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Australian Sustainable Energy

Zero Carbon Australia Stationary Energy Plan
Synopsis

> A ten year roadmap for 100% renewable energy
> Baseload energy supplied by renewable sources
> Affordable at $8 per household per week

beyond
ZERO
emissions

Part 1: Introduction and overview

The world stands on the precipice of significant change. Climate scientists predict severe impacts from even the lowest estimates of global warming. Atmospheric CO_2 already exceeds safe levels. A rational response to the problem demands a rapid shift to a zero-fossil-fuel, zero-emissions future. The Zero Carbon Australia 2020 Stationary Energy Plan (the ZCA2020 Plan) outlines a technically feasible and economically attractive way for Australia to transition to 100% renewable energy within ten years. Social and political leadership are now required in order for the transition to begin.

This document is a synopsis of the ZCA2020 Plan. For full references and analysis, see the ZCA2020 Plan full report.

With a combination of energy efficiency, fuel switching from gas and oil to electrified energy services, then using a combination of commercially available renewable energy technologies, Australia's energy needs can be met with 100% renewables. Wind and Concentrating Solar Thermal (CST) with Molten Salt Storage are the two primary technologies used, with minimal contingency backup from biomass and existing hydro. Modelling on a half-hourly timescale shows that this combination can ensure 100% reliable supply. Implementing the proposed renewable infrastructure over a ten-year timescale would require a small percentage of Australia's industrial capacity, in terms of resources and labour force. The required investment of $37 Billion/year is the equivalent of 3% of GDP. Estimated funding cost, including generation and grid upgrades, would be equivalent to an additional 6.5cents/kWh on delivered electricity.

Why do we need a Plan for zero emissions?

We know that climate change is a real threat, and we know what to do about it. The cause of the problem is that the level of atmospheric CO_2 is already too high. For atmospheric CO_2 to stabilise, human activities must stop emitting greenhouse gases, particularly from our use of fossil fuels for energy.

The threat comes from dangerous 'tipping point' mechanisms, which can be triggered by excessive temperatures and would prevent us from returning to safe climate conditions. To avoid this threat, we need to reduce atmospheric CO_2 from the present level of 390 ppm to well below 350 ppm, significantly closer to pre-industrial concentrations of 285 ppm.

Evidence of a tipping point is the sudden decline in Arctic sea ice, which has accelerated beyond the worst-case forecasts of the IPCC (Figure 1).

To avoid more severe risks, such as that presented by the melting of sub-artic permafrost, our path is clear - we need to attain a zero-emissions economy. That transition is the focus of the ZCA2020 Project. The aim of the Project as a whole is to outline how each sector of the Australian

FIGURE 1
Arctic Sea Ice Extent
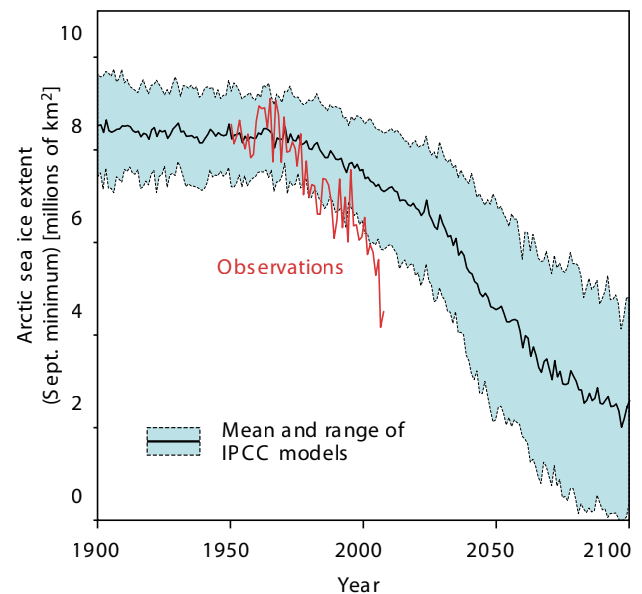
economy can achieve zero or negative greenhouse emissions: in Stationary Energy, Transport, Buildings, Industrial Processes, and Land Use. This Stationary Energy Plan is the first of the installments.

Why ten years?

The premise of a ten-year transition is based on 'The Budget Approach' from the German Advisory Council on Global Change. In order to have a 67% chance of keeping global warming below 2°C above pre-industrial temperatures, on a basis of equal allocation of emissions on a per-capita basis, it would be necessary for the USA to reduce emissions to zero in 10 years. Australia has about the same per-capita emissions as the USA, and would need to pursue the same goal.

Figure 2 shows a "global budget per-capita" (the blue block in the background), which limits emissions across all populations of the world to 110 tonnes of CO_2 per-capita (2.75 tonnes per capita per annum over 40 years) from 2010-2050. With decisive action beginning now, the target of zero emissions by 2020 for high emitting countries is a realistic and necessary goal.

Should the start of transition be deferred, then the Plan still serves as a blueprint that could see 100% renewable energy achieved at a later date. However delays pose an ever greater risk of exceeding safe limits within the climate system.

Guiding parameter: commercially-available-now

To make an immediate transition, we can use only the solutions that are available to us today. The ZCA2020 Plan has specified the 100% renewable grid based on proven technologies that are already commercially available and that have already been demonstrated in large industries.

FIGURE 2
Global Carbon Budget for Emissions
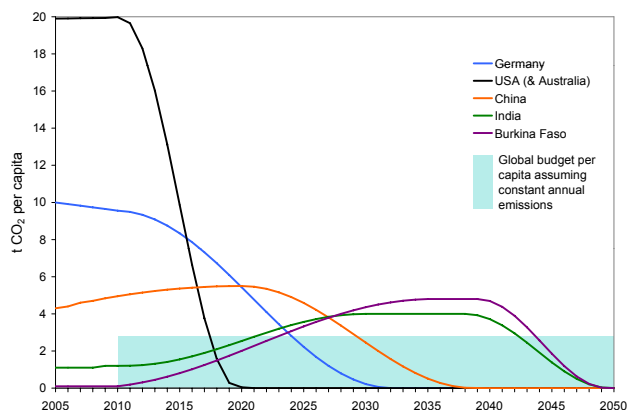
The ZCA2020 Plan is only one scenario in which 100% renewable energy could be achieved, not necessarily the only way, and is not dependent upon promising technologies that are on the horizon. The choices for the Plan were made in order for the proposed scenario to be rigorously assessed, and to show that all the solutions necessary are already available. Should new zero-emissions technologies become viable, cost-competitive and available by 2020, their inclusion may reduce costs and increase benefits even further.

Part 2: Designing the system

Under the ZCA2020 Plan, it is projected that 2020 grid electricity demand will be over 40% higher than today, from 228TWh/yr up to 325TWh/yr. This increase in electricity demand is due largely to the switch of services currently provided by gas and oil to be supplied more efficiently, with renewable electricity. The increase is significantly offset by ambitious but achievable electrical energy efficiency targets. This is more electricity demand than would be required under Business-As-Usual growth.

To meet this demand, a combination of wind and solar thermal with storage are proposed as the primary electricity generation technologies. Biomass and hydro are utilised as contingency, supplying about 2% of annual electricity. This limited use is due to capacity constraints imposed by environmental considerations.

Forecasting demand

There are several key considerations in forecasting the evolution of demand up to 2020 and beyond:
- Business-As-Usual projections of energy consumption, driven by population growth, and growth in per-capita consumption;
- Energy-efficiency improvements for existing electricity

FIGURE 3
Australian Energy Sources: Present and Under ZCA2020
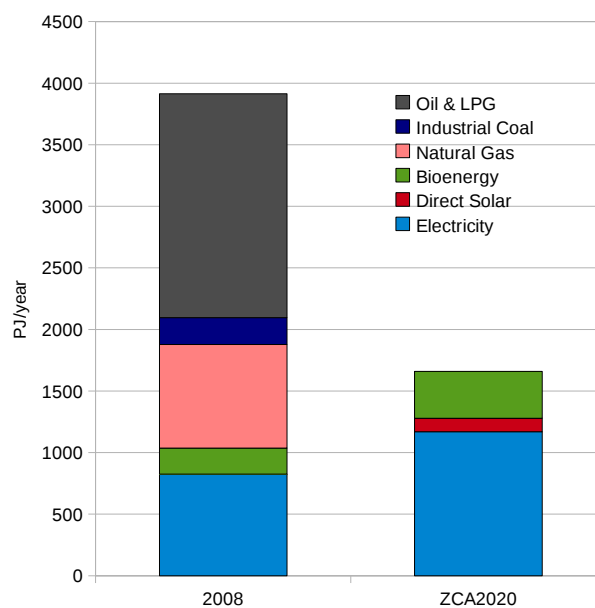
use, a cost-effective strategy that reduces the need to increase installed generating capacity;
- A fuel switch from gas and oil for end-use applications to renewable electricity. Electrical systems for heating and transport can have significantly higher efficiency;
- Improved thermal insulation for buildings to flatten demand peaks and seasonal variations in demand, reducing the need for peak generators.
- Energy supplied from onsite generation, which displaces grid electricity.

Replacing inefficient fossil fuels and introducing energy efficiency measures decreases total energy consumption in Australia by more than 50%, from 3,915 PJ/yr in 2008 to 1,660 PJ/yr in 2020 (Figure 3). This is accompanied by a 40% increase in electricity demand, from the present 228 TWh/yr to 325 TWh/yr. The provision of energy services shows no decline, and may even increase, a result achievable through significantly improved energy efficiency throughout the system.

Energy efficiency

Australia is an energy-intensive country, both in terms of energy consumption per capita and per dollar of Gross Domestic Product (GDP). An efficiency gain of 33% per capita is assumed compared to current energy services. This is an achievable target that will bring Australia in line with other modern economies.

The ZCA2020 Plan calls for energy-efficiency measures to progressively reduce electricity used for current services. Examples include efficient appliances, improved building

FIGURE 4
Per-capita electricity consumption for existing electrical services, Australia and Germany
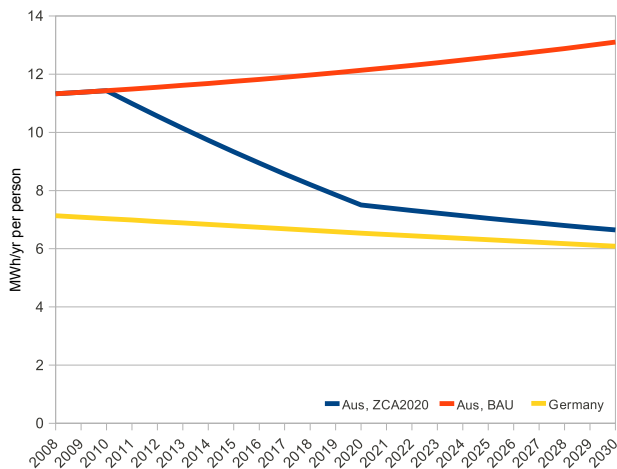
design, retrofitting insulation, double- and triple-glazing, as well as improved industrial efficiency.

In Figure 4, the red curve shows Australia's per capita electricity use under Business-As-Usual, projected to continue rising over the next 20 years. The yellow curve shows Germany's per capita use, which is currently 30% less than Australia, will reduce over the next 20 years due to ongoing official government programs. Germany is a modern industrial economy, with a high standard of living, manufacturing and metals production (including five aluminium smelters). The blue curve shows the effect of proposed energy efficiency measures under the ZCA2020 Plan, of 3.5-4% per capita per year until 2020.

Fuel-switch from oil and gas to electricity

The switch of end-use applications from gas and oil to electricity yields substantial efficiency gains. These result in a reduction in total energy use, accompanied by a lesser increase in renewable electricity use (Figure 5). Key switched services include:

- Low-temperature gas heating (e.g. space and hot water) is replaced with highly efficient electrical heat pump heating, bringing an average gain in energy efficiency of around 3:1;
- High-temperature heating applications (e.g. cooking, industrial processes) can be converted to induction or electric resistance heating. This is typically more efficient, with no losses from hot flue gases caused by fuel combustion;
- Replacement of oil with electricity for cars, freight rail, and passenger rail transport brings a high gain in overall efficiency. This occurs partly through the inherent efficiency of electric motors (>80%) relative to internal combustion engines (<20%) and partly through a proposed modal shift to light and heavy rail for both passenger and freight.

FIGURE 5
Total Electricity Demand including fuel switch and transport electrification
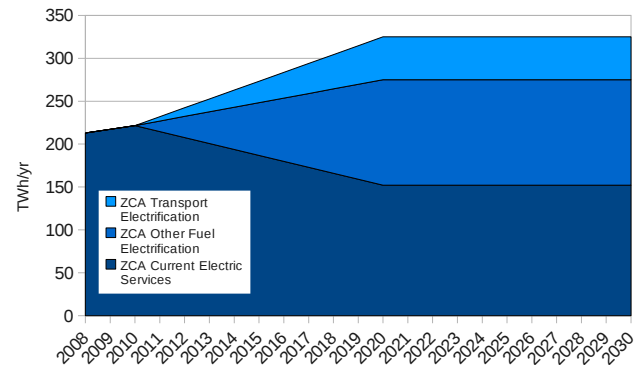
Demand curve flattening measures:

In the present electricity system, high demand peaks can lead to significant increases in the electricity price. This is because companies which own 'peaking' generators can exploit high demand events to charge many times the normal price for their electricity, and this is passed on to consumers.

Improving thermal insulation for buildings promises to reduce both seasonal and daily variation in energy demand for heating and cooling. This reduction in load peaking reduces the total installed generating capacity required for the system.

Identifying suitable commercially-available generation technologies

Technologies that were chosen for the ZCA2020 Plan:
- can supply the required 325 TWh/yr with the flexibility to meet seasonal and daily variation in demand;
- are commercially available today;
- produce zero greenhouse emissions after construction;

The chosen renewable energy technologies are a mix of wind turbines, concentrating solar thermal with storage, small-scale solar, and contingency capacity from biomass and existing hydroelectricity.
- **Wind Turbines**. Wind generation is a key component because of its relatively low cost and industry maturity. Wind is proposed to meet 40% of the total grid-connected demand.
- **Concentrating Solar Thermal (CST).** Large-scale Concentrating Solar Thermal with molten salt storage offers reliable electricity 24 hours per day. Solar power towers are proposed because of their technological maturity, higher operating temperatures and efficiency compared to other technologies. CST is proposed to meet 60% of the total grid-connected demand.
- **Small-scale solar.** Small-scale solar photovoltaic (PV) power has a role in reducing the demand for grid electricity during sunlight hours. This in turn allows

the CST plants to accumulate more stored energy for release at night.

- **Hydroelectric generators.** Existing hydroelectric generators have a useful role in providing first-dispatch backup and peaking power.
- **Biomass contingency**. Backup from crop-residual biomass for the CST plants offers energy security, protecting against occasions when a combination of low wind and low daily solar radiation occurs.

Life-Cycle Emissions

Life-cycle analysis of energy technologies measures the total CO_2-e emissions resulting from the construction of the plant, its continuing operation and the final decomissioning.

Wind generators and solar thermal generators have the lowest life-cycle emissions of all available technologies. Coal Carbon Capture and Storage, in contrast, has life-cycle emissions at least 25 times larger than CST. Similarly, average estimates of nuclear power life cycle emissions are several times larger than CST due mainly to fuel mining, processing, transporting and handling.

TABLE 1
Investment cost of ZCA2020 renewable grid

Component	AUD$, Bn
CST	$175
Backup Heaters	$8
Bioenergy supply	$6
Wind	$72
Transmission	$92
TOTAL	**$353**
Off-grid CST + Backup	$17
TOTAL + Offgrid	**$370**

In addition, both Coal Carbon Capture and Storage as well as Nuclear plants take considerably longer to commission than wind and CST plants. This lengthens the time span over which the old fossil fuel plants must continue to operate and emit.

FIGURE 6
Proposed Power Grid for 100% Renewable Electricity
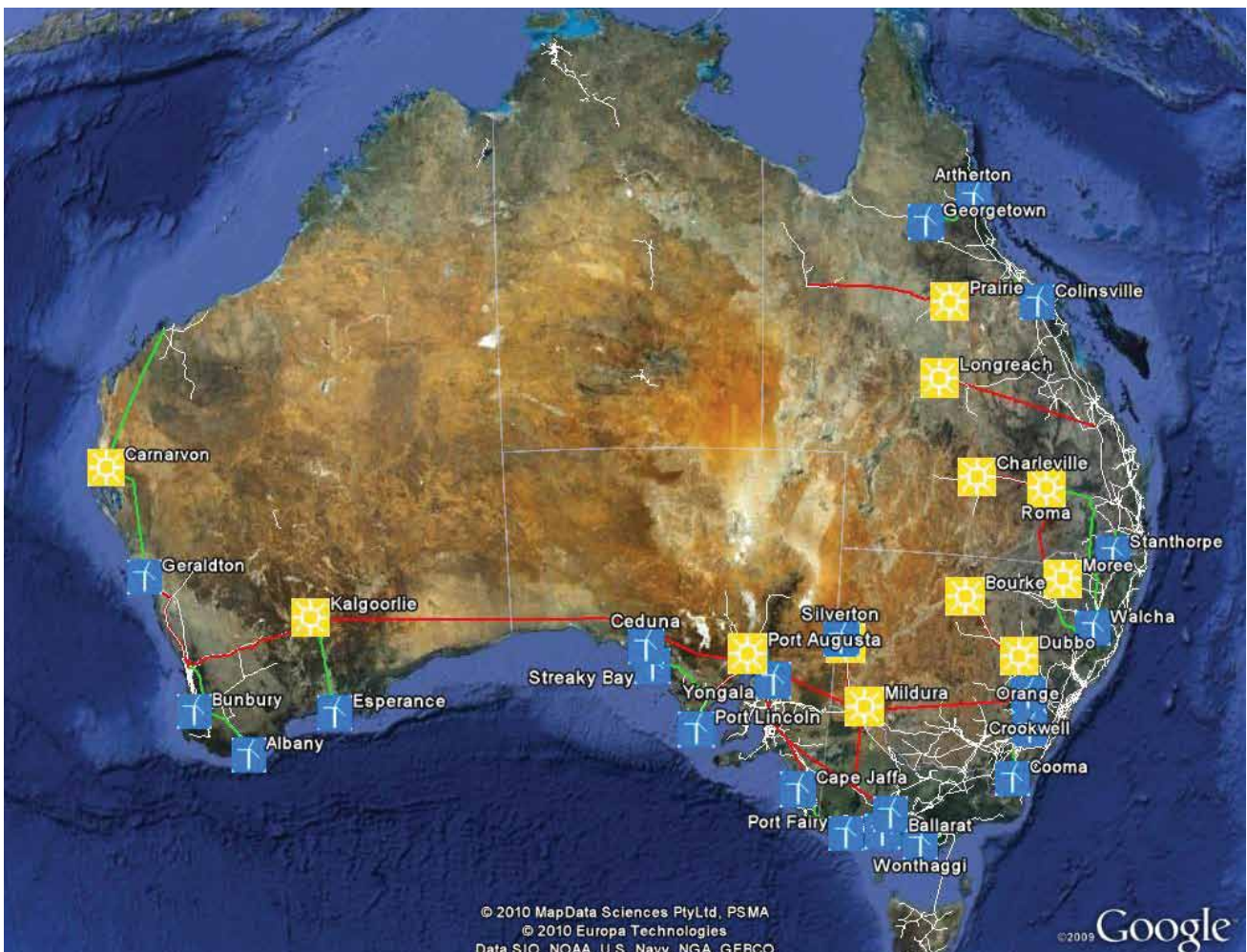
Part 3: Australia's 100% renewable energy supply

Australia's projected on-grid electricity demand in 2020 is 325TWh/yr. The ZCA2020 plan proposes that this can be provided through a combination of renewable power sources.

40% of this electricity (130TWh/yr), will be supplied from wind power, which is to be provided through 50,000 MW of wind turbine capacity. The rest of the electricity will be supplied from 42,500 MW of Concentrating Solar Thermal (CST) with storage, providing reliable, 24-hour dispatchable power through molten salt thermal storage. The investment costs of these technologies have been based on expected cost reductions from significant scale up of the renewable industry, coming to a total cost of $370 billion for the ten-year Plan, as shown in Table 1.

The plants are located at sites around Australia that are selected for their wind availability, solar incidence, ability to support economies of scale, transmission costs, and geographical diversity, giving 23 sites for wind, and 12 sites for CST (Figure 6). Extra generation capacity is also costed for remote off-grid power generation, as shown in Table 1.

Contingency will be provided by existing hydropower capacity, and from biomass fired heaters attached to some of the CST plants.

The supply of Tasmania's electricity demand is included in this scenario, however future work will separately detail Tasmanian wind installations.

Concentrating solar thermal with storage (CST)

There are four main types of CST systems: power tower, dish, linear fresnel and parabolic trough systems. Power towers are selected for their high temperatures and efficiency, high year-round solar collection performance, and easy integration with molten salt thermal storage.

Solar thermal power towers with storage have been proven at commercial scale during three years of operation of the Solar Two tower in the USA, from 1996 to 1999. There are a number of companies building and operating utility-scale solar thermal with storage around the world, including Torresol, SolarReserve and ACS Cobra.

The proposed CST power towers consists of a central tower receiver surrounded by a field of 18,000 heliostats, as shown in Figure 7. The heliostats are two-axis tracking mirrors that follow the sun, reflecting focused sunlight on the receiver heating it to at least 565°C. Importantly, the ability

FIGURE 7
Solar Thermal Power Tower

of heliostats to track both the daily passage and seasonal elevation of the sun's position in the sky means they have increased solar energy collection efficiency compared to systems with less tracking ability.

The receiver is similar to conventional boiler tubes, except that instead of water as the working fluid, molten salt is used. The molten salt flows through the receiver accumulating thermal energy from the focus and then flows into the hot salt tank (shown in red). When there is a demand for electricity, the hot molten salt is passed through a heat exchanger to generate high-temperature steam for the turbine. The steam spins the turbine to generate the required amount of electricity. The heat extracted from the molten salt cools it to $290^{\circ}C$ (still molten), and it is returned to the cold tank (shown in yellow) where it waits to be pumped up the tower again for heating.

These power towers are able to operate at 70-75% annual capacity factor, similar to conventional fossil fuel plants. They are capable of dispatching power 24 hours a day, and are as reliable as conventional 'baseload' power. Furthermore, they are in fact more flexible to meeting varying demand. The steam heat-exchange and turbine systems are specifically designed for rapid start up, allowing CST to balance changing electricity demand patterns, and providing 'firming' power to more variable wind generation.

Scale of the CST units

Each of the 12 CST sites has an operational capacity of just over 3,500MW. The CST power towers are optimally sized as 'Solar 220' generating units, rated at 217 MW with air cooling. Thirteen Solar 220 units are to be installed at each site, along with an allowance for smaller rated modules in initial years of scaleup.

CST site locations

CST is suited to large installations in areas of high solar incidence, and as it can store energy, it is less affected by daily weather patterns as are more variable renewable energy sources.

As the locations with high solar radiation are typically inland, at a distance from Australia's coastal centres with high electricity demand, the CST plants require high voltage transmission to connect them to the locations of demand. Building a smaller number of high-power-rating transmission cables is more economical than a large number of lower power transmission cables. This has been taken into account in determining the number of solar sites and their locations.

Furthermore, the impact of seasonal solar variations can be mitigated by the choice of geographically diverse sites for CST plant locations. The annual average daily insolation collected across all of the 12 sites is 7.95 kWh/m^2/day, with winter-time energy availability 25% below average. The solar thermal capacity is sized to make sure that demand during the winter is met.

Land and water use

Each 3,500MW CST site requires an area of 230 km^2, the equivalent of just over 15km x 15km. This would ideally be situated in areas of marginal farming land. In total, the land use for CST sites would be 2,760km^2, less than 0.04% of Australia's total land mass. It is less than the land area of the largest single cattle station, or about the size of Kangaroo Island.

Water use is minimised by using air cooling. This reduces the rated plant output by 1.3%, but requires only 12% of the

FIGURE 8
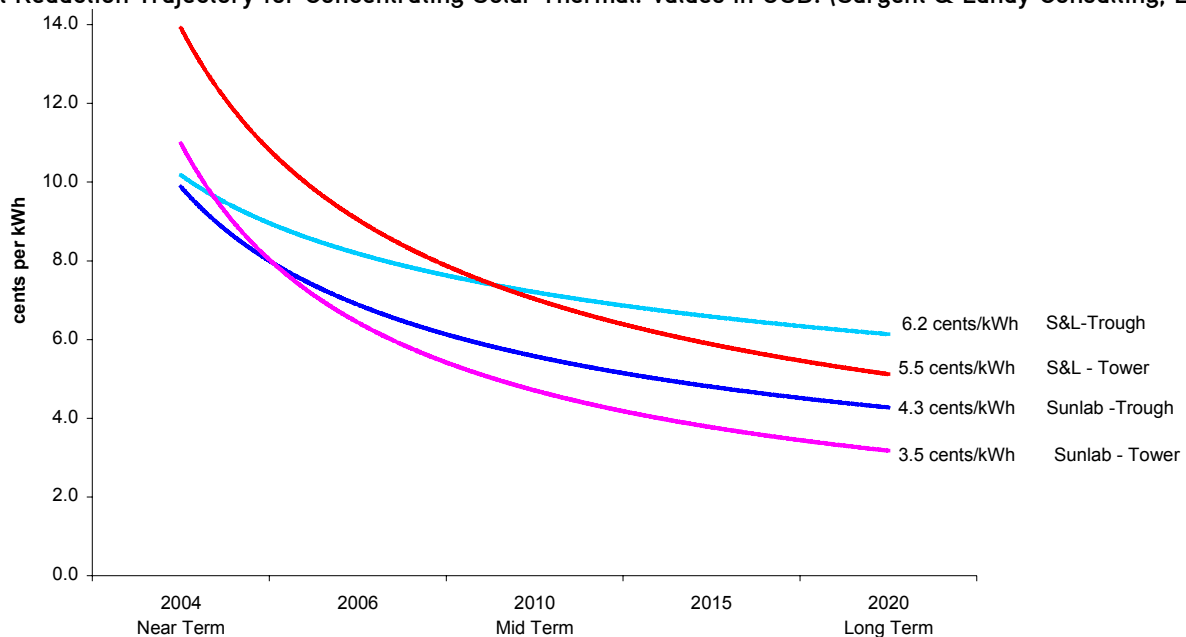**Cost Reduction Trajectory for Concentrating Solar Thermal. Values in USD. (Sargent & Lundy Consulting, LLC)**

6.2 cents/kWh	S&L-Trough
5.5 cents/kWh	S&L - Tower
4.3 cents/kWh	Sunlab -Trough
3.5 cents/kWh	Sunlab - Tower

TABLE 2
CST installation cost table

Phase	Cost (2009 AUD$)
Phase one – First 8700 MW	$60 Billion
Phase two – 156 x Solar 220	$115 Billion
Total Ongrid CST	**$175 Billion**
Off-grid CST – 4,475 MW	$15 Billion
All CST sites for ZCA2020 + off-grid	**$190 Billion**

water of a conventional power station. The total CST water consumption is projected to be 0.4% of Australia's total water consumption, significantly less than the water used by existing fossil fuel plants. A preliminary study of water resource availability at each of the 12 sites has found that there is ample water available for the proposed CST usage of 6.3GL/yr per site. Even in Kalgoorlie, mining activities currently use twice this.

Total cost of CST plants

The total cost of the CST plants is $190 Billion, as shown in Table 2. The initial power plants are priced in line with detailed current project costs in the United States, with later installations becoming cheaper following the cost reduction trajectory as projected by reports from the U.S. Department of Energy's solar thermal program.

As detailed by the cost curve from this report (Figure 8) it is projected that at an installed power tower capacity of 8,700 MW, the price of electricity will drop to 3.5c/kWh (US,

Enercon E-126 Turbines in Belgium. SOURCE: STEENKI

2003 dollars). This translates to about 5-6c/kWh in today's Australian dollars, which is competitive with the price of conventional coal power. The key factors in achieving these cost reductions are economies of scale of construction (with an ongoing "pipeline" of projects) and mass-manufacture of heliostat mirrors.

Wind power details

The ZCA2020 Plan proposes that 40% of Australia's total estimated electricity demand be met by wind power. The Danish target for wind power is 50% of annual electricity by 2025. The Australian grid has greater geographical diversity than the Danish grid, so a 40% level of wind power for Australia is considered conservatively low.

Due to the variable nature of the wind resource, wind turbines do not operate at full capacity all of the time. Based on the annual energy generated by a particular wind farm, the equivalent percentage of the time operating at full ouput is called the capacity factor. In Australia capacity factors for operating wind farms are in the range of 30-35%. We estimate an average capacity factor of 30% for proposed wind farms, as only a few wind farms will be located in the best high wind resource areas. The ZCA2020 Plan also proposes new transmission lines to access high wind resource areas that currently have low proximity to the grid.

At a minimum, the reliable instantaneous output is 7,500 MW from the wind generators - 15% of the combined rated capacity (50,000 MW) of all wind generators installed across the country. This 'firm' wind output is as reliable as conventional baseload power. The 15% figure is conservatively estimated based on detailed studies of interconnected wind farms carried out in the U.S., by the National Renewable Energy Laboratories. This study found that depending upon the levels of transmission interconnection, a grid of onshore wind farms produced 14-27% of nameplate capacity with firm reliability. As our wind farms are planned to operate at 30% annual average capacity factor, we can expect half of the system- wide electricity produced from wind to be 'firm'.

Scale of wind units

To supply 130TWh/yr from wind power, 50,000MW of wind capacity is proposed. This requires the construction of an additional 48,000MW of wind turbines on top of Australia's 2010 wind capacity. We propose that 6,400 high quality, technologically advanced 7.5MW wind turbines be utilised. E126 Enercon turbines are specified as they are currently the only commercially available 7.5MW turbines. Large turbine sizes enables the extraction of more energy from a given site by tapping into stronger and more consistent wind resource at higher altitudes.

Wind power sites

The Plan proposes 23 sites for wind power, each consisting of either 2,000 or 3,000 MW of turbines. The geographically dispersed wind sites exploit the diversity

in weather systems that occur simultaneously across the Australian continent and counter localised wind variability. Attempts have been made to select wind sites according to highest average winter wind speeds rather than highest average annual speeds, to accommodate the projected winter peak.

Managing wind variability

Wind power integrates well with CST, because CST has storage that can readily dispatch power, providing back-up for wind power during lows in energy production. Similarly, periods of high wind output offset CST electricity production, and allow the CST plants to direct more heat to storage for later use.

40% penetration of wind is considered possible, based on studies by British Energy Consultant David Milborough and Danish grid operator Energinet. These studies show that oversupply of power, above the amount which the grid can handle, is only 4%, at penetration levels of 40%.

Total Cost for Wind power plants

The total investment for wind farms is $72 Billion, as detailed in Table 3.

TABLE 3
ZCA2020 Projected Annual Capital Costs of Wind (AUD 2010 prices)

Year	$Million/ MW	Constructed Capacity (MW)	Operational Capacity (MW)	Costs ($Million)
2011	2.2	1,250	2,000	$2,750
2012	1.9	3,250	2,500	$6,175
2013	1.9	5,500	4,500	$10,450
2014	1.65	6,000	9,000	$9,900
2015	1.65	6,000	15,000	$9,900
2016	1.25	6,000	21,000	$7,500
2017	1.25	6,000	27,000	$7,500
2018	1.25	6,000	33,000	$7,500
2019	1.25	6,000	39,000	$7,500
2020	1.25	2,000	45,000	$2,500
2021			50,000	
			Total Capital Costs	$71,675

Currently the average Australian capital cost for wind farms is $2.2-2.5 Million/MW. This cost is relatively high compared to other regions such as Europe and America as Australia has seen a slower growth in wind power.

The ZCA2020 Plan involves a large scale roll out of wind turbines that will require a ramp up in production and assist a subsequent reduction in wind farm capital costs, bringing Australian costs in line with the world market. For the first

5 years of the Stationary Energy plan, the capital costs of wind turbines are expected to transition to the forecast 2015 European amount, $1.65 Million/MW, based on estimates from the European Wind Energy Association. It is expected that the final 5 years of the plan will benefit from the influence of Chinese manufacturers on the market, with capital costs expected to drop by 25% to approximately $1.25 Million/MW in Australia. This is based on capital costs estimates for the Gansu Province "Three Gorges of Wind" 20,000MW project, currently under construction.

Hydroelectric and biomass backup

There is the possibility of simultaneous cloud cover over several of the CST sites coinciding with a period of low wind and high demand. To completely ensure energy security under the plan, a system of biomass co-firing of the CST plants is incorporated, utilising only waste biomass. The proposed system incorporates a simple biomass-fired thermal heater alongside the molten salt tanks at the actual CST sites. Biomass is burnt, and the energy used to heat the molten salt reservoirs, so that the existing steam power cycle, turbine and transmission can be utilised. This means the only extra expenditure is for the biomass heater, minimising the extra cost of the backup system.

A combination of 5 GW of existing hydro capacity and 15 GW electrical equivalent of biomass-fired backup heaters will be sufficient to ensure reliable supply of electricity even at times of low wind and solar radiation at several power plants/sites. ZCA2020 does not propose additional hydro dams in Australia. Future work will investigate the feasibility of upgrading existing hydro dams to pumped storage hydro for long-term seasonal supply, which would replace biomass backup. If further analysis and optimisation demonstrate that more or less biomass backup generation is required, this is not expected to affect the overall system cost significantly, as the biomass backup heaters represent only 2% of overall investment for the ZCA2020 Plan.

Part 4: Modelling the ZCA2020 100% renewable energy mix

The ZCA2020 electricity generation mix has been quantitatively modelled in fine detail using real-world data, with the results demonstrating that Australia's electricity demand can be met by 100% renewable energy.

The data underlying the model are derived from real meteorological recordings of solar insolation at the 12 proposed CST sites, real wind speeds at existing wind farms, and grid demand based on actual demand in the National Electricity Market (NEM). Modelling has been performed on a half-hourly timescale for the years 2008 and 2009.

The wind data used in the model come from existing wind farms in South Eastern Australia. As a result, the model overstates wind variability, which would in reality

FIGURE 9
ZCA2020 Model Results (daily average data). 'Excess' is combined solar and wind energy in excess of demand.
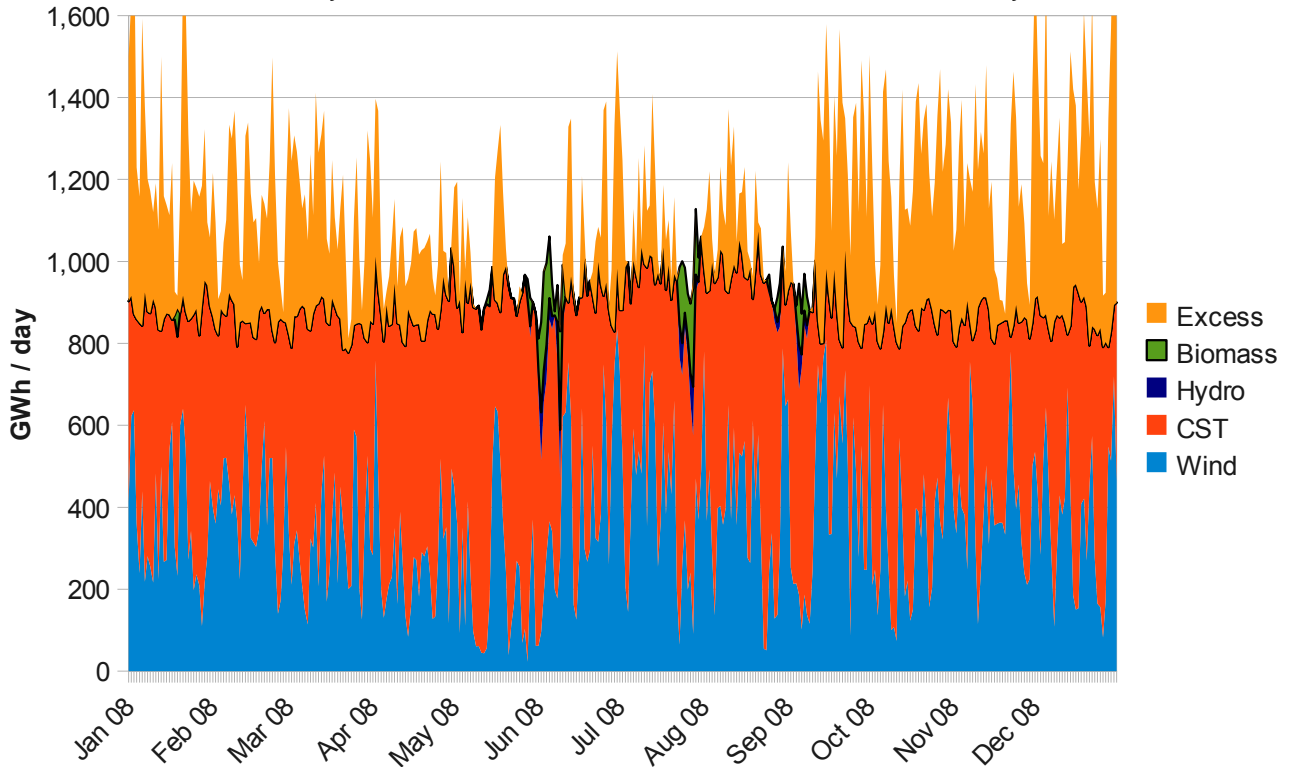
be significantly lower due to the highly dispersed sites outlined in the Plan.

The demand data derived from the NEM has been scaled to account for the extra demand for electricity under the Plan, when transport and present fossil fuel applications are converted to renewable electricity.

Results from the model

Figure 9 shows the daily averages of electrical output from the model, running over a full year of data (2008). The black line between the red and orange areas signifies the electricity demand. The output from wind generators is shown as blue at the bottom, while the red area is dispatched energy from CST turbines. The light orange area is the excess energy that is available from the solar and wind sites but is unused.

The Plan's proposed combination of 42.5 GW of CST and 50 GW of wind provides enough energy to cover 98% of the electricity demand modelled, with the remaining 2% being supplied by existing hydro power (5 GW) and heat from biomass co-firing on the equivalent of 10 GW of the CST plants, though spread out over many of the plants. This is represented by the small green and navy blue areas in Figure 9.

Thermal storage

Figure 10 shows how the CST thermal storage operates on a randomly selected normal day. The light orange lines show the solar input during the day, and the purple line shows the reserve thermal energy stored in the molten salt

FIGURE 10
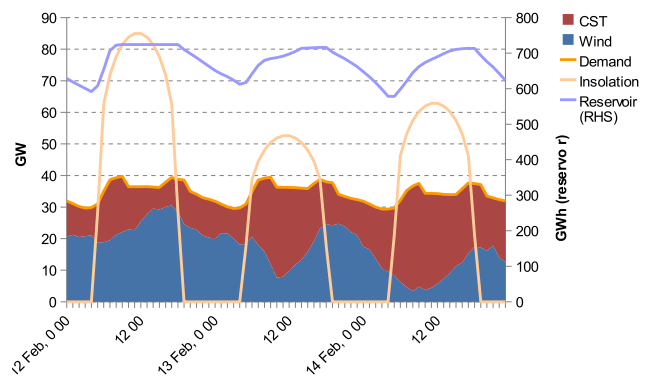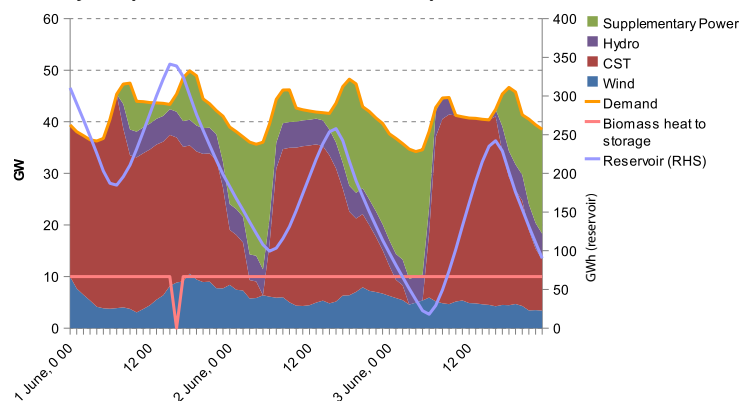**Hourly dispatch with excess supply in February 2009**

FIGURE 11
Hourly dispatch with biomass backup

reservoirs of the CST plants, which decreases when the solar input is not available (i.e. during the night). The blue area shows the electrical output from the wind generators, and the red area shows the electrical output from the CST turbines, which work together to meet demand.

Biomass generation for backup

Figure 11 shows how the hydro and biomass backup operate over three days of low input from solar and wind energy. The purple line shows the reserve thermal energy cycling with the daily solar input, but progressively running lower.

The pink line shows the input of heat energy from the biomass backup system, which is triggered when the reserve energy falls below a set point. While the biomass firing is operating, this adds heat into the thermal storage tanks of the CST system. In this example, the biomass firing stops briefly when the reserve energy rises above the trigger on the afternoon of June 1. The blue area shows the electrical output from the wind generators, which is unusually low. The red area shows the electrical output coming from the CST stored solar energy. The purple area shows output from the hydro generators. Finally the green area shows the output that is drawn from the stored biomass thermal energy.

Although the modelling shows that 10 GW(e) of biomass backup generation will suffice for expected scenarios that have been modelled, the ZCA2020 Plan includes a total 15GW of biomass capacity to conservatively provide for energy security.

Model simplifications and further work

This model does not yet take into account transmission constraints within the ZCA2020 electricity grid. The grid connections to individual generator sites are sized to take the full output, but some of the internal connections may place some constraints on the transfer of energy.

On the other hand, the model does not take account of demand management benefits that are included in the ZCA2020 Plan, or other advantages yet to be accounted for, such as a much more spatially diversified wind portfolio.

Part 5: Grid and load management — creation of a national grid

New national grid

The Stationary Energy Plan proposes a comprehensive upgrade to Australia's electricity grid to allow full utilisation of the distributed renewable energy network.

Creation of the new National Grid requires four main upgrades to the existing grid:
1. "Plug in" connections from proposed power generators to the electricity grid.
2. Interconnection of the three main existing grids.
3. Transmission upgrade of existing grids to provide resilience and reinforcement.
4. More active demand-side load management.

Grid upgrades use High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) transmission lines, which are already in widespread use around the world.

The proposed National Grid is illustrated in Figure 12, minus the plug in transmission lines from the generators.

HVDC is the most economical technology for long-distance bulk power transmission links. However the high cost of converter stations means that HVAC is specified for shorter lengths and if multiple connections to the existing AC grid are needed along their length.

High-voltage transmission lines have been designed to connect into the key distribution nodes of the existing grid, enabling an easy merger with present infrastructure and secure distribution of electricity around the country.

The total cost of the upgrade is $92 Billion, which is considered an important investment in Australia's future energy security.

Control of supply and demand

Total stationary energy demand reduces by conversion of gas heating to efficient electric heat pumps and building efficiency programs. The conversion of gas heating to electric results in an increase in total non-peak electricity demand.

Peak demand is reduced through active load management using SmartGrid systems. The electrification of heating, in conjunction with active load management systems, enables the pre-emption of heating and cooling load to smooth out peaks in demand. Deferral of electric vehicle charging also provides a form of load management.

FIGURE 12
Grid Strengthening and Interconnections
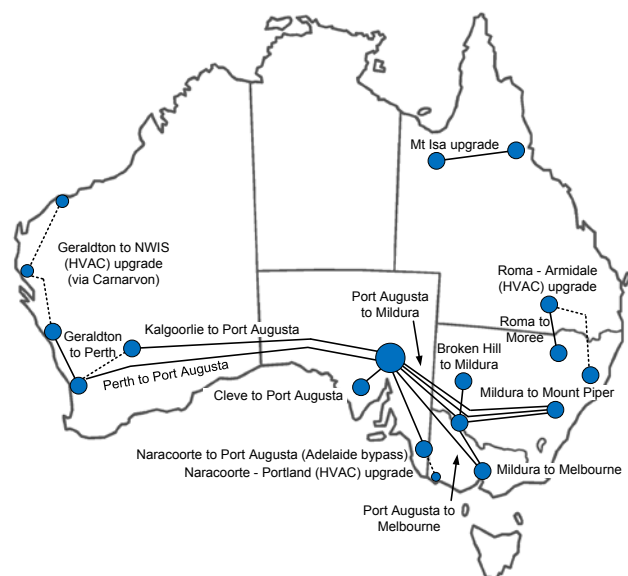
In the worst case scenario of low wind and low sun, there is a minimum of 55GW reliable generation capacity, which in combination with passive and active load management is sufficient to meet peak demand.

Backed by Sinclair Knight Merz review

The engineering firm Sinclair Knight Merz has reviewed the transmission network of the generation scenario proposed in the ZCA2020 Plan. The review found:

"the transmission scenario proposed is technically feasible in terms of capacity and reliability. In addition, the proposed transmission uses mature technology with proven capability around the world."

Part 6: Implementing the transition

This section presents an analysis of the feasibility of the Plan within the context of Australia's industrial, human, and material resource profile. The analysis clearly shows that Australia has more than enough capacity to meet the challenge of achieving 100% renewable energy within ten years. The roll-out would require approximately 8% of Australia's existing construction workforce. Manufacturing half of the turbines and heliostats domestically would require 3% of Australia's manufacturing workforce, along with a few additional factories.

The construction timeline

The ten-year timeline proposed by the Plan projects a gradual scale-up of the renewable industry that would see most of the proposed infrastructure completed in the second half of the decade. Fast-track of permitting and planning approvals will be required.

Accordingly, the construction of CST plants ramps up relatively slowly at first (Figure 13). Then, as economies of scale are developed, the rate increases and 80% of the capacity is completed from 2015-2020. It is not expected that any CST would become operational until 2014-2015.

The CST plants are modular, and once the design and planning for the first plant is complete then the process becomes one of replication on each of the 12 sites. Construction thus becomes progressively faster in the later stages as companies gain experience and become more efficient. Current power tower projects have a construction time of 2-2.5 years, though more mature parabolic trough projects of similar nameplate capacity are being completed in 1.5 years.

The timeline for wind power (Figure 14) has a somewhat earlier and faster start-up because Australia already possesses some experience with wind technology, and because there are already 11,000MW of wind power projects are already in the pipeline.

FIGURE 13
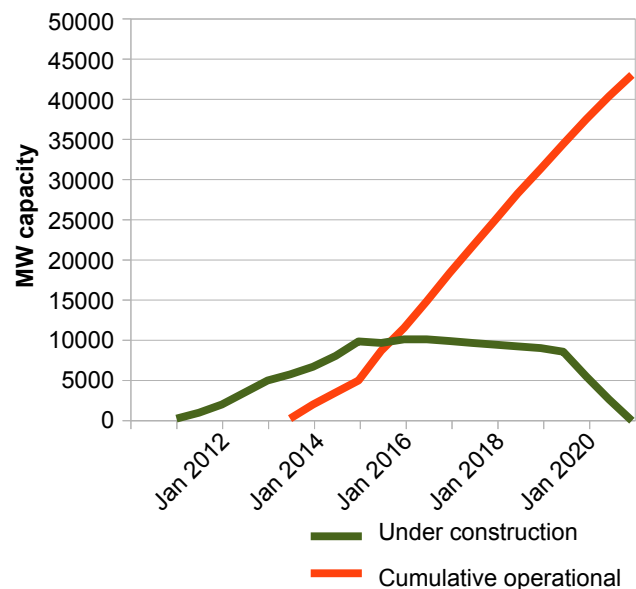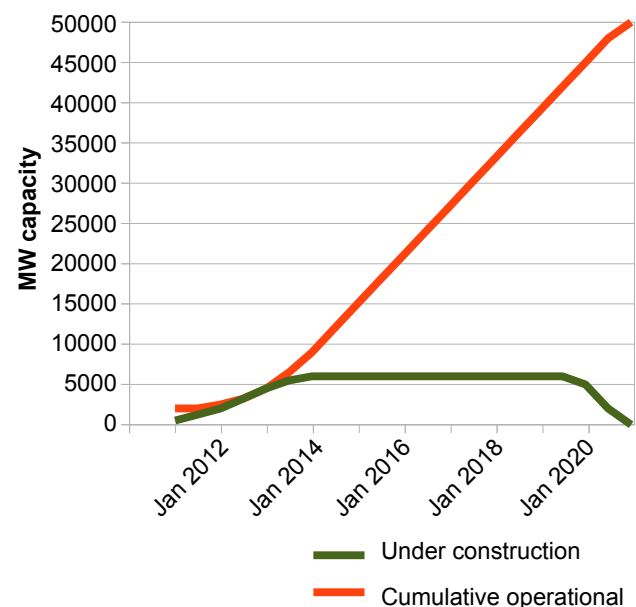**Solar Thermal Installation Timeline**

FIGURE 14
Windpower Installation Timeline

Manufacturing capacity

Due to the consistent demand generated from the Plan's construction timeline, the wind and solar factories have a guaranteed pipeline of projects. This allows the manufacturing industry to run continuously, achieving efficient operations with significant economies of scale.

At the peak of construction activity, the significant manufactured components required by the Plan will include 1000 wind turbines and 600,000 heliostats per year. While this may seem like a significant demand on

our manufacturing industry it is well within our capability. Across the globe there are examples of wind turbine manufacture being ramped up quickly. Enercon has established a wind turbine manufacturing hub in less than two years in Portugal. The manufacturing capacity required for the specified wind turbines in the Plan is equivalent to only 2-4 factories of similar size overseas. Manufacturing heliostats, on the other hand, is a much simpler process and is equivalent to establishing one medium-to-large automobile factory of a similar size to existing car factories overseas in Europe and Japan.

Alternatively, turbines and heliostats could be imported.

FIGURE 15
Total Jobs created by the ZCA2020 Plan

There are, however, great advantages to creating a local manufacturing industry—most significantly, it presents an opportunity to participate in the global renewable energy boom.

Jobs

ZCA2020 modelling shows that many more jobs are created with the construction of a 100% renewable energy grid than are lost with the phasing out of coal and gas from the stationary energy supply chain. The Plan will create up to 80,000 jobs from installation of renewable energy generation at the peak of construction, and over 45,000 jobs in operations and maintenance that will continue for the life of the plant, as shown in Figure 15. If half the manufacturing for wind turbines and heliostats is done domestically, this would create up to 30,000 jobs in manufacturing.

The level of expansion in jobs would boost overall employment in the economy.

Placing the job requirements for the ZCA2020 Plan in context (Figure 16) with the existing Australian workforce in relevant industries shows the relatively modest labour requirements that would need to be put towards the roll-out of the Plan. There are already just under 1 million people employed in the Australian construction industry, with another 1 million people in manufacturing.

In the five years leading up to 2008, the Australian construction industry was growing at the rate of 50,000 new jobs per year. This has approximately flatlined since the Global Financial Crisis of 2008. Under mid-term government forecasts, growth in construction and manufacturing is projected to be slow. The scale-up of construction required for the plan is not as fast as what Australia has already shown itself capable of in the past.
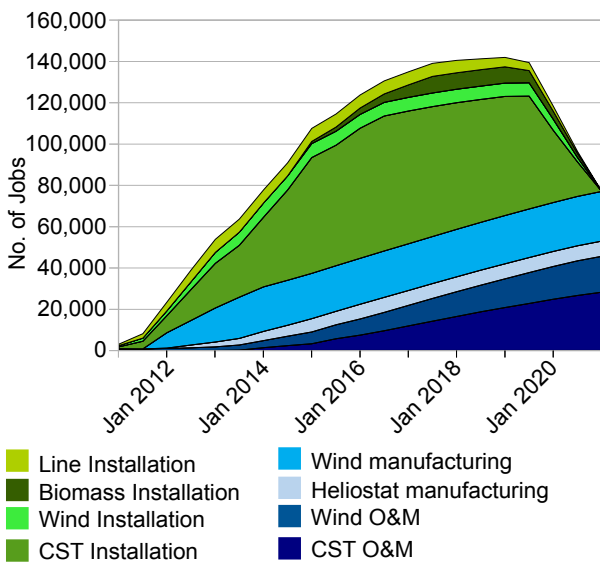
FIGURE 16
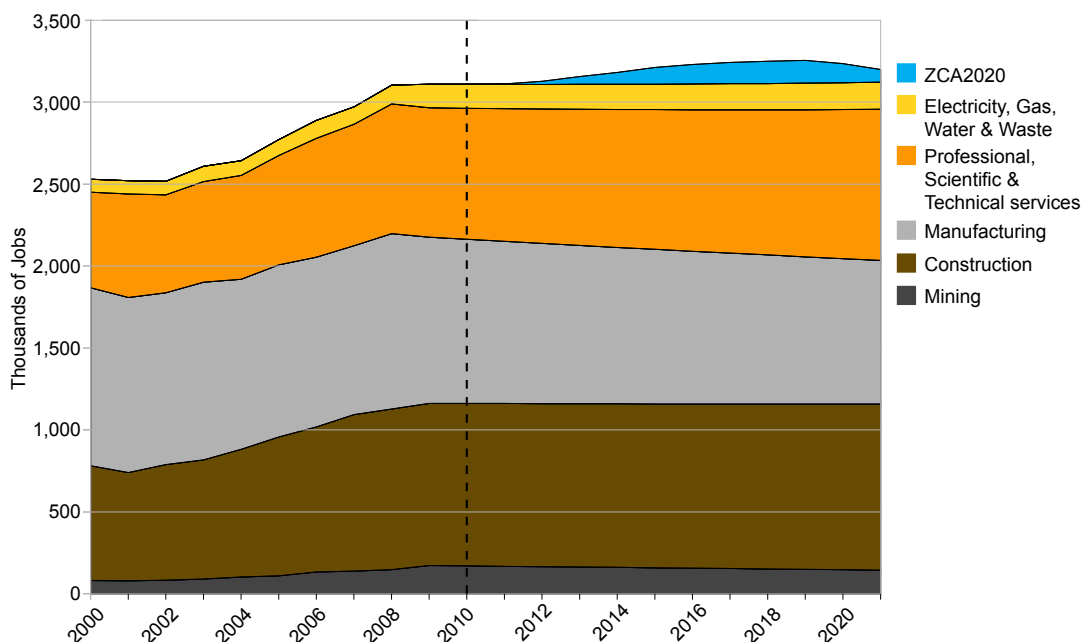**ZCA2020 Jobs in context of existing Australian industries relevant to the Plan**
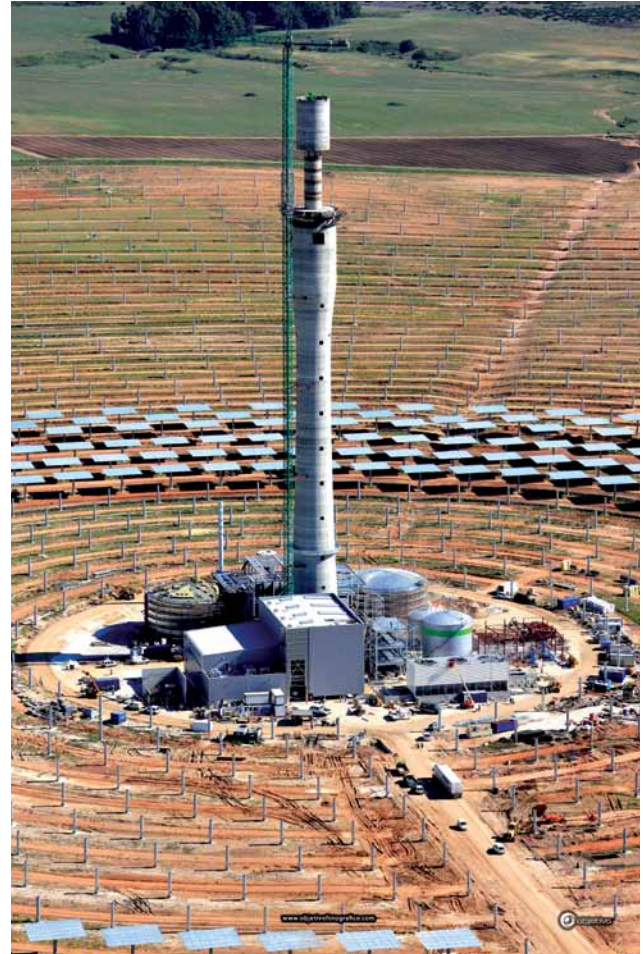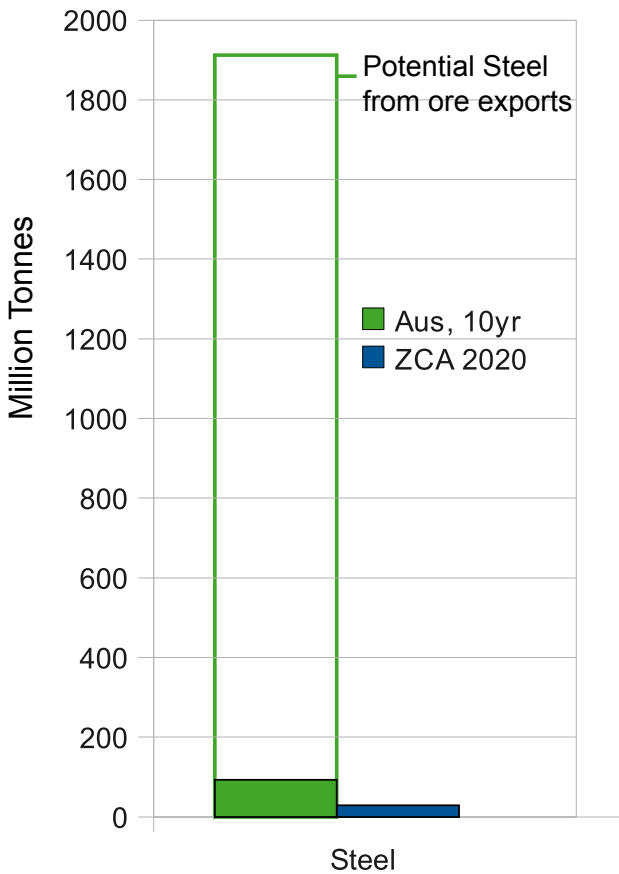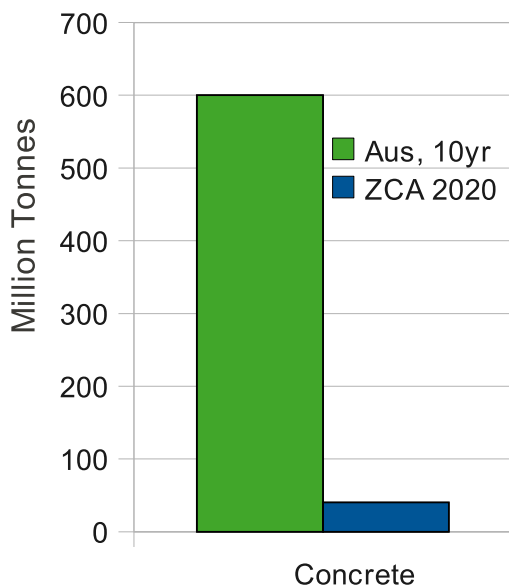
FIGURE 17
ZCA Steel requirements including Steel and Ore Exports

Torresol Gemasolar CST Power Tower under construction in Spain

FIGURE 18
ZCA Concrete Requirements

Resources required

The requirements for concrete and steel for the renewable energy system are well within the capacity of Australia's resources.

The requirement for concrete amounts to 7% of Australia's production over the 10 year timescale (Figure 18).

The requirement for steel is 20-30% of Australia's domestic production, but only 1.3% of Australia's total of iron ore exports and steel production (Figure 17).

The main components of heliostat mirrors are glass and silver. The glass required is larger than Australia's production, but the demand can be met either by building one or two glass factories, or by imports.

Silver is used as the reflective material in the mirror and a thin film is used on the back of the glass. The silver requirements are very low with the Plan requiring less than 2% of Australia's total production.

Emissions from construction

Stationary energy, including electricity, is responsible for more than half of all Australian emissions. Under Business-As-Usual, the continuing emissions would be 2,950 Mt CO_2-e

over 10 years. The emission embodied in the generating and transmission infrastructure behind the ZCA2020 Plan comes to less than 3% of projected Business-As-Usual emissions, and the investment eliminates all on-going energy-related emissions thereafter.

The most significant emissions from construction arise from the iron and steel for the solar plants - this comprises 60% of the total ZCA2020 construction emissions. While this is substantial, it is dwarfed by the existing level of emissions: in total, the proposed 10 year roll out corresponds to approximately 2 months of current Australian emissions from the stationary energy sector.

Part 7 Economic comparisons

The total investment required to implement the ZCA2020 renewable energy system is $370 billion, averaging $37 billion per year over the 10 year duration of the Plan. This is equivalent to 3% of GDP.

The ZCA2020 Plan does not specify any particular funding mechanism. The money could come from any mix of public and private sources, depending upon a range of possible policies that would lead to the implementation of the Plan.

FIGURE 19
Economic Model Comparison

Legend:
- Capital Investments
- Coal and Gas for electricity
- Operations and Maintenance costs
- Oil - BAU or ZCA2020 ramp-down
- Heating Gas - BAU or ZCA2020 ramp-down
- Emissions (Stationary Energy)
- BAU electricity ramp-down operating and fuel costs (2011-2020, ZCA2020 case only)
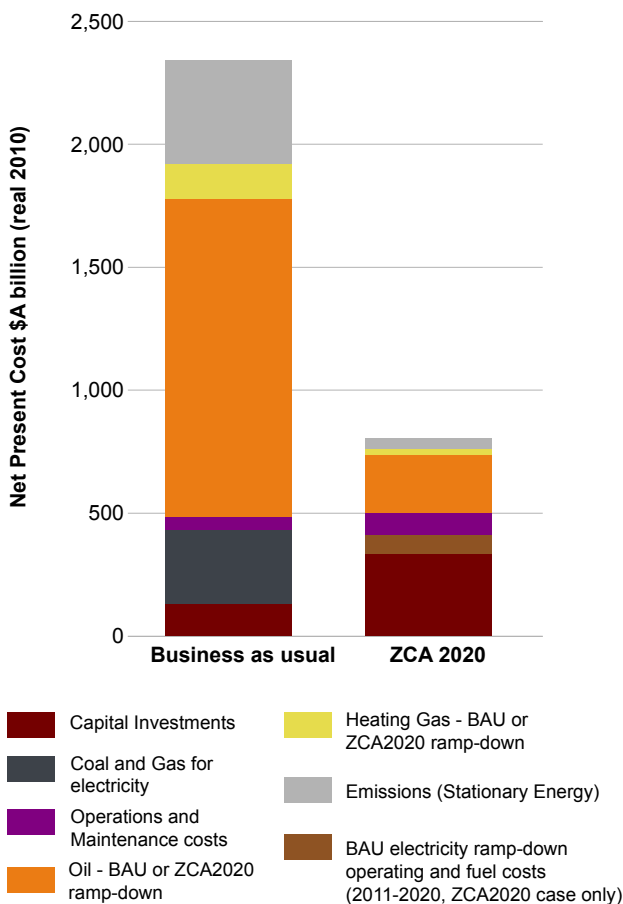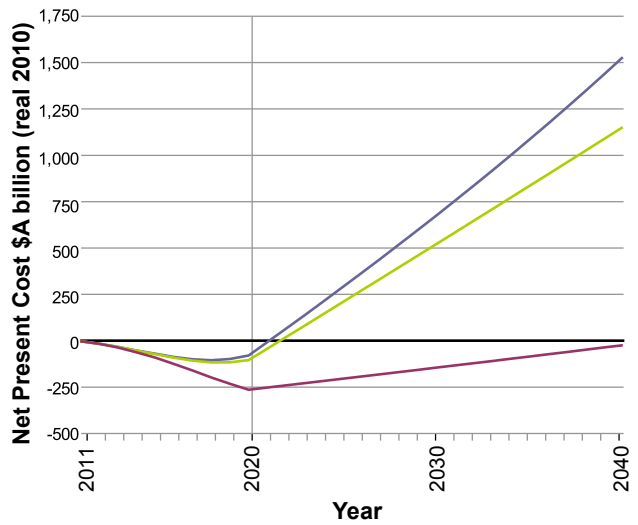
FIGURE 20
Cumulative Net Present Costs: BAU minus ZCA2020

Compared to Business-As-Usual, the ZCA2020 Plan is characterised by higher upfront investment, but lower ongoing costs. Under the Plan, by 2020, there would be $260 Billion more spent on the Stationary Energy sector than Business-As-Usual.

This investment is of course paid back over a longer timeframe. One possible scenario where the ZCA2020 renewable infrastructure is paid for through electricity revenues would lead to a price increase of 6.5c/kWh. This is based on a preliminary analysis and should not be taken as a recommendation of the Plan, but it provides a useful benchmark of the economic impact of the Plan. This price rise would equate to only $420 per household per year for residential consumers, or $8 per household per week.

Net present cost comparison

The ZCA Plan is compared with continuing Business-As-Usual using Net Present Cost (NPC) over the period 2010 to 2040. This comparison can be viewed in narrow terms of direct costs or in wider terms which take into account the fuel costs for transport and also the possibility of a price on carbon emissions.

In narrow terms of direct costs, NPC of Business-As-Usual is approximately the same as that of the ZCA2020 Plan, shown in Figure 19. This is using a societal discount rate of 1.4%, an approach taken by the Stern Review on Climate Change.

If oil costs for transport are taken into account, then there is a very clear financial advantage in converting the transport system to renewable electricity. Even though the comparison here does not include the cost of electrifying transport, it is clearly financially beneficial to replace oil as the major transport fuel.

If the likely costs of emissions are included, then the ZCA2020 Plan is clearly superior to Business-As-Usual.

FIGURE 21

ZCA2020 Stationary Energy Plan capital cost compared to other economic activity. GVA = Gross Value Added of that sector, as a contribution to total Gross Domestic Product
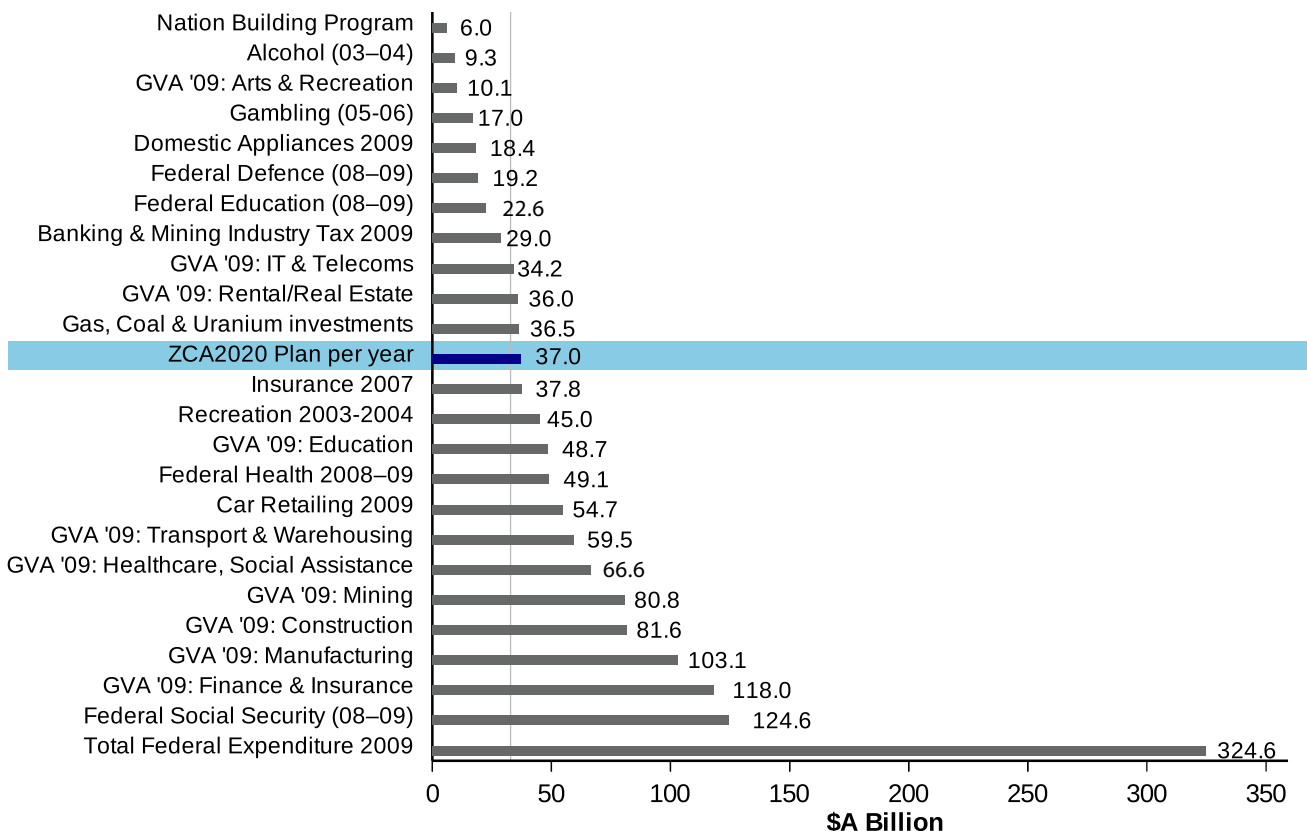
Category	$A Billion
Nation Building Program	6.0
Alcohol (03–04)	9.3
GVA '09: Arts & Recreation	10.1
Gambling (05-06)	17.0
Domestic Appliances 2009	18.4
Federal Defence (08–09)	19.2
Federal Education (08–09)	22.6
Banking & Mining Industry Tax 2009	29.0
GVA '09: IT & Telecoms	34.2
GVA '09: Rental/Real Estate	36.0
Gas, Coal & Uranium investments	36.5
ZCA2020 Plan per year	37.0
Insurance 2007	37.8
Recreation 2003-2004	45.0
GVA '09: Education	48.7
Federal Health 2008–09	49.1
Car Retailing 2009	54.7
GVA '09: Transport & Warehousing	59.5
GVA '09: Healthcare, Social Assistance	66.6
GVA '09: Mining	80.8
GVA '09: Construction	81.6
GVA '09: Manufacturing	103.1
GVA '09: Finance & Insurance	118.0
Federal Social Security (08–09)	124.6
Total Federal Expenditure 2009	324.6

$A Billion

FIGURE 22

ZCA2020 Stationary Energy Plan capital cost compared to Total Australian GDP

Category	$A Billion
ZCA2020 Plan per year	37.0
Total Australian GDP (2009)	1,197.0

$A Billion
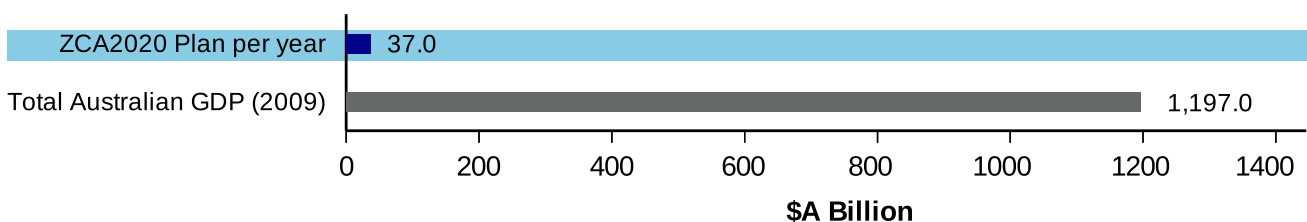
Due to the nature of renewable energy sources having high capital costs but low operating costs, the ZCA2020 Plan requires a higher initial investment than BAU would require out to 2020. This additional expenditure, sourced from both public and private investment, is offset by eliminating the costs associated with oil imports and likely emissions costs. Economic pay-back occurs around 2040 if emissions and oil costs are ignored (purple curve in Figure 20). When oil and emissions costs are included, the Plan achieves economic payback within a much shorter timeframe (blue and green curves in Figure 20).

Comparison of expenditure with other areas of the economy

The $37 billion annual cost for the ZCA2020 renewable grid is a similar order of magnitude to other sectors of the economy (Figure 21 and Figure 22). This illustrates that the Plan is neither beyond Australian capability nor extraordinary for an infrastructure project.

Implementing the ZCA2020 Plan requires investment on a scale that is well within Australian economic capacities and rapidly results in tremendous financial savings as well as other economic advantages such as eliminated dependence on oil imports, eliminated fuel price volatility, job and industry creation and of course creating a zero-emissions energy sector.

Conclusion

The ZCA2020 Stationary Energy Plan outlines a fully costed and detailed blueprint for transforming Australia's energy sources to 100% renewable supply. This is achievable using technology that is commercially available today, with no technical barriers to their deployment. Implementing the proposed infrastructure in ten years is well within the capability of Australia's existing industrial capacity. The required investment is the equivalent of a stimulus to the economy of 3% of GDP.

100% renewable energy in ten years is achievable and necessary, ensuring Australia's energy security, national security and economic prosperity for the future. Australia has some of the best renewable energy resources in the world, and should be positioning itself as a leader in the emerging renewable energy economy. What is required to make this happen is leadership from policymakers and society, with firm decisions made quickly that will allow this transition to occur.

"The time has come to aggressively accelerate that transition... The time has come, once and for all, for this nation to fully embrace a clean-energy future."
- BARACK OBAMA, PRESIDENT OF THE UNITED STATES OF AMERICA, JUNE 2010