicle manufacturers have started to respond to consumer demand for more efficient vehicles by introducing Hybrid Electric Vehicles (HEVs) and Battery Electric Vehicles (BEVs). An intermediate between these will soon be introduced, called Plug in Hybrid Electric Vehicles (PHEVs), whose battery can be charged from grid electricity, allowing significant all-electric driving range with an internal combustion engine (ICE) available for longer distances. The high price premium of current battery technology and the fact that the majority of vehicles are driven for relatively short distances each day with the occasional longer trip, suggests that, in the near term, PHEVs will see the most rapid growth in these new vehicle technologies.

When a number of these PHEVs are parked and plugged in, their batteries represent a significant amount of stored energy that could potentially be fed back into the grid, hence the term Vehicle to Grid or V2G. A large penetration of variable renewable energy (e.g. wind and solar) in the grid will require an increase of ancillary services as well as storage support to avoid expensive fluctuating fossil fuel backup generator start-ups when the renewable supply drops. The batteries in PHEVs can provide these services almost instantaneously upon request at low cost to the utility, and create a source of income for the vehicle owners that can help to offset the price premium and wear and tear on the vehicles. There will also be times when excess renewable energy is available that the batteries can absorb rather than being wasted. Such a system will require the use of sophisticated control systems, known as a Smart Grid, that can allow two way flow of electricity in a highly distributed system.

This is the fundamental concept of Renewable Transport which will be expanded upon in the paper by examining the rapidly growing vehicle technologies involved, the present situation in the electricity supply industry with respect to renewables, the development of Smart Grids, how V2G can provide the missing link, how the concept can be staged as part of a development pathway and how it can provide the basis for carbon free cities. The concept is developed in relation to the Western Australian grid as a case study, but can be applied anywhere, and is finally focused on a new development concept in Perth - North Port Quay- which is prepared to be the first Australian demonstration of this initiative.

Hybrid Technology: Green and Gold

Civilizing the car has been an on-going project in which many options have been pursued. The use of hybrid technology combines the best of green goals in terms of emissions and the best of commercial and consumer goals in terms of power and performance.

A Hybrid electric vehicle is one that uses both electricity and a combustible fuel for propulsion. They are inherently more fuel efficient, to the order of over 30%, compared to similarly sized combustion only vehicles[2] . In fact, the latest model Prius has a fuel economy of 4.4L/100km[3] whereas the average efficiency of all Australian vehicles is only 11.5L/100km[4], and for all new 2007 models is 9.0L/100km[5], making the Prius over 60% more fuel efficient than the average. To achieve these increases hybrids take advantage of the complementary power generating characteristics of electric and internal combustion engines at different speeds. They utilize the maximal power of electric motors at rest, which compensates for the corresponding minimum power available from the internal combustion engine at rest. This enables the ICE to be switched off at low speeds which is where fuel consumption as well as all harmful emissions are at their relatively highest levels, as seen in *Figure 1*[6]. The engine in a HEV generally does not start until it has reached 25 to 50km/hr.

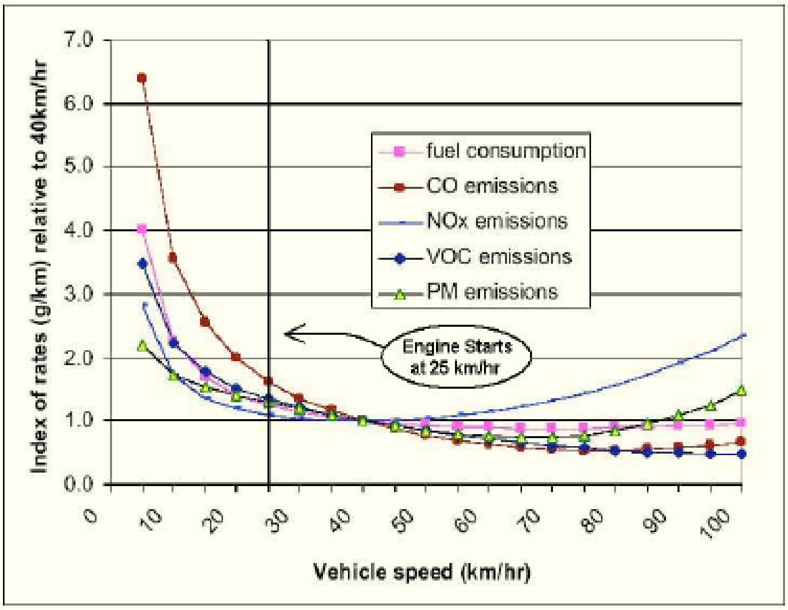

Figure 1: Fuel and Emissions Relative to Speed.

Electrical assistance removes the constraint that the engine must match the instantaneous power demands of the driver, enabling engines to be designed for the average power requirements, rather than the maximum. This allows much lighter and more optimized engine designs since they are not exclusively required to cope with extremes of operating conditions, i.e. low and high speeds and acceleration. They are optimized to perform most efficiently within a narrow operating range and are able to be kept in this position for longer due to the electric assistance.

Another efficiency improving measure is regenerative braking. It is the reverse of the process of providing electricity to the electric motors in the wheels, causing them to spin. When the brakes are applied the spinning wheels turn the electric motor, which generates electricity and charges the battery, slowing the vehicle in the process.

There are two main types of hybrids: parallel and series. In parallel HEVs, both mechanical and electrical energy power a mechanical transmission. The Toyota Prius is an example of a parallel HEV. In contrast, in a series HEV, only the electric motor powers the wheels directly. The engine is used to generate electricity for the motor and to recharge the battery. The lack of a mechanical link between the combustion engine and the wheels simplifies the overall design by eliminating the need for the conventional mechanical transmission elements (gearbox, transmission shafts and differential). The GM Volt, due for mass production in 2010 will be a series plug-in HEV.

The electric-only mode of series hybrids make them the preferred choice for most city driving, but for driving long distances at speed as in the country, they lose some ground due to the better efficiency of a mechanical transmission (~98%) over an electrical transmission at high speeds (~70% efficient). There are combined hybrid drive trains in development that can switch between series and parallel mode to optimize their transmission for any driving condition[7].

Batteries

The main impediment to the widespread adoption of electric vehicles lies in their batteries, as all other components in the vehicles involve essentially mature technologies. Thus an intensive period of R&D has occurred in the past 20 years to find this Holy Grail. The search now seems to be over. A new generation of batteries based around an advanced Lithium-ion chemistry appears to supply the energy and power densities required for an electric vehicle battery to provide sufficient driving range without being too bulky or overly heavy. They also have highly efficient charge and discharge cycles[8], can be charged quickly, and have lifetimes comparable to other components in a vehicle, on the order of 10-15 years [9,10]. Furthermore the new chemistry has resolved the critical safety issues raised with earlier Li-ion batteries[11]. *Figure 2* illustrates some of the advantages that currently available Li-ion technologies have over lead-acid or nickel-metal hydride batteries used in early electric vehicles. The recent flourish of research interest and funding into battery technology, spurred by the push for electric vehicles, should lead to even further increases, with some significant improvements already being claimed[12,13,14]. The CEO of Toyota recently stated 'We are moving from the era of the gas tank to the era of the battery pack' when discussing the next generation of vehicles using Li-ion batteries[15]. Now that the search for a battery suitable for electronic vehicle use appears to be over, the advances in manufacturing techniques and technological optimisation along with economies of scale should see the price premium reduce considerably over the next few years.

Plug-in hybrids: the next big step for cars

PHEVs are the next step towards a lower emission and more fuel efficient transportation system. They will have large batteries that can recharge by plugging into the electricity grid using a standard wall socket, or a more specialized charging station for rapid charging. This allows an all electric driving range sufficient for a majority of short trips. An ICE is included to extend the driving range beyond the battery storage capacity but need only be engaged when driving longer distances. The all electric driving range can lead to significant reductions in fuel consumption provided the battery size is selected according to the daily commuted distance travelled. There is a trade off between increasing the battery for extended all electric driving range and the size, weight and cost of these larger batteries. PHEVs will also have all the other efficiency features of a regular hybrid.

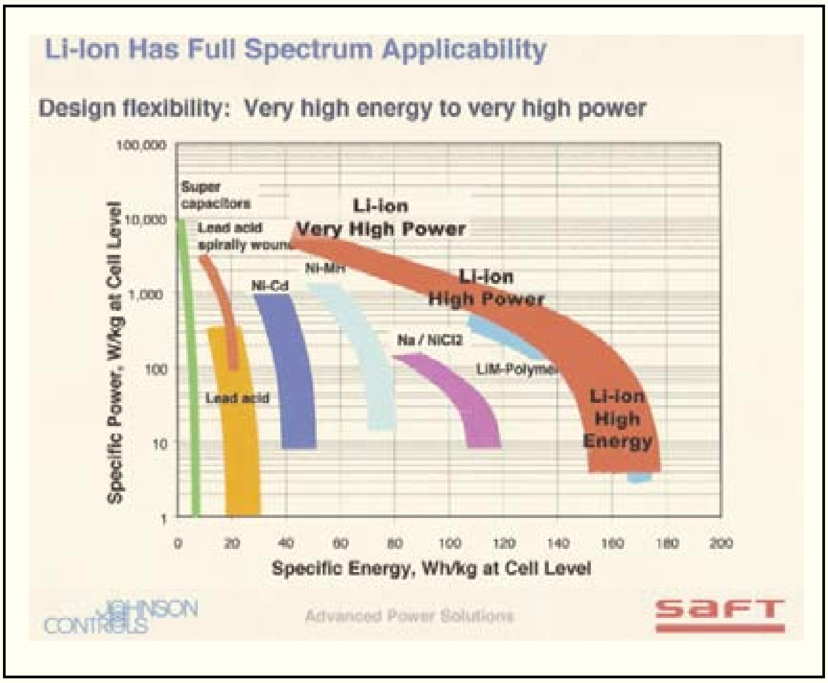

Fig. 2: Li-ion batteries can be designed from very high power density to very high energy density.

How much of a reduction depends on the particular driving requirements. The basis of the following PHEV comparison analysis is the average distance travelled by a passenger car in Australia, being 14,400 km/yr[16] and the average distance driven each day being less than 30km per day[17]. A "utility factor"[18] is used to define the fraction of the total kilometres travelled electrically. A PHEV30km, meaning an all-electric driving range of 30km, was selected and should give a utility factor of around 50% for a typical Australian's driving habits. For continuity, a PHEV30km is assumed in all future calculations.

Figure 3 shows the annual fuel use of the VY-Commodore configured as a conventional internal combustion engine vehicle (ICV), a HEV and a PHEV. The energy used as an ICV and HEV was based on the full cycle of the fuel which takes into account the energy required to extract and refine the fuel which is called the 'well to wheel' (WTW) energy[19]. The electric energy from the grid charged batteries is expressed in litres of ULP fuel equivalent (the energy content of ULP is 32.2 MJ/L). These results reveal a PHEV saves 65% of the fuel use with similar savings on fuel cost but also adds electricity use, though only a small amount.

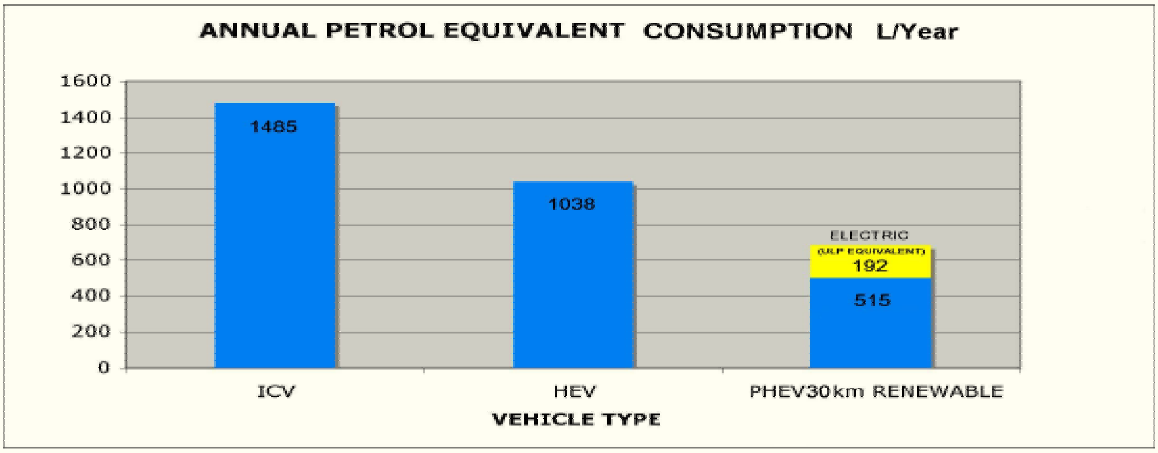

Figure 3: Annual Petrol equivalent consumption L/year.

Figure 4 shows the annual GHG emissions from an ICV, HEV and PHEV. The net mitigated GHG emissions by a PHEV compared to a conventional ICV, provided the electricity is supplied by renewables is 2.6 t/yr. If a coal-fired grid supplies the electricity, the GHG savings would only be 0.69t/yr.

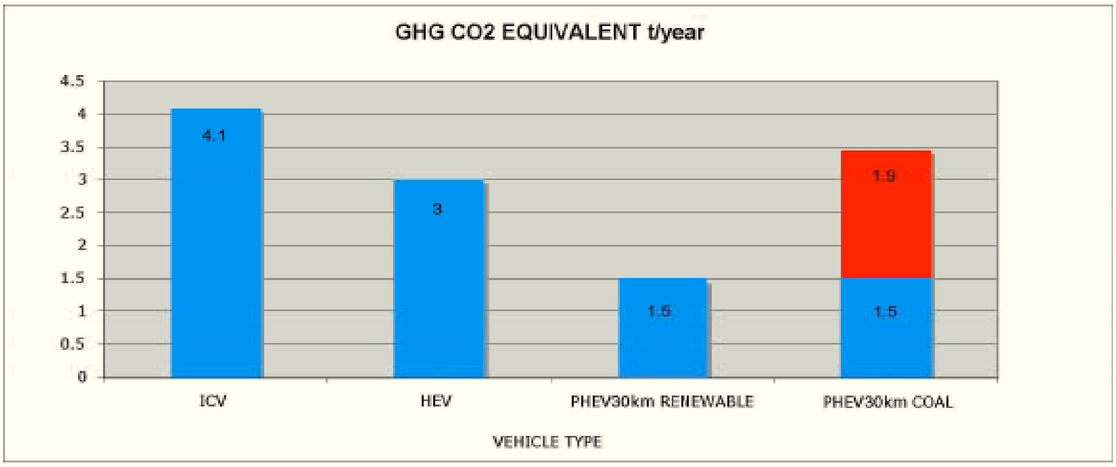

Figure 4: The GHG emissions from a PHEV including from grid electricity sources compared with a hybrid and an ICV.

While the overall GHG reductions from the transportation sector using PHEVs supplied by renewables are considerable, if the fuel used to produce the electricity is coal, the reductions do not look quite as impressive. Still, it is an important point to note that the amount of GHG's and harmful pollutants coming out of the PHEV's tailpipe are substantially reduced. Air pollution is a major problem in many large industrialized cities leading to poor health and respiratory diseases. Even if the electricity was generated by a coal fired power plant, the geographic relocation of the GHG's from the tailpipe to the chimneystack of a power plant would lead to a huge improvement in air quality in the city itself. However the greatest source of GHG emissions are from grid electricity generation, primarily from coal fired power plants. Any serious attempt at reducing total GHG emissions must confront this cause as well.

The significance of plug-in vehicle technology - bikes, scooters, gophers and buses as well as cars - is that typically, the battery in an electric vehicle will be charged overnight. As long as it is full in the morning, the variable supply is irrelevant. The new markets utilities can sell electricity to allow renewables to be commercially applied and thus enable them to replace coal.

Renewables and the Electricity supply industry: Finding a Dancing Partner

Renewable energy generation is seen by many as the saviour of the world's energy supply and climate change problems. Renewables such as wind, solar photovoltaic and solar thermal, hydro, geothermal and wave power offer the potential for virtually unlimited clean and cheap energy production. In fact, at current prices the cost of wind energy will approach parity with coal fired power plants when a price is put on carbon emissions[20]. However, fluctuating renewables like wind and PV must include a storage system if they are to be a substantial part of the future in any city region.

At a conference on 'The Renewable City' in September 2008, the CEO of Western Power, the distribution utility in Western Australia, spoke about how utilities can only increase their proportion of fluctuating renewables in a grid if they had a 'Dancing Partner'. In Europe this is hydro or geothermal which enable the fluctuations to be absorbed by a baseload renewable system. The potentially large storage supply in a fleet of PHEVs provides a means to enable this storage to occur - it is the potential 'Dancing Partner' for renewables.

Western Australia is particularly blessed with renewable energy sources as seen in *Figure 5*[21]. The majority of the vast expanse of the state is drenched with sunlight, the South-West region has some of the highest and most consistent wind speeds in the world, there are many thousands of kilometres of coastline bombarded by powerful waves and in the north-west there are substantial tidal movements. A diversity of generation sources spread over a large area should allow a regular supply of renewable electricity. Hourly data was collected over a year long period for the electricity demand in the West Australian electricity network, the South West Interconnected System (SWIS), as well as wind speed, solar insolation and daily temperature for Perth. This data is summarized in *Appendix 2* into seasonal averages that highlight the correlation between the variations in demand and potential renewable supply. However, there are some issues that need to be addressed before renewables can be considered for supplying a significant fraction of the State's electricity supply which require a more detailed look at how the electricity market operates.

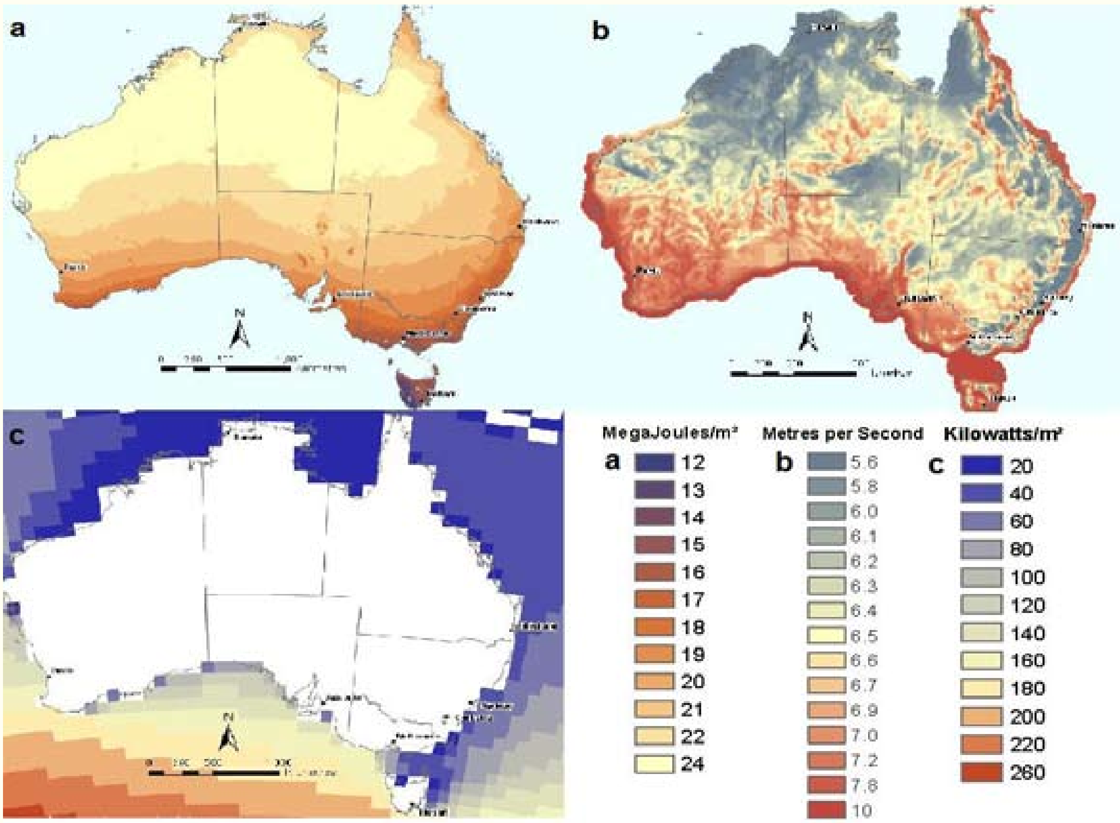

Figure 5: A map of some of Australia's renewable energy resources
(a represents average solar energy per m2, b shows average daily wind speed, and c displays average wave power)

Electricity generators are divided into several categories based on the amount of electricity they can produce, how quickly they can change their output and the cost of the electricity. These are called baseload, mid merit (or load following) and peaking generators. Baseload generators are large and hence expensive to build, but when running can produce large amounts of energy cheaply. The momentum of a large generator makes it difficult to change its output rapidly. Peaking generators are the cheapest to build, but are more expensive to operate, this is one reason why they are only used during peak demand periods. Mid merit generators have cost and performance characteristics between these two types of generators.

Figure 6 illustrates the variation in demand over a hot summer's day for the SWIS. The fairly consistent outputs of the Kwinana, Muja and Collie coal fired power stations are the baseload generators, while the mid merit gas turbines provide load following services and cater to the increase in demand. The peak demand was very high that day and is represented by the distillate gas turbine's output.

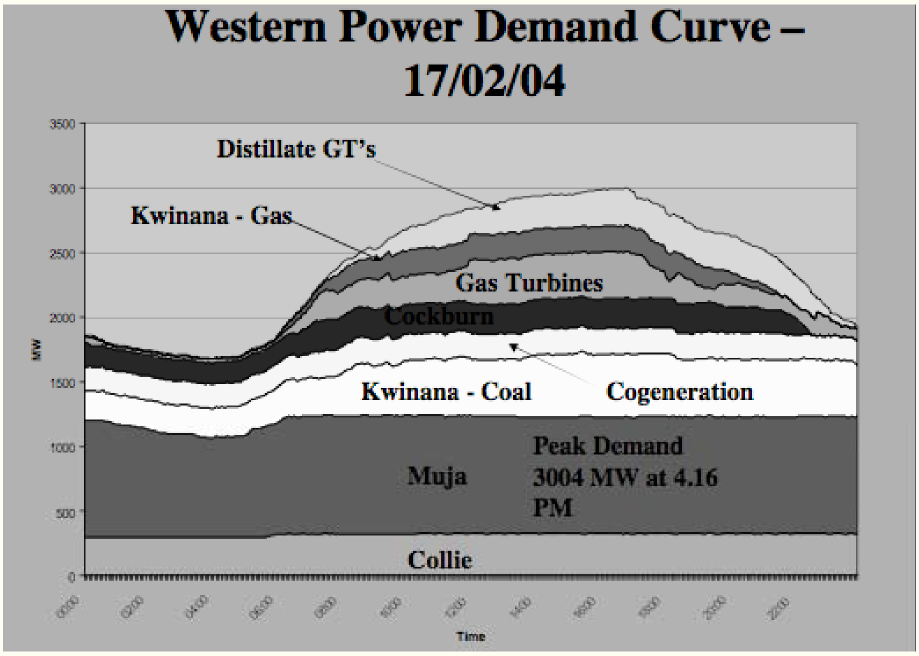

Figure 6: The Power demand curve for the hottest day in February in 2004, reaching 41.5'C (BoM).

There are other components to the electricity supply system which add stability and extra generating capacity to the grid to ensure the supply and demand are balanced as much as is possible. These are collectively known as Frequency Control Ancillary Services, FCAS[22].

The Electricity Network must maintain what is known as Spinning Reserves in case the demand is greater than anticipated or if a large generator experiences a forced outage. Typically, the larger a generator is, the longer it takes to warm up or increase its output, often taking so long for a large baseload generator that they are kept online continuously. However, the backup generators must be able to respond in a matter of seconds to prevent blackouts and so are kept spinning on a partial load, ready to be increased as needed.

Another ancillary service is called Frequency Control (also known as regulation) which provides fine tune balancing of the supply with the demand. It is the most expensive service and must respond within seconds or less to ensure a constant supply of 240V at a frequency of 50Hz. The system must be able to supply small amounts to cover insufficient supply as well as being able to absorb any excess electricity to prevent a potentially destructive overload which could be caused, for example, by a large industrial consumer suddenly switching off. These ancillary services are paid for whether they are utilized or not and their cost is incorporated into the wholesale price of electricity.

The amount of reserve capacity must be sufficient to serve the annual peak load expected to occur not more than once in every 10 years while the largest generator in the SWIS (Collie) is unavailable[23]. Hence there is considerable oversupply of generating capacity in the system most of the time, especially at night. The shedding of power into cooling towers is thus necessary and is a heavy part of the unnecessary production of GHGs due to this old style of power production.

The limits on the penetration of renewables into the grid arise from their variable output that requires an increase in ancillary services to ensure supply and demand can be matched continuously. Computer modelling based on weather forecasts can be used to predict the amount of electricity that can be produced from a renewable energy site a day or more in advance and this generation can be allocated to it by the network operator. There will be times that the renewable supply will exceed its expected output. Without storage, some of it would be discarded so as not to overload the system, since the baseload generators cannot adjust their output in the same timeframe as the renewable fluctuations. If storage is included in the system, and if the renewable supply is less than that forecast, the stored energy can be used to delay or avoid the start up of fossil fuel generators.

While renewables such as Solar and Wind are variable in nature, they have the advantage of being predictably variable. It is true that the output from a single solar panel or wind turbine may vary considerably throughout the day, however the statistical average of a large number of variable generators can be expected to follow a fairly smooth pattern, especially if they are spread out over a large area to reduce the impact that local effects, such as cloud coverage or wind lulls, would have on the group as a whole. The direct consequence of an increase in renewables is therefore a more stable supply since a larger number of generators would exist and they could be spread over a large area. Furthermore, with accurate forecasting, the amount of electricity that can be generated can be estimated fairly reliably. In the country of Denmark, for example, where around 25% of its electricity is supplied by wind farms, the 24-hour-ahead forecasts have a typical accuracy within 7% while the 4-hour-ahead forecasts are correct to within around 5% accurate[24].

It is unlikely that the generating capacity from a renewable source will drop suddenly and unexpectedly; it would typically be a more gradual and predictable decrease, as in the case of the sun setting or a pressure cell moving, causing wind speeds to change, on average, gradually. Should the main generator at Collie Power Station ever stop suddenly, 300MW of generating capacity would immediately be lost from the grid; however, even this loss is catered for by the requirements on the spinning reserves. If a single, or even several wind turbines were to suddenly cease functioning then only a few MWs would be lost. In regards to the reserve capacity for renewables with storage therefore; if the forecasting model is accurate then a smaller reserve margin could be maintained without the loss of system reliability.

The increased take-up of PHEVs could supply the storage required for the reliable supply of renewables at low cost whilst also providing ancillary services. Since they would be able to feed energy back into the grid almost instantly upon request, they would be able to provide frequency control as well as spinning reserves, thereby eliminating much of the overhead operating costs associated with a large penetration of renewable energy into the grid. The increased storage could also allow the shifting of peak loads, thus 'flattening' demand.

The existing electric infrastructure is designed for a small number of large generators to power the grid. Output response is regulated by monitoring changes in the frequency of the AC voltage; if it falls slightly, output is increased and vice versa. A move to smaller, more numerous distributed generators of variable output that utilize a fleet of mobile PHEVs for ancillary services will require an upgrade in the infrastructure's communicating abilities.

Smart Grids: the clever link

With the storage problem essentially solved, the introduction of renewables in large quantities still cannot occur unless an appropriate grid infrastructure, known as a Smart Grid, is provided.

The most general definition of a Smart Grid is an electricity network that takes advantage of advanced two-way communications and computer automated controls to streamline the provision of electricity services to consumers. A Smart Grid enables devices at all levels from utility to customer, to independently sense, anticipate and respond to real-time conditions by accessing, sharing and acting on real-time information.

Thus the appropriation of all the benefits of renewable energy (and most other small scale environmental technologies) requires this kind of smart control system - it is known as the ET-IT connection[(25,26)].

Some of the benefits of a Smart Grid include: increased operational efficiency by reduced distribution losses via optimal power factor performance and system balancing, encouraging consumers to reduce their peak demand consumption by enabling time of use (TOU) rates and real time consumption data, allowing a wide variety of generation and storage options including small scale renewable energy feed-in (and V2G), a more resilient and self-healing network from fault anticipation and prevention, and deferral of capital investment on distribution and transmission upgrades due to improved load estimates, and reduction in peak load from enhanced demand side response (DSR).

In order to implement a Smart Grid, the first step is a smart meter. Smart meters not only communicate back and forth to utilities, they extend into the home, providing information to consumers about their real-time consumption and can interact with 'smart appliances' also.

In April 2007 the Coalition of Australian Governments, COAG, following an extensive cost benefit analysis[27], committed to a nationally mandated roll-out of electricity smart meters to facilitate greater DSR by all energy users. The program has already begun, with over 3 million in total to be installed. The design of these smart meters should incorporate the ability to be upgraded to streamline the adoption of expected advanced technologies such as Smart Grids and V2G.

Governments and Utilities worldwide are realizing the potential benefits of a more intelligent electricity network and are similarly investing in smarter rather than more powerful upgrades; see Appendix 1 for more details. The US had approximately 142 million smart meters installed by 2005. Italy has 30 million, and Canada and Sweden have each committed to 5 million installed by 2010, just to name a few[28].

A Smart Grid extends the communications from just between the end user and the utility, to incorporating the substations, transmission networks and various electricity generators throughout the whole system, which involves more complex challenges. Already a substantially sized demonstration project is underway in Boulder, Colorado[29]. The City was selected because it is a medium-sized metropolitan area (~50 000 customers), is geographically concentrated and operationally well defined in terms of its electricity infrastructure. A number of options are being investigated to determine the optimum technical solutions. The project also includes integration of distributed renewable energy and a small scale V2G demonstration[30].

Not only will a Smart Grid improve the operational efficiency, with the associated environmental benefits of reduced GHG emissions from polluting power stations, it also will provide the essential supporting infrastructure for the myriad of two way communications required for the development of a fully integrated V2G network that will enable a significant amount of renewable energy sources to power the grid, cleanly and reliably.

V2G: the missing link

Smart Grids and renewables linked to electric vehicle storage require the system of V2G to draw them together. The general premise of Vehicle to Grid is that a fleet of plugged-in vehicles represents a potentially significant resource that can be utilized to allow the introduction of a substantial fraction of renewable energy into the grid by acting as a buffer to regulate the variable renewable supply.

Passenger vehicles are parked and perform no useful function for the majority of the day. With the advent of plug-in electric vehicles, PEVs, either hybrid or all electric there is the prospect that idle vehicles can become assets that create value to their owners while parked[31].

To put a perspective on the magnitude of the potential of PHEV, the entire Australian grid is 49GW[32] and the passenger and light commercial fleet is estimated at 169GW (assuming 13 million vehicles[33] at 13 kW each).

The introduction of V2G can be done in 3 stages, distinguished by the number of vehicles available and the services they can provide. The progression of these stages is naturally facilitated by the more profitable early market services which help to offset the price premium inherent to early adoption of any new technology.

The first stage involves the use of PHEVs to provide ancillary services to the grid such as spinning reserves and frequency control. The batteries and power electronics in PHEVs are particularly well suited towards frequency control since the short, sudden demands on the battery are similar to the demands of driving. The net energy transfer of frequency control is typically zero, so only shallow cycling with minimal battery wear and no loss of storage are the consequences of this service. Spinning reserve payments are made just for being available and, should they actually be needed, an additional price is paid for any energy transfers. Spinning reserves could typically be required 20 times per year for 20 minutes each, while regulation could occur 400 times per day with small energy throughputs[34].

Table 1 displays a comparison between the added initial cost of hybridizing a vehicle, with and without plug-in capability, with the savings in operating costs and revenue generated, compared to a similarly sized ICV. The calculations put the price of unleaded petrol at $AU1.50/L and conservatively assumes the price will remain at this value. Any price increase will effectively shorten the payback period. The values used in these calculations are consistent with current West Australian electricity prices. The table shows that the payback period, for a PHEV providing ancillary services can be as little as just under two and a half years, even when the cost of extra wear and tear on the batteries is included[35]. Significantly, although the payback period for a HEV and a PHEV not providing ancillary services are similar, the latter uses only half the fuel and emits only half the GHG.

Table 1: Payback periods for a HEV and a PHEV compared to a standard ICV.

Vehicle type	Hybridization cost $	Fuel cost $/yr	Maint $/yr	Total F&M $/yr	Savings $/yr	Payback yrs	Payback V2G Freq. Con. (yrs)	Payback V2G Sp. Res. (yrs)
ICV	N/A	2224.8	300	2525	N/A	N/A	N/A	N/A
HEV	4727	1555.2	250	1805	720	**6.6**	N/A	N/A
PHEV	8457	182e+777.6f =959.6	200	1160	1365	**6.2**	**2.3**	**4.7**

e=electricity cost   f=fuel cost (ULP)

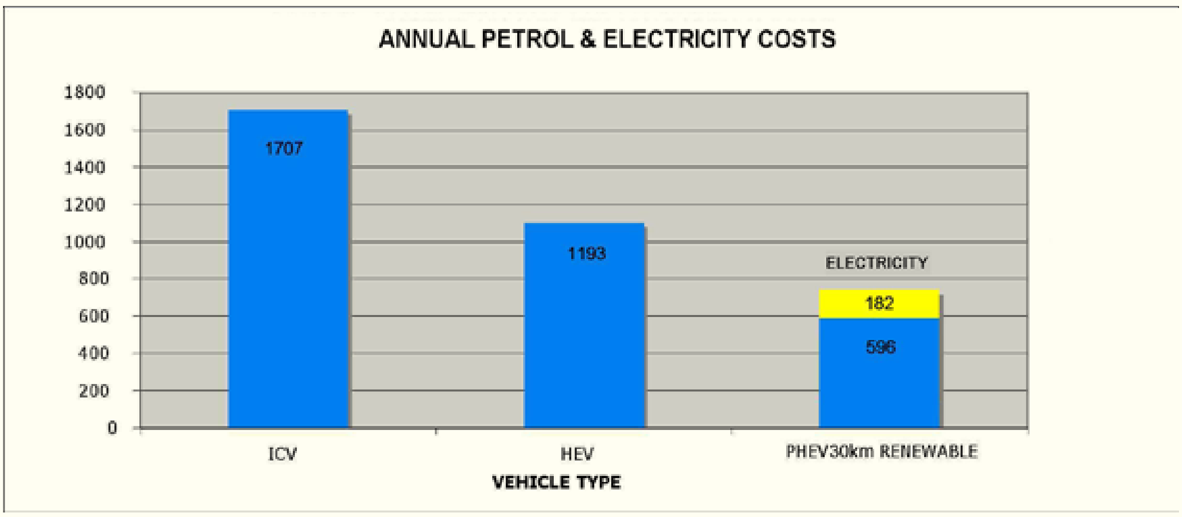

Figure 7: The operating costs for a similarly sized ICV, HEV and PHEV.

Once the ancillary services market has been saturated the growing PHEV fleet will begin to have a combined storage large enough to feed energy back into the grid at times of high peak demand. It is assumed that most PHEV owners will charge up overnight using cheap off-peak electricity that can be sold back to the grid at a higher price to the benefit of both the vehicle owner and the utility. These actions are known as “valley filling” and “peak shaving” respectively and their load levelling effect on the daily demand profile can be seen *in Figure 8*.

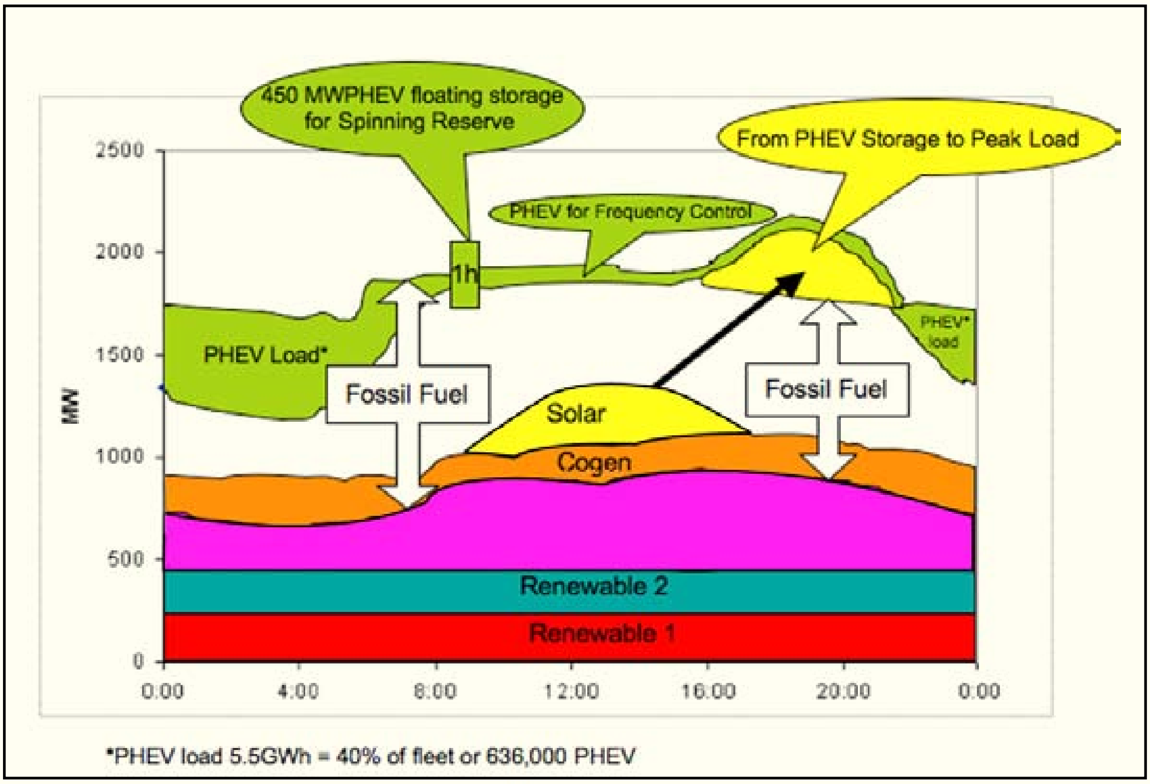

Figure 8: A possible future generation portfolio for the SWIS, involving PHEVs storing solar energy for the peak demand later in the day.

This load levelling effect allows baseload electricity generators to operate closer to their optimum conditions more of the time in a manner analogous to the efficiency increasing measures achieved by HEVs. This is illustrated in *Figure 9*[36]. The use of electricity for private vehicle transportation presents a new source of income to the utility without requiring significant upgrades; the extra electricity required for transportation services is observed as the difference in the area under the green line compared to the area under the red line. Furthermore, using some of the stored energy in PHEVs during peak demand periods will allow the utility to delay expensive additions to their peak power capabilities which are otherwise so under-used they represent a burden on the total supply system that ultimately results in higher electricity prices. They will similarly be able to avoid expensive upgrades to their transmission infrastructure (transmission wires and substations), by meeting some peak demand locally; thereby not adding to the strain on this infrastructure and reducing transmission losses.

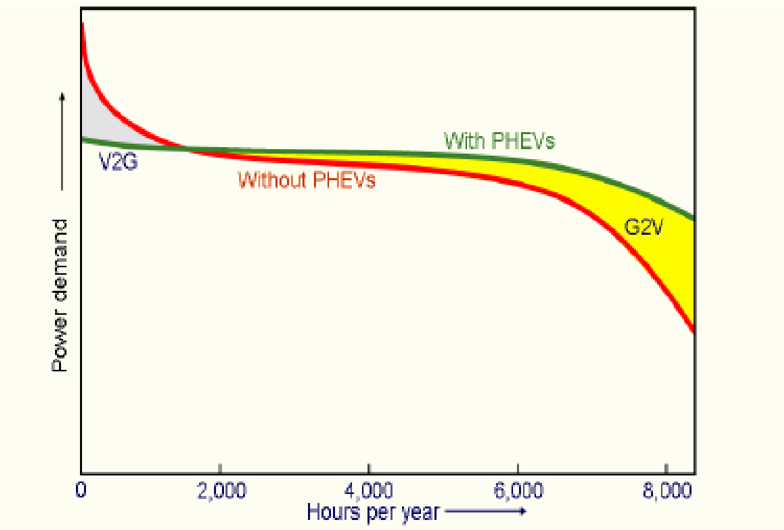

Figure 9: Impact of PHEVs on load-duration curves.

The ultimate manifestation of V2G occurs when PHEVs occupy a large share of the light duty vehicle market, LDV, comprised of passenger vehicles and light trucks; their combined storage capacity being large enough to buffer the variable supply from renewable energy sources providing baseload energy. As more vehicles become available the services they can provide move into a less profitable domain, however, by this time the price premium on PHEVs should be reduced until they are likely only marginally more than a comparable ICE only vehicle, and the fuel savings alone will still be a compelling reason to invest in a PHEV.

Wind power is currently the most competitive, widely scalable (compared to geothermal, biomass, hydro…), mature renewable energy source[37]. Calculations using the method proposed by Kempton and Tomic[38] demonstrate the number of plugged in vehicles required to support a given penetration of wind generation providing baseload electricity as shown in *Table 2*. Since not all the PHEVs will be plugged in or fully charged at any given time, the actual number of vehicles required will be higher. The capacity factor, defined as the percentage of energy generated over a period of time compared to the maximum possible energy that could have been generated, for a wind turbine provided it is in a suitable location can easily reach over 30%[39]. In comparison, the capacity factor of all the existing generating units in Australia, mostly coal fired power stations, is only around 62%[40], this highlights the underutilization required by the reserve margins as a consequence of not having any storage in the existing grid.

The amount of wind power requested by the network operator can be tailored to match the forecast output based on weather conditions. Wind speed data modelling performed by Milligan[41] on the operating reserves needed for high-penetrations of wind, assuming geographically dispersed sites, have shown that a reserve margin of 15% of the contracted generation, available for a full 3 hours is sufficient to cater for fluctuations from forecast output. Should a long wind lull be forecast then the utility can make alternative generating arrangements. Additionally, since this reserve is a battery (as opposed to a generator) it will not only cover shortfalls but also recover excess output over what is contracted from wind farms that otherwise would be lost.

Table 2: Wind capacity increases made possible, as a function of the number of PHEVs

Number of Vehicles	Vehicle Storage (GWh)	Vehicle Capacity Available (GW)	Reserve Capacity available for 3 Hours (GW)	Max. Wind installed name-plate (GW)	Avg Wind output @ 30% C.F. (GW)	%Australia's total generation (29 GW)	GHG Reduction (Mt/yr)
1	12kWh	4.4 kW	1.46kW	9.75kW	2.92kW	N/A	N/A
1 Mill	12	4.4	1.46	9.75	2.92	10	26
2 Mill	24	8.8	2.92	19.46	5.84	20	52
3 Mill	36	13.2	4.38	29.19	8.76	30	79
4 Mill	48	17.6	5.84	38.92	11.68	40	105
5 Mill	60	22	7.3	48.6	14.5	50	131

Table 2 indicates that one million PHEVs, or about 8% of the total Australian LDV fleet, would provide sufficient reserve capacity to add 2.92GW of average generation which represents around 10% of Australia's total generating capacity. This does not include the approximately 20% of wind penetration that could currently be met by existing reserve margins.

Figure 10 shows a possible future scenario, achievable by 2030, where five million PHEVs (40% of the fleet) support the introduction of 14.5 GW of wind average generation, or about 50% of Australia's average generation, reducing the share of coal powered generation from around 77% currently, down to around 27%, which mitigates 131 Mt/yr of GHG, or 65% of the approximate 200 Mt/yr emitted by Australia's coal fired power stations in the process. *Figure 11* highlights the GHG mitigation effect from the introduction of PHEVs is a factor of four times greater in the power generation sector than it is in transportation.

The previous discussion has limited itself to wind generation only. The availability of a large amount of storage makes it possible to reconcile the daily solar intensity peak that precedes the daily electricity demand peak by a few hours. A typical scenario could involve a person driving to work in all-electric mode, then plugging in to take advantage of the peak PV generation from a solar panel on the office's roof to recharge their batteries; allowing them to also drive home in all-electric mode.

The cost per kW of solar PV is rapidly decreasing due to massive research efforts around the world and their increasing economies of scale. The ultimate makeup of a 100% renewable energy society could well be dominated by PV due to the abundance of the raw materials employed and because it is not restricted by a limited number of available sites of decreasing quality; the best sites inevitably being utilized first. In fact, it is likely that the unobtrusive potential of PV to be integrated into the built environment such as on roofing, walls, windows and into products directly will see them able to meet significant amounts of local demand with little reliance on the grid during daylight hours. Furthermore, when solar electricity is available during the peak demand time, its economic value should be compared to the cost of the peak electricity it has displaced.

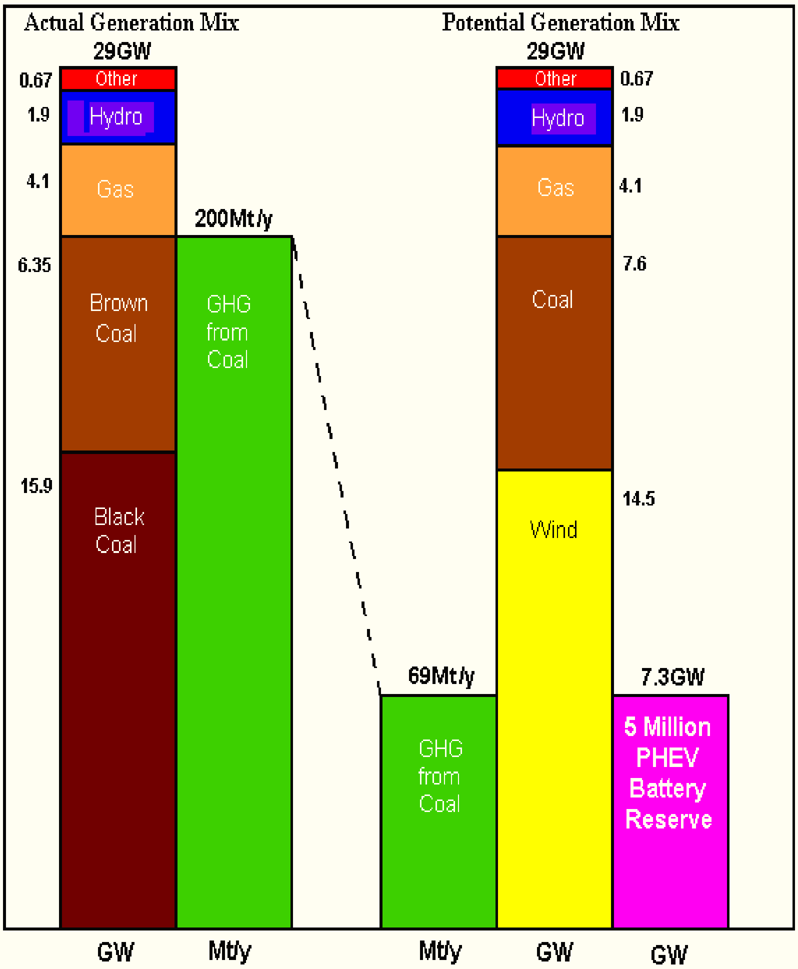

Figure 10: Australia's Potential GHG Reduction in Power Generation with Wind and 5 million PHEV support.

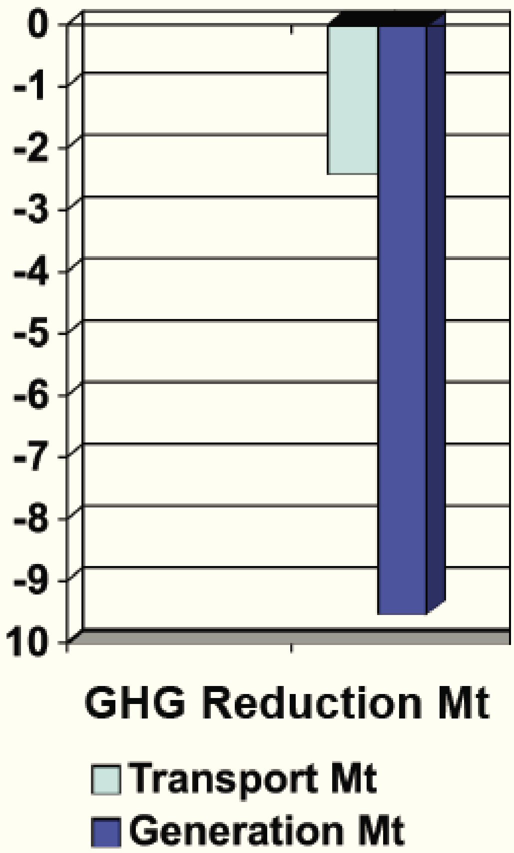

Figure 11: A comparison of the PHEV GHG emission reduction effect in Transport and Power Generation in one year (2030)

Pathways to development: taking the first steps with Renewable Transport

The rate of uptake of PHEVs entering the market will depend on a number of factors, including: the price of petrol; the cost of batteries; the ability to scale up vehicle production; the availability of plug-in infrastructure in parking areas; the prices paid to vehicle owners for providing ancillary services; any financial incentive schemes, government or otherwise, to accelerate their market share including tax cuts on low emission vehicles and encouragement for the establishment of a retrofitting industry. Predictions as to when these numbers could be achieved are discussed elsewhere[34].

To illustrate just how quickly these technologies are being taken up, Appendix 1 lists individual country and company initiatives and future intentions in the respective PHEV, battery, renewable energy, smart grid and V2G industries.

In a recent strategic policy submission to Infrastructure Australia[42], Western Power have acknowledged the need to adapt to a new operating environment that takes into account the effect that GHG emissions, produced from the burning of fossil fuels for electricity generation, have on climate change. There is an urgent need to invest in WA's electricity infrastructure as the majority of the existing network was built 40-50 years ago and the State's substantial economic growth is putting considerable pressure on it. These investment decisions must have a strategic and sustainable long term view and must not be constrained by current definitions of energy infrastructure. Consequently, their investment priorities are now to develop smart solutions to facilitate increased energy efficiency and to develop on a significant scale, embedded and distributed renewable energy systems that capitalize on Western Australia's natural advantages with respect to renewable energy sources.

An interesting scenario arises if the fuel tank is regarded as a backup which is used only occasionally. In this case fuels with a lower energy density such as LPG or CNG will not appear as much of a hindrance. These fuels can be cheaper, more abundant and are locally produced which could further protect Australia from the volatile international oil market. They will probably come after PHEVs using gasoline however as they require more extensive infrastructure.

The introduction of PHEVs into the market will be slow at first due to supply side constraints. A retrofitting industry to convert the legacy left from decades of ICE vehicle production and more recent HEVs into PHEVs can accelerate their adoption and also create many new jobs and business opportunities in Australia.

Another useful feature of PHEVs is that when plugged in they can perform the role of an Uninterrupted Power Supply, or UPS. In many businesses, a UPS is a necessary expense to prevent the sudden loss of power to their offices and especially their computers where large amounts of valuable data could be lost otherwise. Companies investing in a fleet of PHEVs will be able to offset some of the price premium by avoiding having to invest in a separate UPS, and by receiving the revenue from many vehicle providing ancillary services. In a more extreme example, such as in an emergency, a PHEV could have the energy and power conditioning required to provide power directly to essential appliances for an extended period of time, such as lighting and refrigeration that run off mains electricity. Homes could also benefit from this added benefit.

Better Place: the initiators

The wholesale electrification of the transportation industry on a national level is already underway in Israel and Denmark and is being spearheaded by a start-up company called Better Place. Their solution to getting whole countries off oil for transportation using existing technologies on a time scale of years instead of decades, along with their highly attractive business model is so compelling that they have already raised over US$200 million in venture seed capital; have commitments from the governments of Israel and Denmark to provide highly favourable tax incentives for the purchase of electric vehicles and permission to setup a network of recharging stations and battery exchange centres throughout each country; and they have a partnership with the Nissan-Renault Alliance, the fourth largest automotive group in the world by sales volumes[43], to buy as many electric vehicles as they can make. Nissan-Renault will be spending between $500 million and $1 billion USD in developing the technology and manufacturing facilities over the next several years[44].

The approach by Better Place is to separate the ownership of the battery from the all-electric vehicles being developed, which enables consumers to purchase an electric car for less than the cost of a comparable ICV, or, if they commit to a longer contract they may get the car for free. Better Place will own the batteries and charge customers for their use on a subscription-based model similar to a mobile phone company charging for use of their network. Like a mobile phone company, they will offer a number of different plans for different people but, whatever the driving habits or plan, the annual cost of running the vehicle should be less than an equivalent ICV.

Better Place will own and operate a network of public charging stations and battery replacement centres as well as providing in-home chargers. Their vehicles will have comparable performance to a 1.6L petrol engine and a driving range of at least 160km on a full charge and, should extra range be needed, the battery can be exchanged in a matter of minutes at one of the many exchange centres around each country. A variety of different vehicle types will eventually become available.

Furthermore, Better Place will seek to recharge their network of batteries using renewable energy wherever possible. Prototype vehicles will be on the road in Israel by the end of 2008 with mass production starting around 2010, and close to 100 000 vehicles are expected on the roads by the end of 2011.

It was recently announced[45] that Australia will be the next country that Better Place will be developing an electric vehicle industry in; focusing on Melbourne, Sydney and Brisbane and linking each city up by placing battery exchange stations on an interconnecting highway at regular intervals. This development can only serve to accelerate the switch from petroleum based fuels to electricity, either directly or through a transitionary phase of PHEVs. For the full benefits of an electrified transportation network, these vehicles should be incorporated into a V2G network.

A business case with pathways and gateways for the introduction of PHEVs, Smart Grids, V2G and associated infrastructure and industry development is now required to ensure Australia gains from this next stage of industrial innovation.

Carbon free developments

Sustainability is an approach to development that simultaneously improves the environment, the economy and the community for current and future generations. The shift towards a renewably dominated electricity and transportation network is a fundamental step in the design of a truly sustainable and carbon free development.

There are some carbon free developments existing and in development around the world that demonstrate that it is possible to live in a modern society with a high quality of life without impacting on the environment and these efforts are highly commendable. Some examples are BedZED, Masdar City, Dongtan and Treasure Island[46]. However few of these are genuinely carbon free as they do not include transport in the package.

Some of the initiatives employed include a high level of renewable generation, a high quality public transportation system with transit oriented development strategies, intelligent building design with emphasis on passive temperature control, advanced recycling programs, high efficiency appliances, and are all valuable demonstrations.

However, some of the principles involved are not practical when considered for application in a larger setting or to existing cities, or are only possible due to favourable geographical location and conditions. Furthermore, the people occupying these communities are typically more environmentally aware, and are willing to alter their lifestyles slightly to reduce their environmental footprint. V2G tackles the two largest sources of GHGs, electricity generation and transportation, in a technically feasible and mutually beneficial approach. None of the developments mentioned previously have included the initiatives outlined in this paper. Fully carbon free development has not yet been on the agenda as it has not been possible to imagine how it could work technically. Renewable Transport now enables this.

The separate improvements of Renewable Transport - electric vehicle propulsion, renewable energy technologies and smart grids along with their greater combined effect due to V2G, provides the greatest opportunity for new and existing developments to drastically reduce their carbon footprint.

To really illustrate that a Renewable Transport future is possible, a series of large and highly visible, carbon free developments that combine all these aspects of sustainability is needed to prove that it is possible. In the US the closest to this is the Treasure Island project in San Francisco Bay. In Australia a concept has been proposed, North Port Quay, with the potential to provide a world first demonstration of the complete package for a 100% renewably powered urban development.

North Port Quay (NPQ): the first?
NPQ is a proposed development off Fremantle in Perth, WA[47], that represents a unique opportunity to incorporate the V2G package as one of its guiding design principles from the very outset. It would occupy 345ha of degraded, reclaimed seabed on which five island villages would be created. The project would provide 10,000 dwellings as well as commercial space of around 100,000 m2.

NPQ will obtain all of its electricity requirements from renewable sources, including wind, solar and wave power. It will also serve as an ideal and highly visible demonstration site for V2G, linking the renewables and electric vehicles through a Smart Grid. Incorporating the Smart Grid infrastructure into the original plan will reduce overhead costs and allow an optimised design. Due to its geographical isolation, analysis of its interactions with the rest of the grid will be greatly simplified.

Its staggered development process (island by island over a number of years) will allow a staged rollout of Smart Grid technologies with incremental increases in complexity being manageably introduced. The lessons learned can be directly applied to the expansion of the Smart Grid to eventually incorporate the rest of Perth and beyond.

Some of the other features of NPQ include: conscientious selection and transportation of construction materials to minimize carbon emissions; a closed cycle for water and waste; transit oriented development with density and land use mix to minimize the need for enclosed travel and complemented by ample public transport services. Each household will also be provided with a Neighbourhood EV, NEV, such as an electric scooter or golf cart for journeys beyond walking distance and will have incentives to purchase a PHEV.

A substantial demonstration of these carbon-free technologies at NPQ will set new standards in the size and scope of what can be achieved when an overarching philosophy of V2G based sustainability is embraced.

Conclusion
This paper has demonstrated that Renewable Transport - the combination of renewable energy, Smart Grids and plug-in electric vehicles can enable the world to rapidly decarbonise its cities and regions. The breakthroughs in technology for batteries, vehicles and grids are all outlined.

A PHEV can use 65% less petrol than a comparable ICV based on an average Australian's driving patterns, with a similar reduction in GHG emissions if the electricity is derived from renewables. The abundance of renewable energy sources in Australia makes a strong case for their use in electricity generation in a world increasingly concerned with anthropogenically caused global climate change. A Smart Grid involves updating the existing electricity infrastructure to incorporate advanced communication capabilities which will allow it to operate more efficiently and be able to manage a network of distributed renewable generation and mobile storage devices. When these elements are integrated into a Vehicle to Grid system the benefits are far greater than the benefits from each of these areas combined separately.

Estimates of the payback period for the price premium on a PHEV were found to be much less than the life of the vehicle, especially when income from providing ancillary services to the grid is factored in.

A future scenario was considered where PHEVs comprise a large share of the Australian fleet, which allows a large amount of wind power to replace coal fired generators. It was found that the GHG mitigation effect from the introduction of PHEVs is a factor of four times greater in the power generation sector than it is in transportation.

These are the kind of dramatic synergies which can lead to exponential decline in the amount of greenhouse gas being emitted – something that the world must find if an adequate response to rampant climate change is to be made.

The next phase is to begin to enable some major demonstrations that can enable the business case and the policy implications for mainstreaming Renewable Transport to be pursued in greater depth.

APPENDIX 1 i

Car Makers

Car makers worldwide are increasingly realizing the limited future of petroleum based automobiles and are rapidly trying to develop hybrid, plug-in and all electric vehicles as seen below.

This summary was taken from http://www.calcars.org/carmakers.html and was last modified September 24, 2008:

Automaker	Description and summary of official statements	Status of production
AFS Trinity	Prototype of lithium battery + supercapacitor combination for licensing by carmakers	With Ricardo, three prototype conversions of Saturn Vue mild hybrid
Aptera	Futuristic lightweight $30,000 3-wheel vehicles in development	Taking deposits on hybrid version to follow electric version in 2009.
Audi	Volkswagen-owned company exploring PHEVs	Metroproject Quattro Sub-compact PHEV Concept Car shown October 2007
Bright Automotive	For-profit spin off from Rocky Mountain Institute plans to build lightweight PHEVs, successor to late 1990s "Hypercar" concept.	Indiana startup in "stealth mode." No schedule announced.
BYD	BYD Automobile Company, Shenzhen, China	Plan F6DM $20-$30,000 PHEV with 60-mile range for sale, starting in China in 2009, in the US around 2011
Chrysler	ENVI division developing Town & Country minivan and Jeep Wrangler SUV, both EREVs (series hybrids) with 40-mile range	One of the two -- or an all-electric sportscar -- planned for sale in US by end of 2010.
Daimler/Mercedes	Took over Daimler/Chrysler Sprinter PHEV program	Several dozen prototypes on 15-passenger van since 2004; now in second generation development; no production plans.
Fisker	Partner with Quantum Technologies for $100,000 PHEV	Taking deposits for small production runs in 2009 and 2010.
Ford	Five to 10 years away. Small long-term evaluation program, including modeling of vehicle-to-grid benefits and economics, with Southern California Edison. Batteries not ready. Has shown some concept fuel-cell PHEVs.	First Escape PHEV delivered to SCE Nov 2007; 20 in 2008-2009. (Several after-market companies have done PHEV conversions of the Ford Escape hybrid and one has done a retrofit of the F-150 pickup -- see Where PHEVs Are.)
General Motors	Saturn Vue PHEV and Chevy Volt series PHEV, which it calls "extended range electric vehicle" (EREV), part of "E-Flex" multi-fuel platform. Expects to produce Opel and other versions of EREV.	Plans "large demonstration fleet" in 2009. Committed to sales of 10,000 or more vehicles in late 2010, with increasing production in 2011. See Chevy Volt for latest. Aims to get Saturn Vue on road in 2010; no production goal.
Honda	Sees PHEVs as having "unnecessary fuel engine and fuel tank; promises all-electrics "assuming we can come up with a really high-performing battery that we are working on currently." Doubts PHEVs have environmental benefits.	No known plug-ins being planned or on the road.
Hyundai	Partnering with Korean battery companies for hybrids.	Planning PHEV by 2013.
Mazda	Ford-controlled company reportedly developing PHEV	Series PHEV based on Mazda 5 MPV platform. No announced plans.
Nissan	Includes PHEVs in its long-term development program.	Has tested an experimental PHEV model and is deciding whether to bring the car to market. Is also involved with Better Place in developing EVs.
Saab	GM-owned company exploring PHEVs	Joint Venture with Volvo and others to research PHEVs
Toyota	Agrees on environmental and economic benefits; says batteries need further development before a commitment to mass-production. Says demand and whether people will plug in remain to be proven.	Beginning with road-testing of a dozen "Plug-in HV" Prius PHEVs in the US and Europe. Advanced plan for at least 400 leased demonstration vehicles for commercial fleet owners from 2010 to 2009. Some US dealers have begun waiting lists. (Several aftermarket companies and organizations have converted about 150 Priuses -- see Where PHEVs Are.)
Venture Vehicles	3-wheel VentureOne in development.	Expected price around $25,000 for PHEV version in 2010.
Visionary Vehicles	Team w/Malcolm Bricklin (who brought the Subaru and the Yugo to America) is "starting to build the prototype."	Raising money to bring a series PHEV to market in 2010.
Volkswagen	CEO says "Future belongs to electric cars," has gained German government support for development.	Space Up! Blue Concept PHEV Van with diesel or hydrogen fuel cells and rooftop photovoltaic. Aims to put 20 "Twin Drive" PHEV-30 prototypes on Golf platform on road in 2010.
Volvo	Ford-owned company exploring PHEVs	"ReCharge" flex-fuel series 60-mile concept PHEV w/wheel motors. Joint Venture with Saab and others to research PHEVs.

APPENDIX 1 ii

Battery makers

The crucial element in the success of the electrification of the transportation industry lies in the battery. Several large car companies have gone into partnership with large electronics companies to develop batteries suitable for mass production in electric vehicles. Links to summaries of many of the battery producers are here:

http://evtransportal.com/batterycompanies.html

http://www.advancedbatteryprogress.com/

Smart Grids

Many countries have electrical infrastructures that are reaching an age where they need to be replaced and many are looking into Smart Grids.

In Australia Smart Grids are being investigated by CSIRO as well as other research collaborations:

www.csiro.au/science/IntelligentGrid.html

http://igrid.net.au/

http://www.smartgridaustralia.com.au/index.html

The Department of Energy in the US has a vision for a Smart Grid by 2030: http://www.oe.energy.gov/smartgrid.htm.

The organizations listed below are at the forefront of the Smart Energy revolution:

GridWise Alliance: The leading trade association for the Smart Grid sector
http://www.gridwise.org/

GridWise Architecture Council: Creating the technical foundation for the next-generation grid
http://www.gridwiseac.org/

Intelligrid: An effort to create a common platform for the Smart Grid, led by the Electric Power Research Institute
http://intelligrid.epri.com/publications.html

Modern Grid Initiative: A DOE-funded program from the National Energy Technology Laboratory to monitor and coordinate the country's various grid research efforts to promote a common vision and the widespread sharing of data
http://www.pserc.wisc.edu/

Power Systems Engineering Research Center (PSERC): University research consortium.
http://www.pserc.wisc.edu/

U.S. Department of Energy Office of Electricity Delivery and Energy Reliability: The home of GridWise, GridWorks and other R&D programs.
http://www.electricdistribution.ctc.com/

Europe is also looking into a Smart Grid (http://www.smartgrids.eu/) and is even thinking about a more ambitious plan to harness renewable energy from Africa, called the Super Smart Grid.
www.DESERTEC.org

APPENDIX 1 iii

V2G

More information on V2G is available from these sites:

http://www.udel.edu/V2G/

http://phev.ucdavis.edu/

http://www.calcars.org/

http://www.evworld.com/index.cfm

http://www.acpropulsion.com/technology/v2g.htm

http://www.pluginpartners.com/resources/index.cfm

http://www.pluginamerica.org/links-and-resources/links-and-resources.html

http://blogs.edmunds.com/greencaradvisor/

http://www.eaaev.org/

http://ev.starttips.com/

http://www.greencarcongress.com/

http://www.nrel.gov/vehiclesandfuels/hev/publications.html

http://www1.eere.energy.gov/vehiclesandfuels/technologies/systems/index.html

APPENDIX 2

The seasonal average variation in generated load and renewable supply throughout the day is shown in *Figure 11*. Daily temperature variation is also included as much of the peak demand stems from air conditioning in summer and from heaters in winter. Importantly, for storage considerations, the renewable peak either precedes or is coincident with the demand peak. The absolute values for each data set are not shown as it is the variation in conditions which is most relevant and each data set is scaled to a similar magnitude to fit on the same graph, and by the same amount between graphs. Data for each of the variables in the same year was not available. Electric load data was obtained from the IMO for the year 2007 (personal correspondence), solar insolation and temperature for 2003 from the Murdoch University weather site (http://wwwmet.murdoch.edu.au), and wind speed for 2003 for the Swanbourne weather station from the Bureau of Meteorology (personal correspondence).

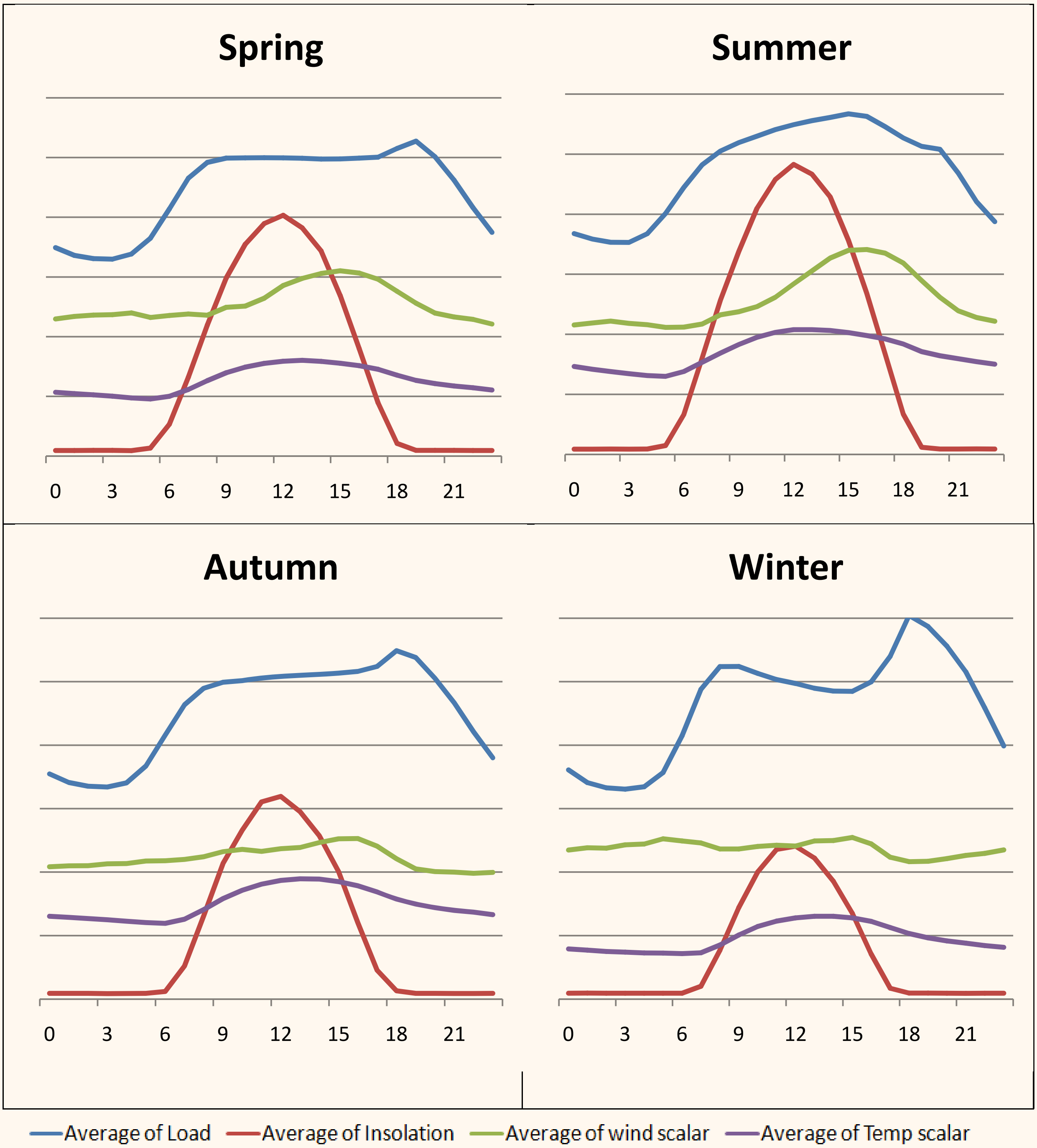

Figure 12: Daily variation of renewable supply and electricity demand, averaged for each season.

REFERENCES

1 Jamison Group (2008), *"A Roadmap for Alternative Fuels in Australia: Ending our Dependence on Oil"*, Report to NRMA Motoring and Services, Sydney.

2 <www.greenvehicleguide.gov.au>

3 <www.toyota.com.au/prius/range>

4 Australian Bureau of Statistics (2008), *"Survey of Motor Vehicle Use"*, accessed 28 October 2008, retrieved from <http://www.ausstats.abs.gov.au/ausstats/>

5 BITRE (2007), *"How do fuel use and emissions respond to price changes?"*, retrieved from <http://www.bitre.gov.au/publications/69/Files/bitre_briefing_1.pdf>

6 Bureau of Transport and Regional Economics (BTRE), retrieved from <www.btre.gov.au.>

7 General Motors (2007), *"Global Alliance for Hybrid Drive Development: Cooperation between BMW, DaimlerChrysler and General Motors"*, 2005-09-07, retrieved from <http://media.gm.com/>

8 Inderscience Publishers (2008), *"Sweet Nanotech Batteries: Nanotechnology Could Solve Lithium Battery Charging Problems"*, April 10, 2008.

9 <www.gm-volt.com/2008/08/05/gm-says-chevy-volt-battery-will-have-a-10-year-150000-mile-warranty/>, August 5, 2008.

10 House E., Ross F., (2007), *"How to build a battery that lasts longer than a car"*, Altairnano Inc, posted 08/27/2007, retrieved from <http://www.powermanagementdesignline.com/>

11 American Chemical Society (2007), *"Toward Improving the Safety of Lithium-ion Batteries"*, December 19, 2007.

12 Stanford University (2007), *"New Nanowire Battery Holds 10 Times The Charge Of Existing Ones"*, December 20, 2007.

13 American Chemical Society (2008), *"Improved Polymers For Lithium Ion Batteries Pave The Way For Next Generation Of Electric And Hybrid Cars"*, February 20, 2008.

14 American Chemical Society (2008), *"New Electrodes May Provide Safer, More Powerful Lithium-ion (Li-ion) Batteries"*, February 27, 2008.

15 Presentation to Australia-Japan Industry Association, Perth, October 13, 2008.

16 Australian Bureau of Statistics, (2005), *"Survey of motor vehicle use"*, September 2005.

17 Renne J. (2005), *"Measuring the Performance of Transit-Oriented Developments in Western Australia"*, Planning and Transport Research Centre.

18 Graham R. (2001),*"Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options"* EPRI, Palo Alto, CA:2001. 1000349.

19 Simpson A. (2005), *"Full- cycle assessment of Alternative Fuels for Light-Duty road vehicles in Australia"*, University of Queensland, Australia. Data from this document has been updated (July 2006) in correspondence with the author.

20 Garnaut R. (2008), *"The Garnaut Climate Change Review – Final Report"*, Cambridge University Press, Melbourne.

REFERENCES

21 Renewable Energy Atlas of Australia (2008), <www.environment.gov.au/renewable/atlas>

22 Independent Market Operator (2006), *"Wholesale Electricity Market Design Summary"*, September 2006.

23 Independent Market Operator (2006), *"The South West Interconnected System Wholesale Electricity Market: An Overview"*, October 2006.

24 Morton A., Cowdry S., Stevens D. (2005), *"South West Interconnected System (SWIS) Maximising the Penetration of Intermittent Generation in the SWIS"*, Prepared for the Office of Energy, Western Australia, page 25- sec-3.1.5.

25 Newman PWG and Kenworthy JR (1999) *"Sustainability and Cities"*, Island Press, Washington, DC.,

26 Newman P and Jennings I (2008), *"Cities as Sustainable Ecosystems: Principles and Practices"*, Island Press, Washington DC.

27 Ministerial Council on Energy (2008), *"Smart Meter decision paper. Cost-benefit analysis of an accelerated smart meter roll-out"*.

28 Ministerial Council on Energy (2007), *"Smart Meters Information Paper: on the development of an implementation plan for the roll-out of smart meters"*, Appendix 1.

29 Xcel Energy (2008), *"Smart Grid City Design Plan"*, accessed October 10, 2008, retrieved from <www.xcelenergy.com/smartgrid>

30 K. Parks, P. Denholm, and T. Markel, (2007), *"Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory"*, Technical Report NREL/TP-640-41410, retrieved from <http://www.nrel.gov/docs/fy07osti/41410.pdf >

31 Brooks A., Gage T. (2001), *"Integration of electric drive vehicles with the electric power grid- a new value stream"*, presented at the 18th International Electric Vehicle Symposium and Exhibition, Berlin, Germany, October 20–24, 2001. Retrieved from <www.acpropulsion.com/EVS18/ACP V2G EVS18.pdf>

32 Energy Supply Association of Australia (ESAA) (2008), Electricity Gas Australia, Energy Supply Association of Australia, Melbourne.

33 Australian Bureau of Statistics (2003), *"Motor Vehicle Census"*, retrieved from <www.abs.gov.au>

34 Kempton W. & Tomic J. (2005), *"Vehicle to Grid Fundamentals: Calculating Capacity and Net Revenue"*, Journal of Power Sources, Vol. 144, No. 1, pp. 268-279.

35 Brooks A. (2002), *"Vehicle to grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle"*, AC Propulsion, December 2002.

36 Hunwick R. (2007), *"PHEVs: An energy policy silver bullet?"*, paper presented to the Australian Institute of Energy, Sydney Branch, June 2007.

37 Future Fuels Forum (2008), *"Fuel for Thought – The Future of Transport Fuels: Challenges and Opportunities"*, Commonwealth Scientific and Industry Research Organisation (CSIRO), Campbell ACT, appendix B.

38 Kempton W., Tomic J. (2005), *"Vehicle to grid Implementation: From stabilizing the grid to supporting large-scale renewable Energy"*, University of Delaware, Newark, DE 19716, USA.

REFERENCES

39 Sustainable Energy Australia (2004), *"Wind farming and the Australian electricity system"*, Table 4, pg 59.

40 Australian Bureau of Agricultural and Resource Economics (ABARE) (2008), *"Key statistics for the Australian electricity industry"*, Table 28, pg 39. Retrieved from: <http://www.abareconomics.com/publications_html/energy/energy_08/energyAUS08.pdf>

41 M.S. Milligan (2001), *"A chronological reliability model to assess operating reserve allocation to wind power plants"*, presented at the 2001 European Wind Energy Conference, Document #NREL/CP-500-30490, Copenhagen, Denmark, July 2–6, 2001. Available October 2004 at: <http://www.osti.gov/bridge>

42 Western Power (2008), *"Australia's Future Infrastructure Requirements"*, Submission to Infrastructure Australia (15 October 2008).

43 Renault (2007), *"Renault Atlas"*, September 2007.

44 Reuters (2008), *"Renault seen investing up to $1 bln in electric car"*, retrieved from www.reuters.com/

45 Better Place (2008), *"Better place partners to bring electric vehicles to Australia"*, retrieved from http://www.betterplace.com/australia on the 20th Oct 2008.

46 Newman P , Beatley T and Boyer H (2008), *"Resilient Cities: Responding to Climate Change and Peak Oil"*, Island Press, Washington DC

47 North Port Quay (2008), http://www.northportquay.com.au/

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